ACCIDENTAL RELEASE PROBLEMS IN NATURAL RIVERS: ALARM MODELS AND EXPERIMENTAL INVESTIGATIONS

P. M. Rowiński

Institute of Geophysics, Polish Academy of Sciences
Ks. Janusza 64, 01-452 Warszawa, Poland
pawelr@igf.edu.pl

CONTENTS

Abstract

In the paper the basic information towards understanding of the behaviour of rivers with respect to the propagation and retention of pollutants accidentally entering the water body has been provided. One-dimensional approach leading to traditional Fickian formulation and further to transient storage equations has been presented. Methods of the determination of dispersion and storage zone parameters through the direct measurements have been discussed. A special attention has been paid to an example of the studies in the multithread part of the Upper Narew river leading to the creation of an alarm model.

1. Introduction

Accidental spills happen all over the world and decision makers with the help of research community have to be prepared to mitigate their effects. Oil slicks, floating sewage debris, dead fish and unusual or unnatural water discolorations or smells are all indications of pollution problems and are encountered every year in many places. Very often we deal with less visible substances such as some toxin compounds and heavy metals and these require scientific sampling and analysis to determine their presence. A very important practical question is the origin of pollution and one should know whether it is coming from a discernable source, such as a point on shore or a particular discharge or does it appear to be coming from a undetermined upstream location. One of the tools that are needed to predict the behaviour of the released pollution are mathematical models. There are, however, still heard opinions that it would be enough to avoid accidents instead of preparing alarm tools. Nevertheless accidents are unavoidable in the nearest future. For example statistics from the US Department of Transportation on truck accidents show that between 1 and 10 percent of all accidents where hazardous materials are involved, the vehicle entered a body of water. Accidents occur in other situations as well and very often they are catastrophic for the nature and humans. There is nothing like case histories to illustrate a point and let us shortly present a few situations that had or could have tragic consequences.

A notable spill occurred near Dunsmuir in California in July, 1991. The spill involved 19500 gallons of a solution of metam sodium into the Sacramento River. Metam sodium is a fungicide, herbicide, insecticide and soil fumigant. In that accident a diesel locomotive and six railway cars derailed and went into the river. The tanker car holding the concentrated solution of metam sodium was punctured and the contents of the tank car were lost in the river. Another accident happened in different part of the world. On 13 November 2005 an explosion occurred at a petrochemical plant of the Jilin Petrochemical Corporation in Jilin Province in China. That explosion led to a spill of an estimated 100 tons of toxic substances made up of a mixture of benzene, aniline and nitrobenzene, with surface waters concentrations exceeding the surface water levels permissible in China. The pollution entered subsequently the Songhua River which joins the Heilongjang River continuing in Russia as Amur River. One more disaster to be cited occurred in Guyana. The disaster struck in August 1995, when a failed tailings dam gushed an estimated 4 million cubic meters of cyanide-laced effluent into the Omai and Essequibo rivers, enough to fill a one-kilometer high tank with a base as wide as a US football field, sidelines included. Three days after the accident 80 kilometers of the Essequibo was declared an environmental disaster zone. One may find numerous other examples - Jirka and Weitbrecht (2005) mentioned for example European disasters – on the rivers Rhine, Dniepr, Guadalquivir and Tisza. Smaller scale accidents are met almost everywhere. A common feature of all those accidental releases of toxic material is that the cloud of pollutant propagates downstream from the release point and at the same time it is gradually being dispersed and partially retained due to various heterogeneities in the river reach. It has to be noted that not only the maximum values of pollutant concentrations are dangerous for the living organisms but also the time of exposure to lower but lasting for longer times concentrations. Understanding of the fate of soluble pollutants is therefore essential for the efficient management of the river environment. It is not only to deal with catastrophic situations that have already occurred but also for environmental assessment tasks and for the evaluation of potential threats to a water body under consideration. In principle the release of contaminants in water bodies poses questions concerning the regulation of pollution sources, the evaluation of risk due to accidental contaminant releases and the design of any effluent discharge system. Laws regulating the discharge of civil, industrial and agricultural effluents in river systems are often based on concepts of a mixing zone, claiming for the need of deep understanding of the mechanical, chemical and biological processes whereby a solute is spread out and diluted by the stream.

2. Modelling of pollution transport in rivers

To make all the presentation simpler for the reader, let us assume that the considered mixture is passive that is one, in which the fluid-particle interaction does not affect the dynamics of the flow. Otherwise one would have to include momentum considerations in order to properly represent certain two-phase flows. Further limitation is the consideration of the fate of solutes only, i.e. the substances that are dissolved in the water. Throughout the paper, we use the macroscopic treatment, i.e. the theory of continuum. Because of practical importance, we do not care about the motion of individual particles of the matter and are interested only in the resultant effects due to the motion of a large number of particles. It is possible because in practical problems the smallest length scales of interest are much larger than the distance between molecules.

The fate of an accidental spill of a pollutant into a natural stream is governed by a combination of the mechanisms of advective transport by the mean flow, hydromechanical dispersion due to the random turbulence fluctuations and the mixing that eventually occurs in the transient storage zone. In general three-dimensional case, construction of the mass transport equation for a dissolved quantity requires the application of the Reynolds hypothesis allowing for the decomposition of the velocities and concentrations into mean and fluctuating values, and further additional information about the turbulent mass flux, for example based on a linear relationship between the turbulent flux and the gradient of the mean concentration. The main obstacles to progress in that approach is the lack of reliable theory which relates the spatial variation of turbulent diffusion coefficients to flow and boundary conditions, mathematical difficulties in solving the transport equation for variable diffusion coefficients and realistic spatial domains. Another important problem is the lack of knowledge of the realistic detailed 3D velocity field. 3D approach is probably suitable in the vicinity of the injection point in the river when one is interested in studying the heterogeneity in vertical and lateral directions. Such strong heterogeneity may occur due to the variability of river geometry like meanders, or the ones caused by fairways and weirs.

Various simplifications of the model are necessary to tackle real life problems. One option is to eliminate one or two dimensions in cases where such operation is justified by the conditions in the considered river reach. This elimination may be realized by relevant averaging of the governing equations - both hydrodynamics and mass transfer equations. It is usually the case that in the mid-field region the governing equations may be averaged over the depth giving two-dimensional models. Two-dimensional models are in principle extremely demanding in terms of data requirements and computational costs. Additionally an ongoing debate is carried out on the correct use of 2D models to realistic situations (see e.g. Rowiński and Kalinowska, 2006).

In the far field, in case when the river geometry is simply enough to do it, one is mostly interested in the cross-sectionally averaged concentrations. The governing equations may be then averaged over the cross-section, which results in a one-dimensional model of the spread of the constituent under consideration.

3. One-dimensional approach. Longitudinal dispersion

To make things as simple as possible and having in mind all the processes and complexities one can try to formulate the mass balance for a given, well defined natural volume of water (for instance well-defined river reach). Basically the mass balance is an accounting of all mass entering, leaving and remaining in the system of interest and it may be summarized in the following equation built over a selected period of time and a selected volume of water body:

Change in mass = inflow due to advection – outflow due to advection
+ inflow due to dispersion – outflow due to dispersion
+ external load from point sources
+ external load from non-point sources
+ internal load
+ lateral inflows
+ transient storage
∀ reaction

Herein dispersion embraces both the spreading relative to the cross-section averaged velocity and the turbulent diffusion. It is worth to note that the temporal character of various terms in the above equation varies significantly and various terms operate at different time scales. Therefore when particular problem is considered one need to decide which term is significant and which may be omitted without detriment to the results of analyses. This simplified 1D approach may be a result of the averaging of a generalized 3D model.

As mentioned before in the situation where the concentration distribution in lateral direction more or less equalizes, the main interest is paid to constituents' concentrations averaged over the cross-section. This usually occurs at long distances from the release point particularly in rivers of relatively simple geometry. Integration of the advection-diffusion equation in 3D form, an assumption that the dispersive flux obeys Fick's law, i.e. it is proportional to the gradient of the area averaged concentration and some algebraic manipulations lead to the following 1D mass conservation equation:

$$\frac{\partial C}{\partial t}+U\frac{\partial C}{\partial x}=\frac{1}{A}\frac{\partial}{\partial x}\left(AE_L\frac{\partial C}{\partial x}\right) \tag{3.1}$$

where C is the admixture concentration averaged over the cross-section *A*, U is cross-sectional averaged velocity and E_L is the longitudinal dispersion coefficient.

It is very important to note here that advective flux accounts for the turbulent diffusion and the additional flux resulting from the non-uniformity over the cross-section of the longitudinal velocity and concentration. Longitudinal dispersion coefficient is hence a key parameter for the description of the longitudinal transport of a constituent in a river. First term of Eq. (3.1) describes the change of mass with respect to time (mass equals concentration times volume). Two other terms represent two net advective and dispersion fluxes through the control volume of water. As boundary conditions are considered, concentrations should be given for inflows, while the zero gradient condition is used otherwise, since no mass transport takes place along riverbanks. Because of the parabolic nature of the transport equation, no boundary condition should be specified to outflows corresponding to the downstream cross-section of a river.

For channels in which an assumption about constant cross-sectional area and a constant mean longitudinal velocity is a reasonable approximation, Eq. (3.1) may be simplified to

$$\frac{\partial C}{\partial t}+U\frac{\partial C}{\partial x}=E_L\frac{\partial^2 C}{\partial x^2} \tag{3.2}$$

Eq. (3.2) has a relatively simple form and some boundary value problems associated with this equation have analytical solutions. Assume that at the time t=0 an instantaneous release of mass M at the origin x occurs and the concentration tends to zero at the infinite time, i.e.

$$C(\pm\infty,t)=0,\quad C(x,0)=M\delta(x) \tag{3.3}$$

where $\delta(x)$ is a Dirac delta function. Then the solution of Eq. (3.2) reads:

$$C(x,t)=\frac{M}{\sqrt{4\pi E_L t}}\exp\left(-\frac{(x-Ut)^2}{4E_L t}\right),\quad t>0 \tag{3.4}$$

It can be shown that the variance of the solute fulfilling Eq.(3.2) increases linearly with time and the longitudinal dispersion coefficient satisfies the following relation allowing for its experimental determination:

$$E_L=\frac{1}{2}\frac{d\sigma_x^2}{dt} \tag{3.5}$$

where σ_x^2 is the spatial variance in the longitudinal direction.

The literature contains many different forms and methods of the evaluation of dispersion coefficients dependent on various hydraulic conditions (e.g. Fischer, 1967; Holley & Jirka, 1986; Sukhodolov *et al*., 1997; Guymer, 1998; Deng *et al*., 2001, 2002; Rutherford, 1994). Estimation of the longitudinal dispersion coefficient constitutes a basic difficulty in the application of the so-called Fick model. Several estimation methods have been elaborated in the literature, such as physically-based empirical methods, fitting of the theoretical slope of the Laplace transformed solution for the concentration of the flow zone to the observed slope, moments matching procedures, or even visual determination of the set of parameters yielding the best fit to the concentration data. An obvious element is the relation of the computed solute concentrations to some experimentally obtained curves.

One of the most popular expressions for the evaluation of longitudinal dispersion is the one derived by Fischer and co-workers and it reads:

$$E_L = -\frac{1}{A}\int_0^B hu'\int_0^y \frac{1}{\varepsilon_t h}\int_0^y hu'\,dydydy \tag{3.6}$$

where A is the cross-sectional area, u' is the deviation of local depth mean velocity from the cross-sectional mean velocity, B is the channel width and $\varepsilon_t = \varepsilon_t(y)$ is the local transverse mixing coefficient, h is the mean depth. The reader will agree that the application of Eq. (3.6) is not always very practical and the computation of a triple integral involving the velocity profile and the transverse mixing coefficient is possible only if an extensive data is obtained from an experiment. This theoretically based expression serves as the starting point for a number of empirical methods allowing for the evaluation of the longitudinal dispersion coefficients. It is pointless to provide the reader even with a partial list of the available formulae. Such list without a detailed substantiation of the applicability of every formula would be useless.

All these methods work when one knows the breakthrough curves for a particular river reach, but the question remains whether one is able to predict the value of the dispersion coefficient based on previous experience. Assuming a good quality of the historical data in this respect, one may try to use the technique based on artificial neural networks (Rowiński et al., 2005b). It turned out that although the results obtained with the use of artificial neural networks are not fully satisfying, they are more accurate and far less costly than physically-based models allowing for the prediction of longitudinal dispersion coefficient and, consequently, the pattern of pollution spread in rivers. The neural networks proved to be very useful in situations where the local data cannot be easily provided. The artificial neural networks can be readily integrated with, for example, decision support systems and, as such, can constitute a very useful tool for decision makers. The performance of neural networks methodology was very much improved when the input data was extended by river sinuosity index and the results turned out to be better than those based on any other method. The analysed data embraced dispersion coefficients from a range in which minimum and maximum values differed by four orders of magnitude. A very good performance of such prediction is seen in Figure 3.1.

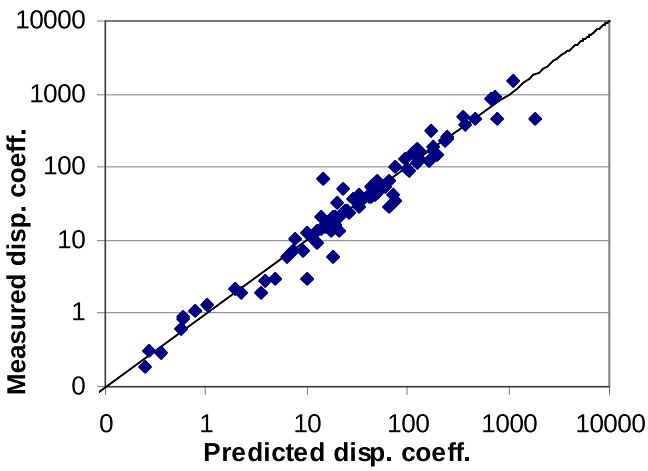

Figure 3.1. Comparison of predicted and measured dispersion coefficients E_L ($m^2\ s^{-1}$) for large data sets (modified from Rowiński et al., 2005).

The advection-dispersion equation has been successfully applied for many real cases; nevertheless very often the questions about its applicability arise. The tail of a solute tracer pulse is often more pronounced than can be accounted for by the traditional advection-dispersion model. A common method for simulating these long tails has been to allow for storage zones along the stream channel. These storage zones are assumed to be stagnant relative to the longitudinal flow of the stream and to obey a first-order mass transfer type of exchange relationship. Very often a quicker decrease of the concentration maximum than follows from Eq. (3.2) is observed. Also a nonlinear growth of the concentration distribution variance and dependence of the dispersion coefficient on time has been often manifested in experimental studies (Sukhodolov et al., 1997).

To account for the existence in the rivers of stagnant zones of water that are stationary relative to the faster moving waters near the centre of the channel the so-called dead-zone model has become increasingly popular for the calculation of the longitudinal dispersion of a solute in a river with irregular cross-sections (e.g. Bencala and Walters, 1983; Nordin and Troutman, 1980; Czernuszenko and Rowiński, 1997). It constitutes a kind of a compromise between data consuming two-dimensional models and the simpler one-dimensional approach. This model is traditionally developed by deriving the one-dimensional mass balance equation with source term in the form

$$\frac{\partial C}{\partial t}+U\frac{\partial C}{\partial x}-D\frac{\partial^2 C}{\partial x^2}=\frac{\varepsilon}{T}(C_d-C) \tag{3.7}$$

where C is the area-averaged concentration in the main stream, U is the area averaged mean stream velocity which is assumed to be constant along the given sub-reach, C_d is the concentration in the dead-zone, D is the constant dispersion coefficient, T and ε are additional constant coefficients. The latter represents the ratio of volume of stagnant areas (dead zones) to volume of mainstream for length unit of a river reach. The former will be explained below equation (3.9). Both concentrations C and C_d are normalized by the total mass of the solute discharged into the river, i.e. at any time t>0.

$$\int_{-\infty}^{\infty} C(x,t)dx=1 \quad and \quad at \quad any\ x>0 \int_{-\infty}^{\infty} UC(x,t)dt=1 \tag{3.8}$$

On the left hand side of equation (3.7) the one-dimensional mathematical representation of basic processes governing the spread of passive admixture in flowing surface waters is given. These processes include advection, i.e. the downstream transport of solute mass at a mean velocity and dispersion - the spreading relative to the depth-averaged or cross-section averaged velocity due to movement with different velocities in different parts of the flow. The right side of equation (3.7) expresses the rate of concentration change due to mass-exchange between the mainstream and the stagnant areas which may for example be created by the marshy vegetation or wetlands existing in the direct neighbourhood of the main channel, also by the irregularities in the riverbeds, groinfields, side pockets, hyporheic storage etc. Taking into account the complexity of the river geometry we may assume that various sets of constant coefficients represent the described situation in each subsection. The mentioned parameters are interpreted as “lumped” parameters that represent a spectrum of storage processes that occur simultaneously in multiple types of storage zones. Depending on the sign, the rate term represents the growth or the decrease of concentration in the main stream of the river. Assuming that the admixture is completely mixed within the storage zones, the mass-exchange balance between the dead zones and the main stream gives:

$$\frac{\partial C_d}{\partial t}=\frac{C-C_d}{T} \tag{3.9}$$

The solution domain is the plane Oxt limited by inequalities $0 \le x \le L$ and $t \ge 0$, where L is the length of the modelled channel reach. The model equations are complemented by the following initial conditions:

$$\mathrm{C(x,\ t=0)=C_p(x),\quad C_d(x,\ t=0)=C_{d_p}(x),\quad for\ x\in[0,\ L]} \tag{3.10}$$

and boundary conditions:

$$C(x=0,t)=C_0(t)\,,\qquad D\left.\frac{\partial C}{\partial x}\right|_{x=L}=0 \qquad t\ \ge\ 0 \tag{3.11}$$

The parameter T may be interpreted as the penetration time of tracer into (or out) the storage zones and it is called a time constant of the system described by equation (3.9). It is easy to see that equations (3.7) and (3.9) converge to the Fickian equation when $\varepsilon \to 0$ and $T \to \infty$.

The influence of the various processes considered in the model on the anticipated breakthrough curves is shown in Fig. 3.2.

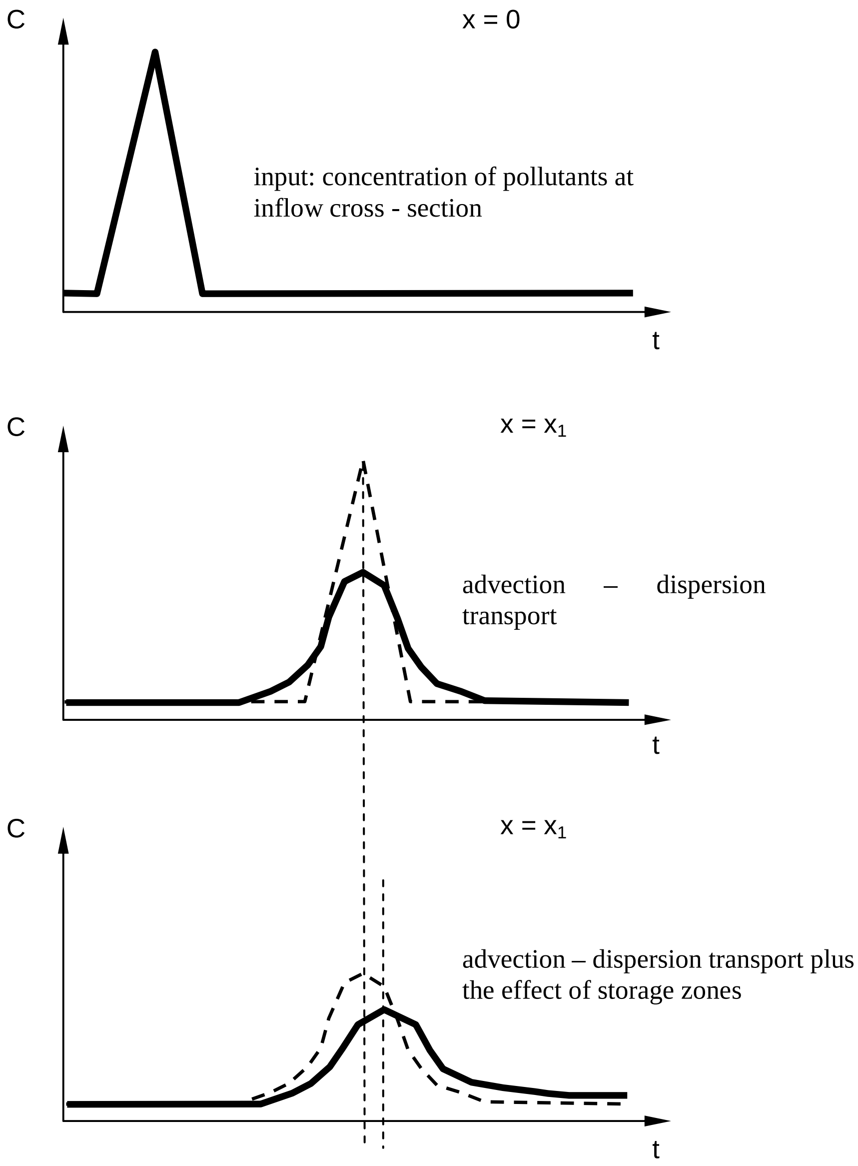

Figure 3.2. The influence of advection, dispersion and effect of storage zones on the breakthrough curves.

To successfully apply such kind of transient storage zone models, appropriate values for various parameters are required. These values can be obtained from analysis of tracer concentration data obtained in natural streams (eg. Fernald et al., 2001; Johansson et al., 2001, Nordin and Troutman, 1980; Wörman, 2000). The problem, as in the case of Fickian model, arises for streams where mixing and dispersion characteristics are unknown. There are empirical equations elaborated for such situations (Pedersen, 1977) but they are of rather disputable validity. The results further shown in the paper are based on the frequency response function and the inverse of Fast Fourier method. Another method based on the random global optimisation technique was presented in (Rowiński et al., 2004).

4. Tracer tests

The need to predict the environmental impact of pollution incidents in rivers has spurned the development of numerous techniques and most of effort has been expanded on the development of mathematical models (for example those described above) (Wallis, 2005). It is also a consensus among researchers that much can be learned about the response of rivers to the release of pollutants by undertaking controlled tracer experiments.

In order to determine tracer content, the conductivity, photometric, fluorescence and radiometric techniques are used, depending on the used substance. In investigation of dispersion and dilution of pollutants in surface waters the radioactive and fluorescent tracers are widely used. These two kinds of tracers are highly stable in aqueous media and are featured by high sensitivity of their detection. Examples of the used tracers may be ^{82}Br in the form of KBr as a radioactive tracer and of rhodamine WT and uranine as fluorescent dyes. Also it is a frequent practice to use solutions of different chlorides like sodium chloride or lithium chloride. Literature in this respect is very rich (see e.g. Broshears et al., 1993; Fernald et al., 2001; Johansson et al., 2001; Sukhodolov et al., 1997).

Tracer investigation of pollutant transport in surface waters consists in injection of a tracer at a predetermined site and recording distribution of its concentration as a function of time and position within the river reach under consideration. Concentration measurements are usually made at several cross-sections that are located far enough from the injection point that the tracer is well mixed across the width of the river. If such measuring cross-section is located closer, than the measurements should be taken across the river to allow for the evaluation of lateral dispersion. The interpretation of such test would call for the use of 2D models. Such experiments are, however, much more difficult in realization and much more expensive. The decreasing part of the distribution is usually longer than the increasing part and the measurements should be taken until the natural background concentrations of the tracer are achieved. After the mixing within a cross-section is completed, the mass of tracer M to pass a cross-section is readily computed as:

$$M = \int_{T_l}^{T_t} CQdt \tag{4.1}$$

where T_l is the elapsed time to the arrival of the leading edge of the tracer cloud at a sampling location, T_t is the elapsed time to the trailing edge of the tracer cloud at the same location. In other words the integral (4.1) is taken over the duration of the tracer cloud, i.e. T_t-T_l.

It is important to note that all the tracer experiments should be accompanied by a detailed survey of the bathymetry and hydraulic conditions in the considered river reach.

5. Case study – Development of the Narew River Alarm System

In this section a short overview of the research studies allowing for the creation of the expert system related to water quality issues in the area of the Narew National Park will be given. The study concerns a meridional part of the Upper Narew River. The multichannel Narew River section extends in the marshy area from Suraż to Rzędziany villages and this part of the river constitutes the basis for the Narew National Park (NNP). Until the Rzędziany section the river has a natural character, since no drainage works have ever been done there (Mioduszewski, 2001). The only important unnatural factor influencing both the water quantity and quality in this area is the Siemianówka water reservoir built upstream, along the stream - about 90 km from the Narew National Park. The river system within NNP maintains its absolutely unique character with its frequently branching and rejoining streams. The Narew valley in this area is characterized by a relatively flat bottom bordered by gentle slopes of low hills built mostly of glacial clays. The Upper Narew River in the considered meridional part is of an anastomosing type (Gradziński et al., 2000).

The study presented herein has been concentrated on the initial reach of the river within NNP starting from the bridge in Suraż and with the last measuring site in Bokiny village and it extended along the main river stream over a distance of 16.8 km according to the GPS-reading. The imagination about the complexity of the river system can be gained from a snapshot of the created computer expert system (Figure 5.1).

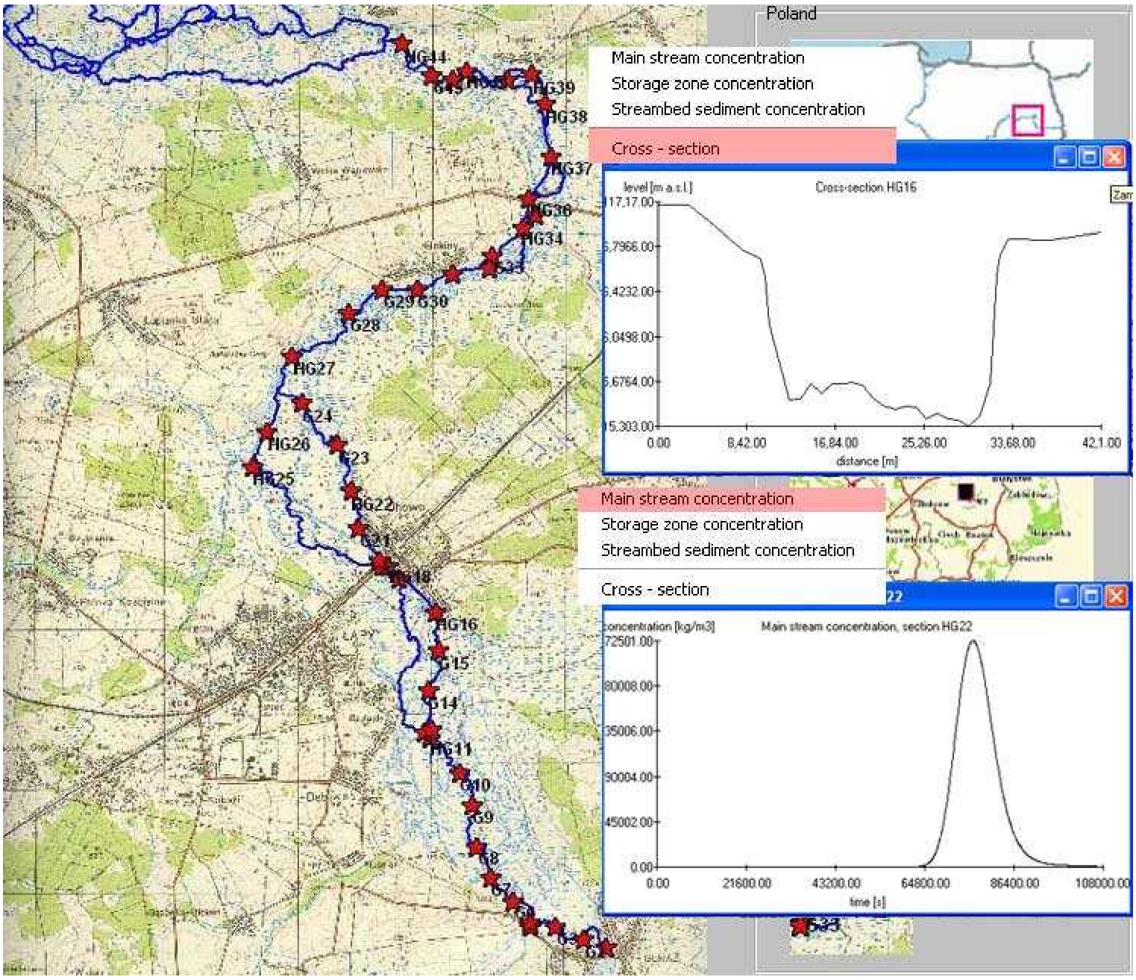

Figure 5.1. Snapshot from the expert system on the pollution transport in the Upper Narew River created at the Institute of Geophysics, Polish Academy of Sciences.

A precondition for understanding the pattern of pollutants spread in the river system is its detailed hydrologic and hydraulic recognition. Comprehension of that system was achieved in a multi-stage process starting from the recognition of the geometry of the river system together with the adjacent floodplain areas based on the existing maps, GPS-based map, field surveys and monitoring of two flood waves that occurred during the realization of the project (Rowiński et al., 2005a). Further steps consisted in the simulations with the use of CCHE1D model and creation of respective anticipated flood area maps. Special hydrological measurements were performed. The main aim of that measurements was the recognition of the streamwise velocity field. The knowledge of actual velocity distributions allowed also for the determination of the discharges at the selected cross-sections. Water surface slope along the whole river reach, slopes between measuring cross-sections, local water surface slopes, riparian (overbank parts) of riverbed profiles and ordinates of the free surface were fixed by levelling in relation to provisional benchmarks levelled to a geodetic benchmark in Suraż, in the Kronstadt reference system. The provisional benchmarks were installed in the measurement profiles.

The velocity distribution data could be further analyzed to reveal properties of river hydraulics. Measuring river discharge is always an important task and in fact one of our key questions allowing to balance water outflows and inflows to the system. Other hydraulic and topographic characteristics such as the hydraulic radius, local water surface slopes, Manning coefficient, Froude and Reynolds numbers were determined in respect to all the measuring cross-sections.

The course of the tracer test was extorted by its needs, i.e. the evaluation of the threats by an accidental release of the pollutants at the downstream locations and by the economical and technical feasibility. Therefore the initial part of the stream where the solute mixes across the depth and the width of the river is ignored and the study is concerned with one-dimensional, longitudinal transport of the dye. Rutherford (1994) stresses that when studying longitudinal dispersion it is necessary to sample for long enough to measure the entire concentration versus time profile at each site and check for tracer loss and indeed it was extremely time consuming and made us to have people in the field for almost a week. The reason is the long tail associated with tracer becoming trapped in various river arms and bights and the classical dead zones. The method of instantaneous injection of the tracer was applied and it did not require the complex dosing facilities and allowed to obtain high initial concentrations of the tracer. The dye release consisted of 20 liters of 20% solution of Rhodamine WT, which was released at three points at the cross-section just downstream of the bridge at Suraż. Concentrations were measured at six transects corresponding to flow distances of 3.62 km (cross-section A), 8.34 km (cross-section B), 9.01 km (cross-section C), 9.23 km (cross-section D), 13.58 km (cross-section E), and 16.83 km (cross-section F). First cross-section was established at a distance at which 1D conditions were supposed to be achieved. During the early stages of a test, dye is visible to the naked eye, which facilitates sample collections. The dye was detected by using the field fluorometer Turner Design with continuous flow cuvette system on the one hand and also water samples were collected at sampling points. The measuring crew was equipped in fluorometers, graphical register and the pumps enforcing steady flow through the flow cell of the fluorometer. Measuring data were stored on graphical registers in the form of concentration distributions and then digitised to obtain relevant concentration time series. Samples were collected to the glass bottles with Teflon-lined caps to prevent adsorption and were protected from sunlight. The dye concentration curves were registered until the complete decay of fluorescence, i.e. until the background concentrations were achieved.

The described previously storage zone model was fitted to the observed breakthrough curves and thus an evaluation of the model parameters was made. The fitting was performed at subreaches along the stream with the observed temporal concentration curves at one station as a boundary condition for the next one. The use was made of the frequency response function and the inverse fast Fourier transform.

Table 5.1. Parameters of the impulse response model.

Parameters	Sections					
	[AB]	[BC]	[CD]	[DE]	[EF]	[AF]
D [km^2/h]	0.0027	0.0220	0.0051	0.0338	0.0034	0.0120
ε	0.0920	0.0120	0.7920	0.3690	0.2260	0.1020
T [h]	0.4530	0.6550	11.2570	7.0706	0.9030	1.4440
U [km/h]	0.5200	1.8400	0.4880	1.6200	0.7800	0.9190

The results of the described estimation procedure are given in table 5.1. Application of those parameters to the computations of temporal variations of concentrations at the given cross-sections lead to similar results as the ones experimentally observed. Fig.5.2. presents relevant examples of such computations.

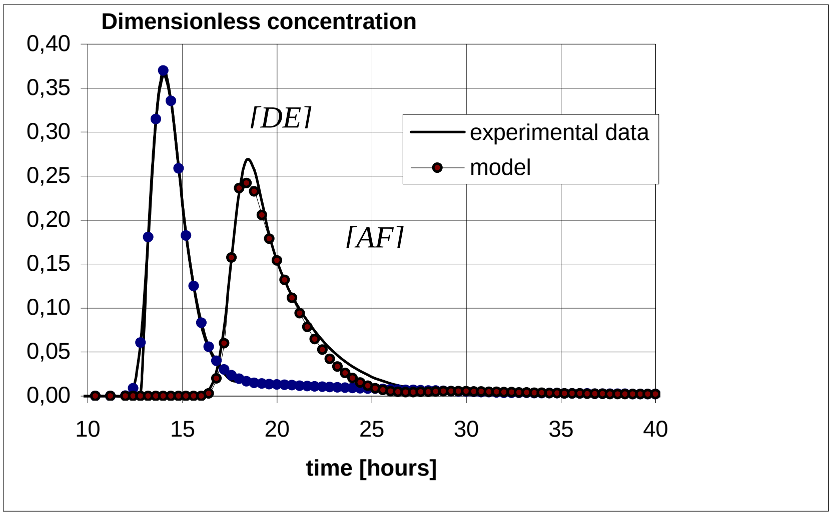

Figure 5.2. Comparison of measured solute concentrations with the modelling results.

Note that the evaluated dispersion coefficient is the smallest in the initial section (0.0027 km^2/h) and it assumes the highest values in the sub-reach [EF], i.e. 0.0338 km^2/h. Such big differences are the result of high variability of geometrical and hydraulic conditions along the stream. Most of the quantitative analyses of the dispersion coefficient were conducted by means of the traditional Fick-type model and such results cannot be automatically transferred to the models that take into account the temporary storage of the admixture. Czernuszenko et al. (1998) showed that when natural rivers are considered, the dispersion coefficients obtained by means of the dead zone model are much smaller than the ones obtained with the use of traditional methods. It is caused that in the Fick-type models, the dispersion coefficient among others accounts for the non-uniformities and irregularities such as islands, rapids, deep pools, which obviously influence the pattern of the spread of pollution. It can be noticed that in the considered case, the dispersion coefficient increases together with the growth of the mean channel velocity. The parameters that account for the temporary storage of the dye vary along the river stream considerably as well. In the first sub-reaches the parameter ε is less than 0.1 and such values have been often observed in relatively regular rivers (Czernuszenko et al., 1998). Such values already testify about the presence of numerous storage zones in which the dye has been trapped and the time of penetration is represented by parameter T. These storage zones occur in the main stream itself. Also part of water and pollution penetrates the adjacent marshes with its specific vegetation which hinders the flow considerably.

Much higher values of ε below the station D is caused by the migration of the part of the tracer to a river branch where the conditions for the transport of mass is much worse and therefore the concentrations curves at the station where the streams rejoin are characterized by long tails stretching upstream and this fact has to be reflected in the source term of Eq. (3.7). Parameter ε and more exactly the ratio of ε ad T is decisive for the magnitude of this term. Note the extremely long time of penetration of the admixture in this river reach. In the light of the presented model the river branches can be treated as additional storage zones, which superimpose with traditional dead zones created by the irregularities of the riverbed. Existence of sand bars and shoal patches, variability in roughness conditions influenced the increase of storage zone parameters. The last set of parameters provides an overview for the entire river reach under consideration and it gives averaged values determined for this highly changeable reach. More details of the described experiment may be found in (Rowiński et al., 2003a, 2003b).

6. Concluding remarks

Complex studies leading to the creation of the alarm model for the protective area of the Upper Narew river have been presented. The major task for decision makers in this and alike water bodies is the preparation for the emergency response to warn downstream users. An important element in this response planning constitute river alarm models. As it was shown in the paper the first step in the creation of such model is the identification of the mathematical treatment of the problem. In natural rivers the so far used advection-dispersion models do not suffice and the so-called transient storage zone models prove to provide better results. It is caused by the fact that natural streams frequently contain quiescent backwater areas, eddies, aquatic vegetation and irregularities in the riverbeds which act as transient storage zones. Such models require more information to be able to identify the model parameters. A best-fit model calibration is possible whenever high quality tracer data sets covering different stretches and hydrologic regimes are available. Studies in this respect have been initiated in that complex river system of the Upper Narew and a reasonably reliable pollution routing tool has been created. One has to remember that a realistic model has to additionally take into account the chemical and biological reactions that a particular constituent is subject to. Despite it was not presented in the paper the considered model has such capabilities.

Acknowledgements

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