

OPERATIONAL MODELLING OF CONTAMINANT TRANSPORT IN THE RIVER ELBE

STEPHAN MAI

*German Federal Institute of Hydrology, Am Mainzer Tor 1
Koblenz, D-56068, Germany*

DIETER LIPPERT

*German Federal Institute of Hydrology, Am Mainzer Tor 1
Koblenz, D-56068, Germany*

ULRICH BARJENBRUCH

*German Federal Institute of Hydrology, Am Mainzer Tor 1
Koblenz, D-56068, Germany*

The forecast of contaminant transport in the river Elbe in case of accidental pollution is supplemented by the operational model Alamo (alarm model Elbe). The modeling concept as well as its implementation is outlined in this paper. Tests of the accuracy of the numerical model Alamo are carried out based on field data acquired in tracer experiments. The rms deviation in the tracer concentration amounts to 14 % and in the travel time to 7 %. The graphical user interface of Alamo and its relation to the International Alarm Plan Elbe, which relates to the requirements of the European Water Directive 2000/60/EC, is demonstrated.

INTRODUCTION

The European Water Directive 2000/60/EC [1] (article 11 (3) 1) requires measures to reduce the impact of accidental pollution incidents for each river basin district. Therefore the International Commission for the Protection of the River Elbe (IKSE), working group H - Accidental River Pollution, worked out the International Alarm Plan Elbe [2].

The Alarm Plan Elbe regulates the messaging in case of accidental river pollution including the forecast of the contaminant transport. This forecast of the contaminant transport is based on the numerical model Alamo, i.e. alarm model Elbe. Alamo was developed by the German Federal Institute of Hydrology in cooperation with the Leichtweiss Institute and the Czech institutes Povodi Labe, CHMU and VUV. The model covers the whole stretch of the not tidally influenced river Elbe. Figure 1 gives a sketch of the model area with the Czech part from Jaromer to Schöna and the German part from Schöna to Geesthacht.

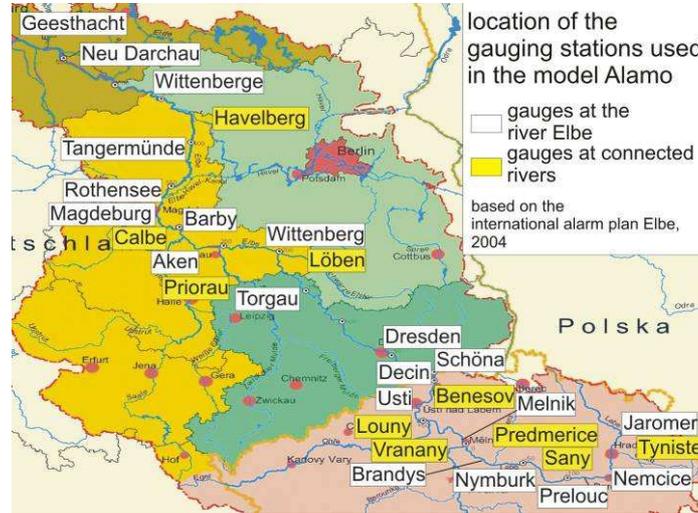


Figure 1. River Elbe form Jaromer to Geesthacht - extend of the model Alamo.

In the following the modeling concept, the accuracy of the model as well as the graphical user interface will be discussed.

MODELING CONCEPT

The concept of Alamo modeling the transport of dissolved matter is based on the dispersion / diffusion equation proposed by Taylor [3]. Besides of the dispersive / diffusive transport in the mainstream of the river the exchange of pollutants between mainstream and dead-water zones [4] as well as the degradation of pollutants is included in Alamo. This leads to the following set of differential equations for the contaminant concentration in the mainstream c and the contaminant concentration in the dead-water zones s

$$\frac{\partial c}{\partial t} = -v \frac{\partial c}{\partial x} + D_L \frac{\partial^2 c}{\partial x^2} - \epsilon D_s (c - s) - k c \quad (1)$$

$$\frac{\partial s}{\partial t} = D_s (c - s) - k s \quad (2)$$

with the flow velocity in the main stream v , the coefficient of decay k , the relative area of the dead-water zone ϵ , the longitudinal dispersion coefficient D_L , and the exchange coefficient D_s between main stream and dead-water zone.

The parameters v , ε , D_S and D_L of differential equations (1) and (2) are parameterized with the river discharge measured at the gauges given in Figure 1, i.e.

$$\varepsilon = a_\varepsilon \cdot Q^{b_\varepsilon} \quad (3)$$

$$v = a_v \cdot Q^{b_v} \quad (4)$$

$$D_L = a_L \cdot Q^{b_L} \quad (5)$$

$$D_S = a_S \cdot Q^{b_S} \quad (6)$$

with the tunable coefficients a and b for each of the parameters.

The determination of the coefficients a_v and b_v is based on the results obtained from a one-dimensional hydraulic modeling described by Drewes et al. [5] while the determination of the coefficients a_L , b_L , a_S , b_S , a_ε and b_ε is carried out using tracer experiments as described in the following chapter.

Within Alamo the set of coupled differential equations is solved using the Rosenbrock-Wanner method as given by Rentrop and Steinebach [6].

VERIFICATION OF THE MODEL

For the calibration and verification of the parameterizations used in Alamo nine tracer experiments were carried out (see Figure 2). Table 1 gives an overview over the tracer experiments along the 850 km long section of the river Elbe between Jaromer, Czech Republic, and Geesthacht, Germany, for discharge conditions between mean low water and mean high water.



Figure 2. Input of the tracer Red Dye and monitoring station of tracer concentration.

Table 1. Tracer experiments for the calibration and verification of the model Alamo

date	location of tracer input	station	mass of tracer	discharge Q	mean low water	mean high water	reference
		[km]	[kg]	[m ³ /s]	[m ³ /s]	[m ³ /s]	
15/07/97	Schmilka	4,1	33,5	330	102	1480	Hanisch et al. [7]
30/11/97	Ústí	-37,0	12,1	130	91	1430	Dostál et al. [8]
27/10/98	Elster	200,4	26,4	265	130	1490	Hanisch et al. [9]
26/04/99	Mělník	-104,8	24,0	255	76	1324	Dostál et al. [10]
11/10/99	Elster	200,4	26,0	160	130	1490	Hanisch et al. [9]
29/11/99	Němčice	-249,2	2,0	16	12	309	Dostál et al. [11]
29/03/01	Schmilka	4,1	75,8	912	102	1480	Hanisch et al. [9]
06/10/04	Mauken	184,5	20,0	136	114	1380	
02/05/05	Němčice	-249,2	8,0	52	12	309	

For each tracer experiment the best set of the parameters D_L , D_S and ϵ was determined along the river [9]. Taking the parameters for each experiment, i.e. for a variety of discharge conditions, the best coefficients a , b were determined by nonlinear least-squares fitting.

Despite of the large effort undertaken in calibration a comparison of model results with in-situ measurements during the tracer experiment on the 06/10/2004 revealed a rms deviation in the tracer concentration of 14 % and in the travel time of 7 %.

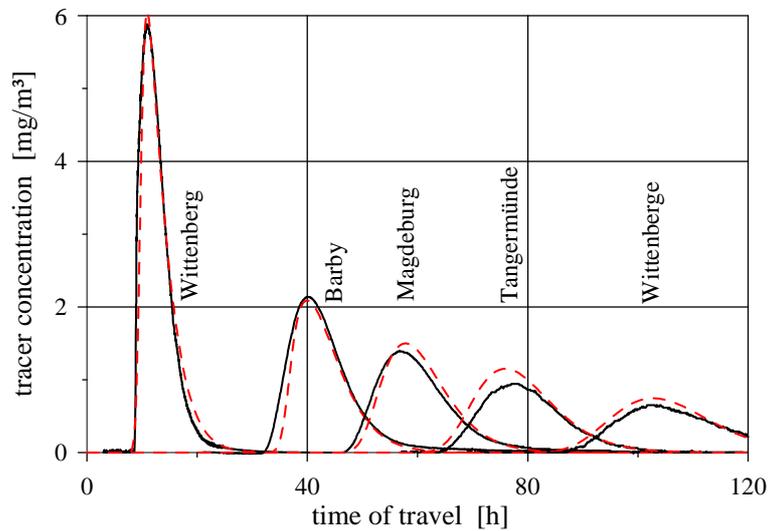


Figure 3. Comparison of modeled and measured tracer concentrations at different locations along the river.

In Figure 3 a comparison of the modeled and the measured time-series of tracer concentration along the river is given. As expected the maximum concentration of the tracer decreases with traveling time. A possible reason for the differences between modeled and measured tracer concentration may be the retardation of the tracer transport due to reversible sorption of the tracer at the river bed.

GRAPHICAL USER INTERFACE

In order to guarantee an optimal usability of the model Alamo a graphical user interface (GUI) was developed. A screenshot of the graphical user interface is given in Figure 4 presenting also the functionality of the GUI, realized in pull-down menus. According to the location of the river Elbe the GUI is actually available in German and Czech. However the GUI, programmed in Java, can easily be adapted to other languages just by altering template files. This also holds for figures and reports generated by the program. When using Alamo after a contamination of the river Elbe the operators in the responsible warning center are guided by the GUI in order to guarantee a complete and correct input of the information on the contamination.

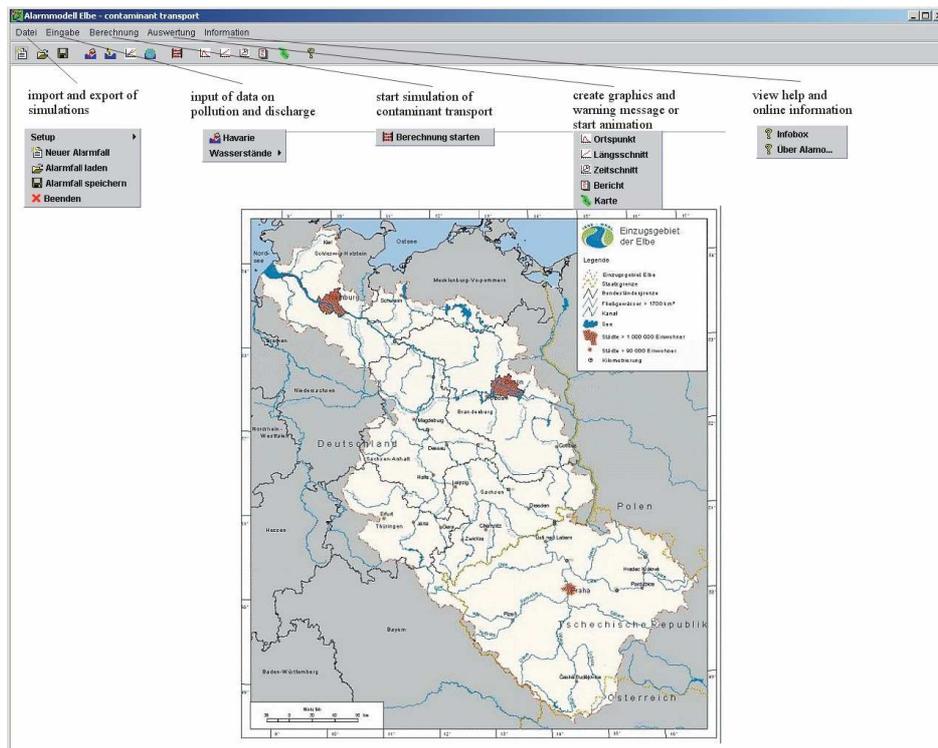


Figure 4. Starting screen of Alamo and built-in functions.

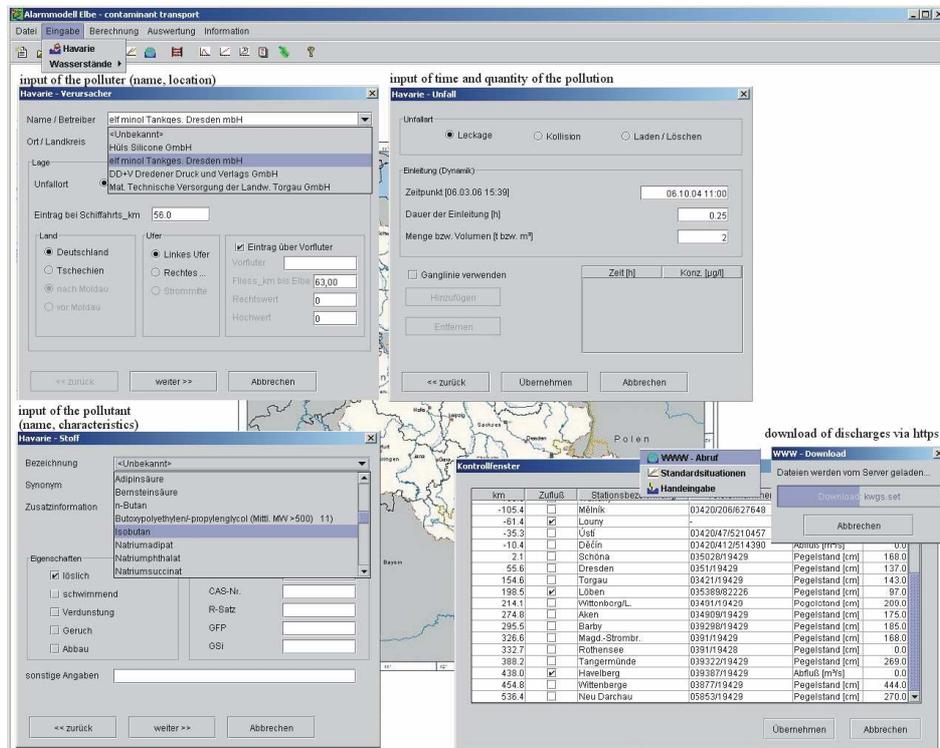


Figure 5. Guidance of the user for the input of the characteristics of the pollution.

The operator has to supply information on the polluter (name, location), on the pollutant (name, material properties, quantity, characteristics) as well as on the time and duration of the pollution. As a help for the user lists of the major industrial sites and of typical contaminants are given. Besides that the GUI provides an https-access to the actual water levels and stage-discharge relations as well as to the actual set of model coefficients. The structure of the menus is given in Figure 5.

The results of the simulation of the transport of contaminants are summarized in data sheets giving the estimated beginning, peak and end of the contaminant passage at various locations along the river. In addition graphics of the maximum contaminant concentration to be expected along the river and the corresponding time of passage as well as time series of tracer concentration at certain locations are available. The Figure 6 exemplifies this graphical output of Alamo. The given charts are supplemented by an animation of the contaminant transport.

Within the workflow of the alarm plan Elbe Alamo automatically generates the warning messages prescribed in case of river contamination.

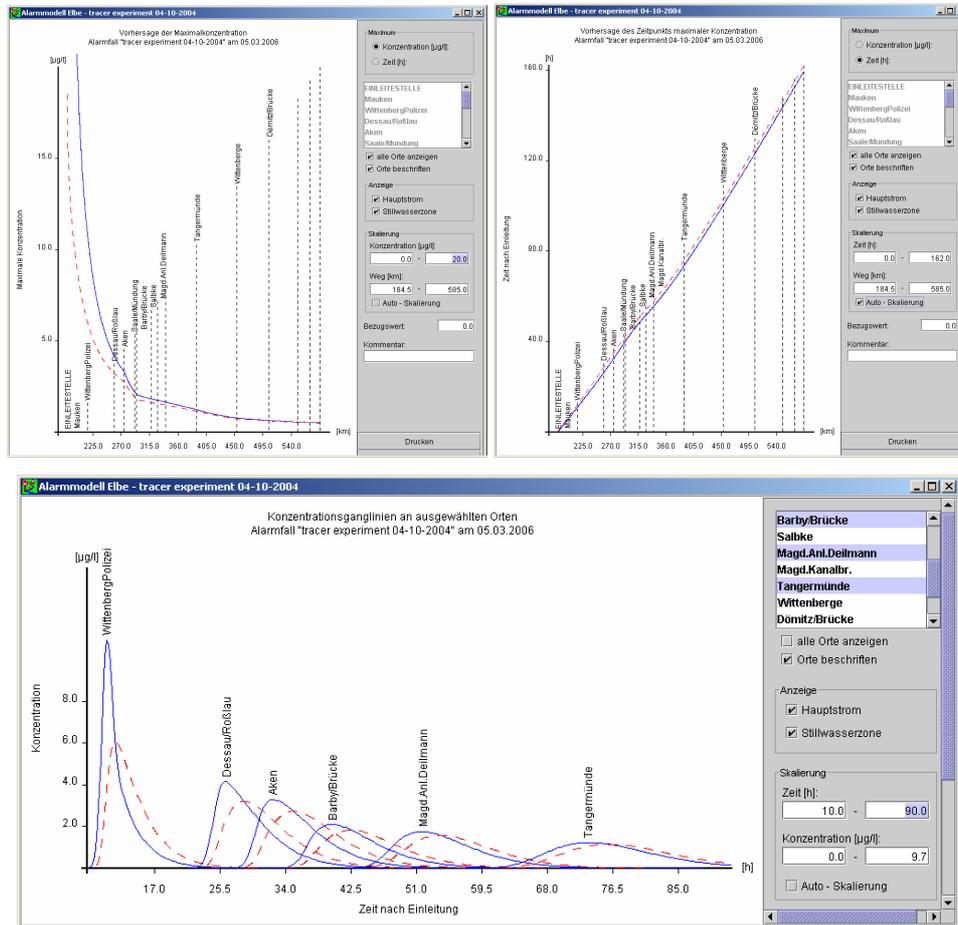


Figure 6. Screenshots of the graphical presentation of the modeling results by Alamo – maximum concentration along the river (top left), estimated time of concentration maximum (top right) and time series of tracer concentration (bottom).

CONCLUSION

The alarm model Elbe contributes to the fulfillment of the requirements of the European Water Directive 2000/60/EC (Water Framework Directive). It is an important tool for the operational handling of accidental river pollution. The International Commission for the Protection of the River Elbe therefore agreed about the integration of Alamo into the workflow of the four warning centers along the river Elbe. During the first case of emergency after pollution with cyanide in January 2006 Alamo showed its applicability. However the experience during this real pollution incident will be used for a further improvement of the model with respect to user guidance and model calibration.

ACKNOWLEDGEMENT

The author gratefully acknowledge the cooperative work with the International Commission for the Protection of the River Elbe (IKSE) and the very good collaboration with the Czech institutions Povodi Labe, CHMU and VUV as well as the Leichtweiss Institute, Germany.

Special thanks are addressed to the colleagues at the local waterways and shipping offices (WSA) in Dresden, Magdeburg and Lauenburg who helped to carry out the tracer experiments in 2004.

REFERENCES

- [1] European Parliament and the Council of the European Union “Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy (short title: EU Water Framework Directive (WFD))”, Official Journal of the European Communities, L327/1, (2000).
- [2] IKSE (International commission for the protection of the river Elbe) “International alarm plan of the river Elbe (original in German: Internationaler Warn- und Alarmplan Elbe)”, report, Magdeburg, (2004), pp 1-23.
- [3] Taylor, G.I. “The dispersion of matter in turbulent flow through a pipe”, Proc. Roy. Soc. London, Ser. A, Vol. 223, (1954), pp 446-468.
- [4] Weitbrecht, V. “Influence of dead-water zones on the dispersive mass transport in rivers”, Universitätsverlag Karlsruhe (2004).
- [5] Drewes, U., Ettmer, B. Mende, M. “Hydraulic calculations of the river Elbe from Nemcice to the German-Czech border (original in German: Hydraulische Berechnungen von Nemcice bis zur deutsch-tschechischen Grenze)“, report, Leichtweiss Institute, no. 869, Braunschweig (2001).
- [6] Rentrop, P., Steinebach, G. “Model and numerical techniques for the alarm system of river Rhine”, Surveys on Mathematics for Industry, Vol. 6, (1997), pp 245-265.
- [7] Hanisch H.-H., Dostál K., Trejtnar K., Vosika S., Specht F.-J., Eidner R. “Tracer experiments in the river Elbe (original in German: Traceruntersuchungen in der Elbe)”, Proc. of the 8th Seminar on inland water protection (original German title: Magdeburger Gewässerschutzseminar), Magdeburg, (1998), pp 29-32.
- [8] Dostál K., Koza V., Rederer L. “Tracer experiment in the river Elbe (original in Czech: Zpráva o testovacím pocusu na Labi)”, report, Povodi Labe, Hradec Králové (1998).
- [9] Hanisch, H., Dostál, K., Rederer, L., Specht, F.-J., Mende, M., Stahl, K. “Tracer experiments in the river Elbe (original in German: Tracerversuche Elbe)”, report, German Federal Institute of Hydrology, Koblenz (2004).
- [10] Dostál K., Koza V., Rederer L. “2nd Tracer experiment in the river Elbe (original in Czech: Zpráva o 2. testovacím pocusu na Labi)”, report, Povodi Labe, Hradec Králové (1999).
- [11] Dostál K., Koza V., Rederer L. “3rd Tracer experiment in the river Elbe (original in Czech: Zpráva o 3. testovacím pocusu na Labi)”, report, Povodi Labe, Hradec Králové (2000).