Chapter 2
Basic Notions

Abstract Mathematical models are now essential tools in water resources management and are currently applied for the solution of environmental problems including those of polluting discharge into surface and underground water bodies. Following the development of computational facilities and mathematical procedures, the models can provide reliable solutions, provided that they use proper data and are operated by competent professionals.

2.1 Modelling and Water Quality Problems

The progress of computer technology and mathematical procedures has introduced tools that are now essential for any activity of human life. This quite general and global aspect includes also the problems of water quality protection. The advantage of applying these tools for water quality control in rivers, lakes and aquifers is now appreciated by all scientists and professionals working in this field.

A tool that promises enormous power to address the water quality problems and give rational solutions is the mathematical model. According to Cox (2003), a water quality model *can mean anything from a single empirical relationship through a set of mass balance equations, to a complex software piece*. Much work has been done during the past decades, and today several mechanisms are available, not only in the scientific field but also in the flourishing software market. The use of mathematical models is now in the reach of any person who has a sufficient professional background to understand and deal with water quality problems. The mathematical models belong to a large family of models that is not new in the daily practice of water resources management and protection.

Because many aspects and variables have to be taken into account simultaneously dealing with water, the models are becoming more and more important in order to achieve reliable solutions in practical problems. The model acts as a representation of the reality and allows its problems to be handled without directly interfering with it. Verifying a solution directly in natural entities requires costly

M. Benedini and G. Tsakiris, *Water Quality Modelling for Rivers and Streams*,
Water Science and Technology Library 70, DOI 10.1007/978-94-007-5509-3_2,

and complex engineering interventions, very often destructive. Vice versa, if the model represents correctly the reality and all its related phenomena, it can allow a solution to be examined in a short time and at a much lower cost.

As known, three types of models are currently used to solve water-related problems, namely, the hydraulic, the analogical and the mathematical models.

The *hydraulic* (*physical*) model consists of a reality at a different scale: a river stretch is reproduced by means of a duct having the same geometrical and morphological characteristics but in a size easy to be accommodated in the narrow space of the laboratory. With this model, the phenomena to analyse are the same as in reality (a flow in reality is reproduced by a flow in the model), and there is a plain correspondence between the various components (level, velocity, forces...), according to well-known *laws of similitude*.

The *analogical* models are based on a formal identity of the mathematical expressions that interpret different phenomena. Typical is the case of groundwater, for which the water flow is expressed by the Darcy law, formally identical to the Ohm law that interprets the electric current in a conducting line. After a suitable *scale of correspondence*, the behaviour of an aquifer, somewhat very difficult to analyse directly in the field, can be understood by the behaviour of an electric network having appropriate resistances and capacities.

The *mathematical models* interpret the reality by means of the numerical values that can be adopted to quantify the various phenomena and their components.

It is worthwhile to point out that the first two types of models just mentioned encounter now some drawback and are progressively abandoned in favour of the mathematical models, which are in fact more and more predominant. In the field of water quality, they are now probably the only effective tool.

Nevertheless, a lack of confidence still persists among several people, who think that the mathematical model is a too sophisticated mechanism, useful only for academic exercises but not in the real-world practice, where it has very often undergone unsuccessful outcomes.

To some extent, the use of mathematical model is a complex task, but it can assist in discovering the insight of a process if it is fed with reliable and proper data. The numerous successes during the last years have confirmed that when the mathematical model is in the hands of a skilled person with appropriate professional knowledge, it can give quite successful results. The mathematical model becomes then a device that helps the interested people to abide, step by step, with the ordinary way of thinking and to put into practice what they have learned with their daily experience.

2.2 How to Interpret the Water Quality

A typical incorrect use of water resources, which can cause dangerous effects to humans and other species, is the uncontrolled discharge of sewage into rivers and streams. It destroys the aquatic life and makes the water useless for any other use.

Table 2.1 The most significant quality indicators

1	– Temperature
2	– pH
3	– Dissolved oxygen (DO)
4	– Turbidity
5	– Conductivity
6	– Total organic carbon (TOC)
7	– Bacteria
8	– Viruses
9	– Chemical oxygen demand (COD)
10	– Biochemical oxygen demand (BOD)
11	– Metals and non-metals (Cr, Cd, Ni, As, Hg, Na, Br...)
12	– Phosphates
13	– Nitrogen compounds
14	– Organic compounds
15	– Suspended solids
16	– Salts (total dissolved salts)

Expensive treatments are then necessary, the cost of which becomes a burden for the whole community involved. Deterioration of river water has eventually an effect on the environment, on the human health and the economy.

The concept of water quality can be introduced by adopting some characteristic terms (generally called *parameters* or, better, *quality indicators*), which can be measured in the natural bodies and in the discharged water and are also characteristics of the water use. Table 2.1 lists some of the most important indicators, keeping in mind that such a list must be considered always open to introduce further terms that can be identified and detected by the research in progress. Each indicator can be measured, requires specific techniques of detection and analysis and imposes specific tasks for its control. Any use of water has its minimum and maximum values, determined after proper considerations.

As it will be better explained in the following chapters, the water quality in a river or stream depends on the quantity of water in which the pollutants are contained. It is, therefore, necessary that any action related to water quality is accompanied by accurate evaluations of the hydraulic conditions of the water body. In particular, water flow, level and velocity, which are determinant of pollutant behaviour, are to be carefully and frequently measured in the representative points of the water body. Moreover, the pollutants in water can be affected by rainwater and evaporation, and therefore, suitable measurements of the climatic and hydrological conditions are also of importance. Because the water quality in a natural or artificial body is a consequence of anthropogenic activities, the existing conditions of economic development, or the foreseeable trends, must be taken into consideration, with appropriate evaluation of all the terms to which a quality situation can be referred. Furthermore, water quality is controlled by natural factors that include geology and lithology of the watersheds and aquifers, the residence time, the reactions that take place within the aquifer and the type of land uses (Alexakis 2011).

2.3 Water Resources Exploitation and Water Quality

Among the several uses of water to be considered in the general framework of the "multipurpose" use of water resources, an important role is played by hydropower. It requires great quantities of water, but it is *not consumptive*, because the total amount withdrawn from a river is entirely returned to the natural bodies. Hydropower does not need special quality requisites, provided the natural turbidity is not so high as to cause siltation in the diversion ducts and erosion of pipes, valves and turbine blades.

Connected with the electricity generation is the use for thermal power generation. It is a nonconsumptive use, as the amount of water used for cooling and steam condensing is totally returned to the water body, even though with an increased temperature. To give an idea of the water quantity required for power generation, it is mentioned here that a thermoelectric plant of 660 MW demands about 20 m^3/s for a conventional generating group and about 28 m^3/s for a nuclear reactor. The increase of temperature, from the inlet to the outlet of the condenser, is about 4°C. Although the cooling water should be pure enough to avoid corrosion and crustation in the heat exchangers, particular adjustments in the materials used for the plant construction and an accurate running control allow also for water of poor quality to be used. Frequent is the case of using seawater, while a considerable quantity of freshwater can be saved for other uses demanding higher quality water. A small amount of water is also necessary to feed the boilers for steam generation. This water should be pure, and specific treatments are normally provided.

The agriculture requires huge quantities of water for irrigation. Only a small portion of the total amount delivered to the crops returns to the water bodies, while the largest portion is dispersed through evaporation and deep percolation in the soil, and a small quantity is transformed into the vital components of the plant. In agricultural activities, water can be used also for livestock and for farmer needs.

Irrigation does not require high-quality water, and in some cases, the required water can be produced using domestic and industrial wastewater, following old farming practices. Some salts can affect the growth of the crop and eventually accumulate in the plant with dangerous effects in case the plant or its fruits are used as food for animals and humans. Care must be taken for the use of wastewater containing bacteria, viruses or any kind of toxic substances. Some dissolved salts and suspended solids can alter the soil structure and modify the environmental conditions required by some vegetation species.

In an industrial factory, the water can be used for three different purposes:

– For *processing*, when it enters physically or chemically inside the composition of the final product. Normally, the quality must be high, achieved through appropriate treatment, the complexity and the cost of which depend on the original conditions in the water body and are characterised by the specific process adopted.

– For *cooling*, with more or less the same requirements pointed out for the thermal energy generation. The amount of such a use and the quality requirements are normally connected with the line of production and the size of the plants.
– For *washing*, in the final accomplishment of some production phases or for cleaning the plant premises. The amount and its quality depend on the size of the plant and are a function of the production process. Washing water is returned almost completely to the natural bodies with high pollution level.

The most important use of water is for *urban and domestic purposes*, for which it must have the highest degree of purity, especially from the sanitary viewpoint, and comply with the drinking water quality guidelines of several international organisations (WHO, EU, EPA, etc.). The amount to be supplied is evaluated in accordance with the degree of economical, social and technological development of the population to be served, ranging from a per capita 60 l/day in the case of small rural and scattered houses to a per capita 700 l/day for the largest urban communities.

Another use, although not well defined, is for *recreation*, which can vary in relation to the social and economic level of the population involved. Besides the quantity necessary for supplying vacation sites, hotels and holiday resorts (the quantity of which is determined following the rules of urban and domestic supply, keeping into account appropriate *peak* and *seasonal coefficients*), the recreation facilities are encountered in large water bodies suitable for boating, bathing and angling, with quality kept at the levels requested for the safe and effective exploitation of these uses.

Proper quantity and quality of water are necessary to maintain the original features of the landscape, historical places and sites of cultural heritage. An evaluation of the necessary amount of water for these uses is rather difficult and can be achieved following "ad hoc" investigations. The required level of water quality is normally high.

Due to the natural peculiarity of "washing out", streams and rivers are more and more frequently exploited to remove and dilute the waste discharged through the domestic and industrial sewers. Physical and biological processes contribute to the *self-purification process* so that the amount of pollutants is kept under proper thresholds. Specific values of the quality parameters are used in order to define the pollution level of the water bodies. If such values cannot be achieved through the natural dilution of the pollutants discharged, in order to secure possible further uses of water and to protect the aquatic life, the discharging water must undergo adequate treatment suitable to reduce the original pollutant concentration.

Water abstraction from a polluted natural body contributes to the modification of the original equilibrium of fauna and flora, motivating some irreversible alterations. Through the well-known *food chain*, life in the water environment can change, coming at the end to a threat for human survival. Protecting the water environment is, therefore, a necessity, especially for mankind's future, and has to be accomplished by maintaining the biological species originally existing in the water body biodiversity. Moreover, the protection of aquatic species allows sometimes the development of fisheries, which can be a prosperous activity.

Large rivers and canals are used for interior *navigation*, which assures low cost transportation especially regarding bulky raw materials. For this activity, river depth should be kept at proper levels and water velocity as low as possible, in order to allow for a safe ship motion and all other operations to be safely realised. While there are no requirements for water quality in the natural bodies, concentrated sources of pollution can be caused by accidental spills of fuel, lubricants or contaminating substances carried by the ship.

As seen in the preceding paragraphs, water can be used inside the river or stream (*in situ*) or after withdrawal (or *abstraction*) from the river and subsequent conveyance to another place. In the latter case, the original natural stream can be deprived of the amount of water that is necessary to maintain unaltered the original aquatic life and can prevent the possibility of other utilisations. To avoid such a risk, the regulations enforce in many countries require the fulfilment of a *minimum acceptable flow* in the river, which provides a threshold for limiting the water abstraction.

2.4 What to Model in the Water Quality Problems?

The main problem in water quality control and protection is learning how a pollutant is present in a water bulk and how its presence can vary in time and space. Such an evaluation is necessary in order to assess the attitude of a natural body for the environmental enhancement or in view of a feasible process useful to abate a dangerous contamination. The first step in dealing with a water quality problem is to provide reliable data relevant to the present pollutants. This falls under the responsibility of skilled people experts in geochemistry, analytical chemistry and biology. As already mentioned, a long list of pollutants is available, and the relevant analysis procedures are known, also in form of *standard methods* that can be officially recognised by institutions and authorities.

The reliability of water quality data depends not only on the precision of measuring instruments or the adopted analytical procedures but also on the way the samples are collected from the water body. Very often, a value is not representative of the river condition because it is relevant only to a particular aspect that does not involve the total bulk of the body. Repetition of measurements with direct statistical analysis and interpretation can provide a better data reliability. If a measurement cannot be repeated and only a single value can be collected, the data cannot be considered reliable. Data unreliability is generally due to several aspects, related to concurrent phenomena that cannot be always appreciated.

2.5 The Most Common Way of Modelling

For pollutants whose presence is appreciated in quantity (e.g. milligrams, micrograms), the *concentration*, expressed as mass per unit volume of water (e.g. milligram per litre), is the representative term. The pollutant concentration, C, is then the variable to be introduced in the model, as function of time and space:

$$C = C(x, y, z; t) \tag{2.1}$$

Considering a physical phenomenon, like the heat transfer in the water volume, the water temperature, τ, becomes the model variable:

$$\tau = \tau(x, y, z; t) \tag{2.2}$$

The water quality problem, to face by means of the model, is to find how the variable varies in the water body.

It is worthwhile to note that, once the problem is posed in mathematical form, the significant variable may lose its significance and become just an algorithm term, to be handled among many others, with the best computation procedure. In this context, there is a risk that the attention is brought principally to the mathematics, instead of the real problem. Such a risk has generated some misunderstanding, and very often the people who are competent in mathematics claim to be competent also in other disciplines (water pollution, air pollution and many problems of different nature, like the migration of fish in a river!), just because the significant variable dealt with in the model follows similar mathematical behaviour.

In water quality problems, the approach following the *Fick law* is the most widely adopted. It concerns, in particular, the process of dispersion (or diffusion), which is accompanied by other processes responsible for the migration of pollutants in the water volume, as it will be explained in Chap. 3.

Generally speaking, even some simple correlation of experimental data can be considered as mathematical models. This is so because the analyst can learn from the statistical manipulations and can interpret the real situation without entering into the inner mechanisms of pollutant transport. However, advanced technology and the new way of approaching and interpreting a water quality problem have made the mathematical model a device that can be applied in all the aspects encountered in practice.

Some well-known and widely used mathematical models for water quality in rivers and catchments are listed in Table 2.2, with the indication of the institutions in which they have been developed. These institutions can provide sufficient details about the model structure; in the table, there are also some references useful for the reader, for which they provide the general description, the principles and some applications of these models.

The scientific and technical literature is lavish in providing textbooks and notes on the most recent research findings of water quality models. It might be interesting to recall some original attempts of model development to have an idea of the basic approach and the progress achieved so far.

Table 2.2 Principal water quality models for rivers and streams

Country	Institution	Year	Model name	Purpose	References
USA	USCE	1982	CE-QUAL	Substance transport and transformation	Wells (2000)
Netherlands	DH	1985	DELWAQ	Pollution transport	Delft (1990) and Delft Hydraulics (1992)
USA	USEPA	1987	QUAL2E	Pollution transport	Brown (1987) and Brown and Barnwell (1987)
France-UK	LNH-CEH	1991	TELEMAC	Water flow and pollution transport	Kopman and Markofsky (2000) and Galland et al. (1991)
Switzerland	EAWAG	1994	AQUASIM	Substance transport and transformation	Reichert (1998)
UK	CEH	1997	PC-QUASAR	Water flow and pollution transport	Lewis et al. (1997) and Whitehead et al. (1997)
Denmark	DHI	1999	MIKE 11	Water quality and sediment transport	Hanley et al. (1998)
UK	Newcastle University	2008	TOPCAT-NP	Simulation of flow and nutrient transport	Quinn et al. (2008)
Germany	IGB	2009	MONERIS	Regionally differentiated quantification of nutrient emissions into a river system	Venohr et al. (2009)
UK	EA	2010	SIMCAT	Fate and transport of solutes	Warn (2010)

In this respect, fundamental is the work done by Thomann (1971) to understand and interpret the basic concepts of water quality problems. Interesting applications were described by Beck (1983a, b). Biswas (1981) collected some interesting contributions in a fundamental textbook.

Up to now, a fully comprehensive review has been produced by Chapra (1997), also with the support of a very long reference list. A first general set of considerations was presented originally by Raunch et al. (1998). Two recent reviews of some water quality models also present the recent developments in the field of popular quality modelling (Cox 2003; Tsakiris and Alexakis 2012).

Some of these models are reviewed in the Appendix of this book.

The water quality problems and the role of mathematical models are now one of the main subjects of the scientific research, and consequently, new remarkable contributions can be expected in the qualified journals, while refined advanced software packages are also expected by engineering firms.

2.6 General Features of the Mathematical Models

The recent development in computer science and mathematics has pointed out many particular aspects of the mathematical models that should be briefly recalled, in order to better understand the model structure and its working mode. Great contribution to this knowledge has been given by the *systems science*, which is now useful to interpret and solve the very complex problems of the modern era and for which the mathematical models are some of the most efficient tools.

The fundamental point in the description of a model is the identification of its constituent terms. These can be grouped into three categories, namely:

– *Constants*, which maintain always the same value for the entire application and are determined in a way that is independent on the inner mechanisms of the model
– *Variables*, the numerical value of which can change one or several times during the model application
– *Parameters*, the numerical value of which is arbitrarily fixed for some steps of the application

Some variables describe at every moment the evolution of the problem dealt with: they are the *state variables*. For some others, the numerical value can be altered, although always complying with the model rules: they are the *decision variables*. The initial value given to some variables makes up the *model input,* and consequently, these are the *input variables*; the value inferred from the other variables through the model application is the *model output*.

A primary role is played by the formulae or relationships connecting the variables, able to produce a certain output for a given input. Some formulae, able to clearly interpret the phenomena for which the model is developed, are available in the scientific and technical literature. Otherwise, the formulae can be determined through a statistical interpretation of the available data. Consequently, two large categories of mathematical models can be distinguished: in the first category, the relationship among the variables is a mathematical function, and only one output value (or set of values) corresponds to a given input value (or set of values). Such a model is called *deterministic*. In the second category, the relationship among the variables is based on the probability of occurrence, and the mathematical model becomes *probabilistic* (or *stochastic*). A distinction between probabilistic and stochastic is often pointed out, as the latter term is used generally when the time is one of the variables. Both deterministic and probabilistic models are currently used in the water problems, and in many cases, the same problem has to be treated in both ways.

The mathematical models that represent the reality in descriptive way are the *simulation models*. Their substantial feature is a "translation" in mathematical terms of the evolution phases of the reality.

There are also some models able to give, for a given input, an output that can be considered, within a certain respect, the best one among a set of possible values: they are the *optimisation* (or *programming*) *models,* and their substantial point lies on the identification of an *objective function* to be optimised with the involved variables and in view of a predetermined criterion of operation.

Generally, a problem, particularly in the water context, cannot be thoroughly examined by means of a single model, but several models are often necessary, both of simulation and optimisation, interconnected, in order to achieve a reliable result.

2.7 Need of Data

It is worthwhile to stress again that the mathematical models remain a useless tool if there are no suitable values for the terms involved in their application and that they can show their power only with the availability of proper data. The collection and the way of making data available play a very important role in model application. Any consideration about data implies the highest professional experience of the people working with models, who are responsible to collect them and evaluate their possibility to comply with the requirements of the problem to which the model is concerned.

Mathematical and statistical theories have produced techniques that, with the help of the advanced computing facilities, can be useful in treating the available data, presenting them in a form useful for their insertion into the mathematical models. Such techniques consist essentially of special computer languages or packages that allow the data:

- To be continuously adjourned with the results of the measurements becoming available in the meantime
- To be saved without disturbing the natural interaction existing among them
- To be retrieved according to the specific requests of the user

These techniques allow for the construction of the *data bases*. Getting data available for the application of mathematical models is the concern of some activities and tools that make up the *data banks*, words that reflect the well-known institutions where every client can deposit and cash his money. The data bank consists of the following steps:

- *Data collection*, which is based (1) on machines (*hardware*) able to transfer the values measured at the gauges into a form which can be accepted by the computers, (2) on the appropriate mathematical programmes (software) and (3) on specialised expertise (technicians, software engineers, etc.)
- *Data screening*, based principally on statistical evaluations (calculations of central values, extreme values, etc.)

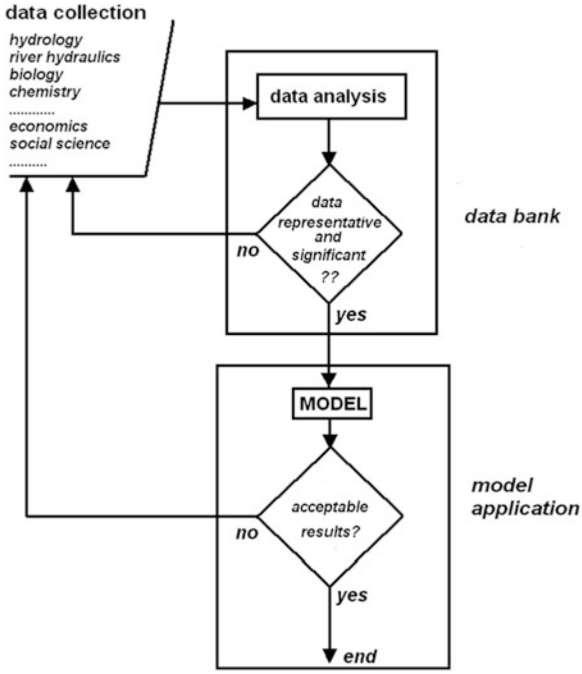

Fig. 2.1 How data are necessary and can be used for a model

- *Data saving*, requiring the proper structure of data bases and the necessary computing facilities
- *Data retrieval*, in favour of the users, relying on appropriate hardware (printer, plotter, hard disk drive, etc.), with adequate software for several operations including presentation

In the problems of water resources management, the data banks should be run preferably by the same people who have the responsibility to intervene for water protection and utilisation. Access to data, however, should be given to all the interested institution and stakeholders.

The way data are considered for the model application is illustrated in Fig. 2.1. Once the problems are clearly defined, data must be collected in all the pertinent disciplinary sectors, with the best possible accuracy, using the proper instrumentation and trying to benefit from the most advanced professional experience. After developing the various steps for constructing the data bank described above, there is the need to verify whether the collected data can respond to the requests of the problem, in a significant and representative way. If the result is not satisfactory, new data must be collected, following criteria and procedures suggested by the need to have more significant details and to better interpret the problem. Refined and acceptable data can then be used for the model, but also at this step, there is a need for other investigations to ascertain that the data can be satisfactory for the proper model application. Otherwise, new and much more refined data are necessary.

The same figure underlines the necessity and the convenience of repeating steps, in order to obtain data that can be acceptable for phenomena interpretation and for an efficient use of the model.

2.8 The River as the Main Water Body for Water Quality Protection

Environmental protection concerns all the water bodies existing in nature, namely, rivers, lakes, lagoons, coastal water and groundwater; the quality of them should be in relation with more general aspects relevant to the living conditions of the involved people.

The rivers characterise the importance of all the natural water bodies, because they fill and empty lakes and lagoons, recharge groundwater and eventually discharge into the coastal water. Rivers play a primary role in assessing the availability of natural resources, supplying the water necessary to the various uses. Monitoring and controlling the river quality is, therefore, an essential and unavoidable step in water resources management.

Both in situ and abstraction water uses have to refer to the amount of water that the river is able to supply, in terms of quantity and quality, taking into account the protection of the environment. Maintaining an acceptable quality in the river can assure the correct resources exploitation, allowing for competitive uses to be fulfilled in the most rational way, according to the most up-to-date view of an integrated resources management.

The fundamental theory of water quality models described in the following chapters is valid for any type of water body. However, several adjustments can transform a water quality model developed for a river into models for stagnant water bodies or for aquifers. The models described in these pages refer to all kinds of bodies with running free surface water, like natural rivers, streams and artificial canals.

To perform a management activity in an effective manner, an appropriate definition of the water resources size and peculiarities is necessary. First of all, adequate space boundaries have to be set, and the most logical way to do this is to ascertain what sort of physical and non-physical ties exist among the various parts of which the resource is built up. Generally, the water belonging to a stream cannot be considered apart from the spring from which the stream originates or from rainwater travelling on the slopes that contributes to the river in question and apart from the water body into which it enters. All the physical aspects relating in one or other way with these quantities of water can find a unitary binding in the *river basin* (also *hydrographic basin*), defined as the whole of water bodies contributing to build up a unique river or, better, the area from which all the water molecules, fallen as natural rainfall or introduced from elsewhere both naturally and artificially, are brought by natural flow to a unique cross section, from which the river discharges into the sea or a great lake. Such a definition is often equivalent to that of *catchment area*, although the latter term is more

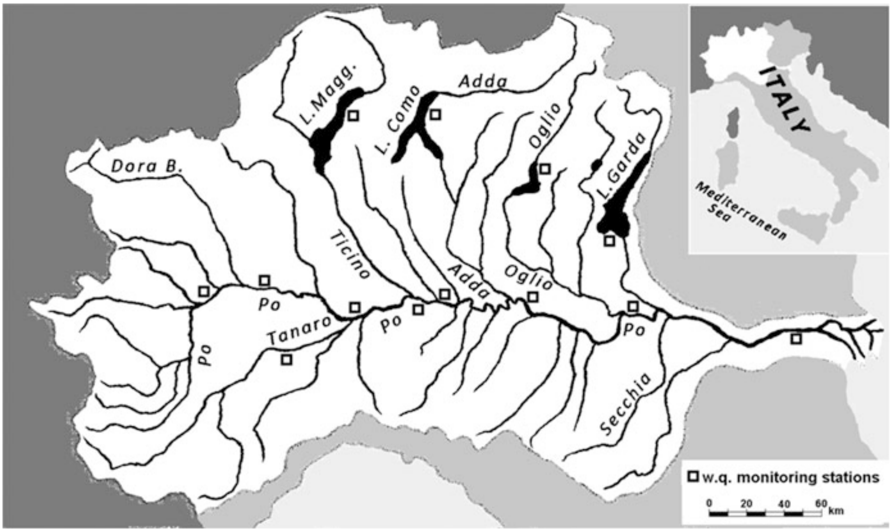

Fig. 2.2 Location of monitoring stations in a large river basin (River Po in Italy)

preferably applied to the area in which the run-off is made up only by the rainfall and other types of precipitation, while the term hydrographic basin, including also groundwater, is more comprehensive. However, as in most publications, the concepts of river basin or catchment are used interchangeably.

From the above, it is understood that it is difficult for a water quality model to study only the river segments and their conditions without studying the processes of water encountered in the entire river basin. This is the reason why most models refer to both the basin and the river.

The management of the water resources in a river basin is also facilitated because very often non-physical aspects are common in it and are distinguished from those that can be found in another basin. Mainly in the case of large rivers, the basin boundaries (*hydrographic divide*) enhance discrimination of life customs and trends of activities; sometimes, people dwellings in the same basin are bound by old and enduring traditions, even though they belong to different states or administrations.

These hydrologic and physical considerations support the identification of a *river authority*, responsible of all the aspects referring to the basin, including water quantity management, water quality control and environmental protection. According to the most current views of an integrated water resources management, the river authority is responsible of all the processes and episodes occurring to water-related aspects in the basin, providing infrastructure tools and financial resources to intervene in order to achieve the optimal rational use of the available water, to prevent inundation and damages caused by floods and to control the water quality and protect the environment. Concerning the water quality problems, the authority should provide suitable *monitoring systems*, collecting data in the most representative points of the basin. In large basins, as in the example shown in Fig. 2.2, the data collection can be a very demanding and costly activity.

2.9 A Fertile Field

During the last decades, the modelling practice has gained a remarkable acceptance in solving real-world problems, as confirmed by the numerous applications promoted by the responsible authorities. A remarkable progress is appreciable if the first attempts to review this area (Ray 1988; Van Pagee 1984) are compared with the more recent publications (Cox 2003; Tsakiris and Alexakis 2012). The technical staff has acquired confidence with the models and their intrinsic powerful characteristics, removing the original scepticism that had characterised the first attempts of application of models as were promoted by the scientific community. The responsible authorities have adopted the model as an essential tool able to support the decision making process, without being necessarily aware of the inner mechanism on which the model is developed and works. The model output is the main answer that is requested after an application carried out using a series of data representative of the application.

The technical literature reports successful examples, relevant to the largest river basins in the world, like that of the Po (Delft 1990), the Nile (Hafez 2003), and the Senne (Van Griensven and Bauwens 2002). The description of these applications underlines the importance of the basic information of the river water quality on which the model is constructed (Harmancioglu 1991). The role of the model in a more general context of water resources management is frequently underlined, also in relation to the design and construction of huge works, like the large dam on the Yellow River (Jinxiu et al. 2001; Yangwen et al. 2007), but also to well-defined goal to which the model is oriented, like the sanitation of the urban environment (Paoletti et al. 2004). Worthy to be mentioned, in particular, is the attempt to combine the pollution transport with the hydraulic aspects of the river, both in steady normal conditions (Schaffranek 1998) and in the case of flood events (Koussis 1983).

Remarkable progress can be observed also in the scientific interest, and a long path has been covered since the beginning. The comprehensive studies carried out just a few decades ago (Stanbury 1986) can be considered tiny in comparison with the more recent developments that will be described in the next pages, even though they can still be considered the reference point of the flourishing research that can be recorded at the present time. The above considerations justify the scientific interest for the subject of water quality models and can be a valid incentive to continue and go deeper and deeper in the study of this matter.

This interest is fostered by the need for producing water quality results required by the governments in order to achieve the goal of better quality water resources in the future, as highlighted in the first chapter of this book, in which the emphasis was given to the implementation of the WFD (Dir.2000/60) in the member states of the European Union.

References

Alexakis D (2011) Diagnosis of stream sediment quality and assessment of toxic element contamination sources in East Attica, Greece. Environ Earth Sci 63(6):1369–1383

Beck MB (1983a) A procedure for modeling. Mathematical modeling of water quality: streams, lakes, and reservoirs. In: Orlob G (ed) International institute for applied systems analysis, Laxenburg, Austria, pp 11–41

Beck MB (1983b) Application of water quality models. Mathematical modeling of water quality: streams, lakes, and reservoirs. In: Orlob G (ed) International institute for applied systems analysis, Laxenburg, Austria, pp 425–467

Biswas AK (ed) (1981) Models for water quality management, Mc Graw-Hill series in water resources and environmental engineering. Mc Graw-Hill, New York

Brown LC (1987) Uncertainty analysis in water quality modelling using QUAL2E. In: Systems analysis in water quality management. Pergamon Press, New York

Brown LC, Barnwell TO (1987) The enhanced stream water quality models QUAL2E and QUAL2E-UNCAS: documentation and user model, EPA-600/3-87/007, US EPA, Athens, GA

Chapra SC (1997) Surface water-quality modeling. WCB-McGraw Hill, Boston

Cox BA (2003) A review of currently available in-stream water quality models and their applicability for simulating dissolved oxygen in lowland rivers. Sci Total Environ 314–316:335–377

Delft Hydraulics (1990) Water quality analysis of the Po river. Report international T690. Delft, The Netherlands

Delft Hydraulics (1992) The water quality model DELWAQ. Release 3.0, User's manual, Deft, The Netherlands

Galland JC, Goutal N, Hervouet JM (1991) TELEMAC: a new numerical model for solving shallow water equations. Adv Water Resour 14(3):138–148

Hafez YI (2003) Some aspects of water quality modeling for the Nile river from Aswan to Cairo, Egypt. In: Proceedings of the 30th IAHR congress, Thessaloniki, Greece, theme B, pp 715–722

Hanley N, Faichney R, Munro A, Shortle JS (1998) Economic and environmental modelling for pollution control in an estuary. J Environ Manage 52(3):211–225

Harmancioglu NB (1991) An information-based approach to monitoring and evaluation of water quality data. In: Tsakiris G (ed) Proceedings of the European conference advances in water resources technology, Athens, Greece. Balkema Publisher, Rotterdam, The Netherlands, pp 377–386

Jinxiu L, Dehui S, Jinchi H, Wengen L, Xuezhong Y, Jing P (2001) Prediction of water quality for the three Gorges reservoir. In: Proceedings of the 29th IAHR congress, Beijing, China, theme B, pp 717–722

Kopman R, Markosfky M (2000) Three–dimensional water quality modelling with TELEMAC-3D. Hydrol Process 14(143):2279–2292

Koussis AD (1983) Unified theory for flood and pollution routing. J Hydraul Eng ASCE 109 (12):1652–1664

Lewis DR, Williams RJ, Whitehead PG (1997) Quality Simulation along Rivers (QUASAR): an application to the Yorkshire Ouse. Sci Total Environ 194–195:399–418

Paoletti A, Sanfilippo U, Innocenti I (2004) Advances in modelling the experimental data on pollutant dynamic in ephemeral streams influenced by transient storage in dead zones. In: Marsalek J et al (eds) Enhancing urban environment by environmental upgrading and restoration. Kluwer Academic Publishers, Dordrecht, pp 289–306

Quinn PF, Hewett CJM, Dayawansa NDK (2008) TOPCAT-NP: a minimum information requirement model for simulation of flow and nutrient transport from agricultural systems. Hydrol Process 22:2565–2580

Raunch W, Henze M, Koncsos L, Reichert P, Shanaham P, Somlyody L, Vanrolleghem P (1998) River water quality modelling: 1. State of the art. Proceedings of the IAWQ biennial conference, Vancouver, Canada

Ray C (1988) In: Biswas AK, Khoshoo TN, Khosla A (eds) Use of QUAL-I and QUAL-II models in evaluating waste loads to streams and rivers: environmental modelling for developing countries. Tycooly Publishing, London, pp 65–79

Reichert P (1998) AQUASIM – a tool for simulation and data analysis of aquatic systems. Water Sci Technol 30(2):21–30

Schaffranek RW (1998) Simulation model for open-channel flow and transport. In: Proceedings of the first federal interagency hydrologic modeling conference, Las Vegas, NV: subcommittee on hydrology of the Interagency Advisory Committee on water data, pp 1–103 to 1–110

Stanbury J (ed) (1986) Water quality modelling in the inland natural environment. Papers presented at the international conference, Bournemouth, England. British Hydromechanics Research Association, Cranfield

Thomann RV (1971) Systems analysis and water quality management. Environmental Science Service Division, New York

Tsakiris G, Alexakis D (2012) Water quality models: an overview. European Water 37:33–46

Van Pagee JA (1984) Water quality modelling of the river Rhine and its tributaries in relation to sanitation strategies. Water Sci Technol 16(3):393–406

Van Griensven A, Bauwens W (2002) River water quality management for the Senne river Basin (Belgium). In: Tsakiris G (ed) Proceedings of the 5th EWRA international conference water resources management in the era of transition, Athens, Greece, pp 520–528

Venohr M, Hirt U, Hofmann J, Opitz D, Gericke A, Wetzig A, Ortelbach K, Natho S, Neumann F, Hurdler J (2009) The model system MONERIS version 2.14.1vba manual. Leibniz Institute of Freshwater Ecology and Inland Fisheries in the Forschungsverbund Berlin e.V., Müggelseedamm 310, D-12587 Berlin, Germany

Warn T (2010) SIMCAT 11.5 a guide and reference for users. Environment Agency. 111_07_SD06 Rotherham, UK

Wells SA (2000) Hydrodynamic and water quality river basin modelling using CE-QUAL-WS version 3. In: Ibarra-Bastegi G, Brebbia C, Zannetti P (eds) Development and application of computer techniques to environmental studies. WOT Press, Boston, pp 195–204

Whitehead PG, Williams RJ, Lewis DR (1997) Quality simulation along River Systems (QUASAR): model theory and development. Sci Total Environ 194–195:447–456

Yangwen J, Cunwen N, Hao W, Hui G, Suhui S (2007) Integrated assessment of water quantity and quality in the Yellow River basin. In: Proceedings of the 32nd IAHR congress, Venezia, Italy, vol 1, p 310 (printed summary)

http://www.springer.com/978-94-007-5508-6

Water Quality Modelling for Rivers and Streams

Benedini, M.; Tsakiris, G.

2013, XVIII, 288 p. 94 illus., 10 illus. in color., Hardcover
ISBN: 978-94-007-5508-6