UNCERTAINTY IN COMPUTATIONS OF THE SPREAD OF WARM WATER IN RIVER

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Abstract

A prerequisite for the construction of gas-steam power plants is the evaluation of the threats caused by heated water discharged into a river and it obviously should be a part of Environmental Impact Assessment. The present study draws from the case studies' computations aimed at building scenarios of spread of heated water discharged from designed gas-steam power plants in actual rivers. Authors aim to share their experience in the use of an up to date model on spread of warm water jet in a river in the light of the scarcity of proper data. In this study the heat transfer has been considered in two-dimensional domain. In general case heat transport may be represented by depth-averaged advection-diffusion equation with relevant source (sink) terms. Then the dispersion coefficients form a non-diagonal dispersion tensor with four dispersion coefficients and particular attention will be paid to the role of all components of that tensor. Other sources of uncertainty will be briefly discussed as well.

Introduction

Solving practical problems concerning environmental impact assessments, usually we deal with limited data and information insufficient to prepare a forecast with a proper accuracy. Since in most cases it is impossible to collect desired amount of measuring data, we have to draw the best possible conclusions on the basis of limited data. At the same time we must remember that the experimental data is not perfect and may be biased. Lack of data, as well as measurement errors are only some of sources of uncertainty affecting problem solutions. Insufficient knowledge of the described phenomena is another reason for uncertainty for the obtained results. In addition we have to consider the errors introduced by the models used in the calculation, which always more or less simplify the described phenomena. For various reasons these models cannot take into account all the variables controlling the phenomena, also they have to usually simplify the problem to make it practically solvable. A discussion about the admissible and inadmissible simplification of pollution transport equation (here we deal with the so-called thermal pollution) authors present in their earlier studies: Rowiński & Kalinowska (2006) and Kalinowska & Rowiński (2008). Any calculation and possible numerical errors caused by selected numerical algorithms used (if necessary) while solving the problem as well must be added (see Kalinowska & Rowiński, 2007). We have to estimate the resulting errors, and examine possible extreme scenarios, which will allow us to predict potential impact on the environment. Analysis of extreme cases appears to be crucial, since even small changes in river ecosystem can significantly disturb the environment.

In this article we will describe some of practical problems that occur and are potential sources of errors while predicting two-dimensional temperature field in case of the discharge of cooling water into river, being a side effect of operation of power plants and other hydraulic engineering facilities using water for cooling purpose. To illustrate those problems an example of a real case study performed in Vistula River in Poland has been used herein. The aim of the study was to predict the spread of heated water discharged from a designed gas-steam power plant located in the lower Vistula River below Włocławek town in Poland. Four different variants of warm water release with constant intensity of 14 m^3/s have been analyzed. The temperature of discharge water was 7°C higher than the temperature of ambient river water. Since we are interested in the extreme conditions, the computations have been done for the mean low-flows of the river $Q = 334\ m^3/s$. The detailed description of the considered case and predicted scenarios of the spread of warm water for different variants may be found in (Kalinowska at al., 2012). All results (also those presented below) have been prepared using a RivMix (temperature filed) and CCHE2D (velocity field) models. The RivMix (River Mixing Model), developed in Institute of Geophysics Polish Academy of Sciences is the two-dimensional numerical model of the spread of passive pollutants in flowing surface water, solving the two-dimensional advection-diffusion equation with the included off-diagonal dispersion coefficients (Kalinowska & Rowiński, 2008). The CCHE2D, developed by NCCHE – National Center for Computational Hydroscience and Engineering is the two-dimensional depth-averaged, unsteady turbulent open channel flow model (Altinakar et al., 2005; Ye & McCorquodale, 1997; Jia & Wang, 2001; Zhang, 2005). The model is based on the depth-averaged Navier–Stokes equations.

Heat transport equation

Although complete vertical mixing occurs relatively quickly, mixing along the width may take a very long time (Kalinowska and Rowiński, 2008). In large rivers, in an extreme case it may be a distance of hundreds of kilometers. Therefore the attempts to describe the process by using one-dimensional approach are very often not sufficient. Variation of the water temperature, in cases similar to those considered here, should be described then by two-dimensional depth-averaged partial differential equation (Rodi et al,. 1981; Seo et al., 2010; Szymkiewicz, 2010):

$$h(\mathbf{x})\frac{\partial T(\mathbf{x},t)}{\partial t} = \nabla\left(h(\mathbf{x})\mathbf{D}(\mathbf{x})\cdot\nabla T(\mathbf{x},t)\right) - \nabla\left(h(\mathbf{x})\mathbf{v}(\mathbf{x})\cdot T(\mathbf{x},t)\right) + q \qquad (1)$$

where: t – time, $\mathbf{x}$ = (x, y) – position vector, T($\mathbf{x}$, t) – depth-averaged water temperature, h($\mathbf{x}$) – local river depth, $\mathbf{v}$($\mathbf{x}$) – depth-averaged velocity vector, $\mathbf{D}$($\mathbf{x}$) – heat dispersion tensor, q – source function describing additional heating or cooling processes.

To solve the heat transport equation (1) we need to know: the two-dimensional velocity field, the geometry of the river, the full dispersion tensor, the boundary and initial conditions and if we want to include any additional sources (e.g. temperature exchange with the atmosphere) additional information (like meteorological data). While collecting and processing all this data we may encounter several problems requiring assumptions and simplifications which affect the final solution to some extent. For the scientific purpose we usually try to gather all necessary data and consider all the possible processes which affect the solution. In real situation when dealing with Environmental Impact Assessments (EIA) such precise approach is practically impossible. Measurements of potentially necessary data are usually limited due to the time, costs and many technical restrictions. We have to use than advanced computational technics and computational models to interpolate, approximate or calculate necessary missing data. Unfortunately, the use of wide available computational recourses and models without proper understanding of their specification and purpose are very common especially when applied to EIA. Also models working perfectly in one case may be not sufficient for another one.

Determination of dispersion coefficients

In the considered case many possible problems have to be taken into consideration. Here we would like to underline problems affecting the final solution, usually not considered by usurers of different available computational models, concern with the determination of dispersion coefficients. In general case in Cartesian coordinates the dispersion coefficients form a non-diagonal dispersion tensor with four dispersion coefficients:

$$\mathbf{D} = \begin{bmatrix} D_{xx} & D_{xy} \\ D_{yx} & D_{yy} \end{bmatrix}. \qquad (2)$$

In some cases when the flow direction is parallel to the x-axis the off-diagonal elements of the tensor could be omitted, but it is not a case in real situations, when the channel geometry could be very complex. Then it is crucial to compute the dispersion tensor **D** in the proper way, otherwise unrealistic results may easily be obtained.
Generally in practical applications terms with mixed derivatives in equation (1) tend to be ignored. In such cases the off-diagonal elements of dispersion tensor are omitted by using various kinds of simplifications. Different erroneous ways of simplifications in the treatment of dispersion tensor often met in literature and applied in computational models have been described by authors in (Rowiński & Kalinowska 2006 and Kalinowska & Rowiński, 2008). The proper way to obtain the full tenor **D** is rotation of a diagonal tensor $\mathbf{D_D}$ containing the so-called longitudinal D_L and transverse D_T dispersion coefficients:

$$\mathbf{D} = \mathbf{R}(\alpha)\cdot\mathbf{D_D}\cdot\mathbf{R}^{-1}(\alpha); \qquad (3)$$

where:

$$\mathbf{R} = \begin{bmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{bmatrix} \text{ – is the rotation matrix,} \qquad (4)$$

$$\mathbf{D_D} = \begin{bmatrix} D_L & 0 \\ 0 & D_T \end{bmatrix} \qquad (5)$$

and α is the angle between the flow direction and x-axis. Results obtained with the proper way of tensor computation in considered case for the variant with continuous point discharge in the middle of the channel (point Z_1 = (1850m, 800m)) have been presented in Figure 1 (the whole computational domain) and Figure 2 (the enlargement of the discharge area). In case when we simply omit the off-diagonal elements of dispersion tensor (2) the resultant temperature distribution has been presented in Figure 3 and Figure 4. Figure 5 and Figure 6 present the results when

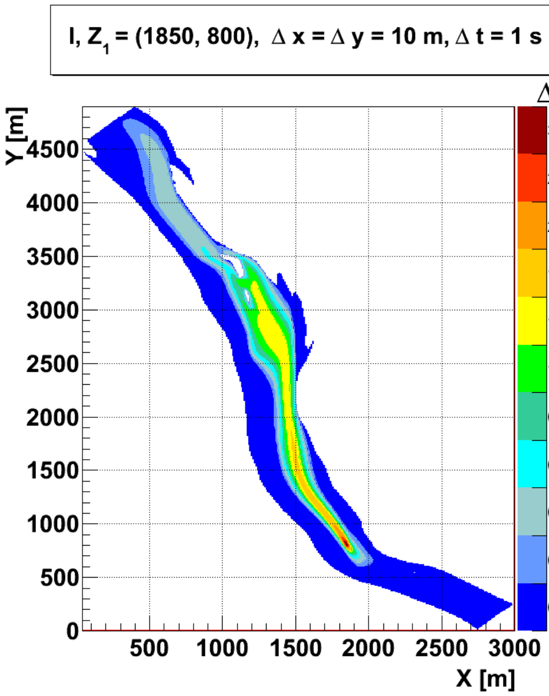

Figure 1. Predicted distribution of the temperature increase (ΔT) for continuous discharge in the middle of the channel at point Z_1 with the proper way of dispersion tensor computation.

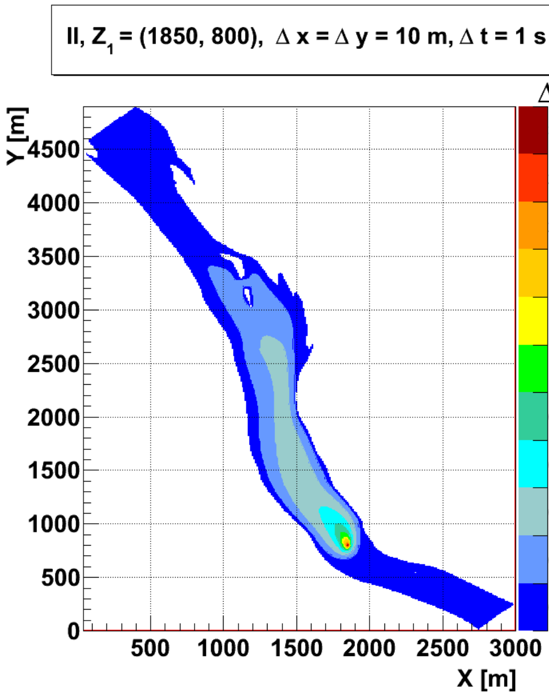

Figure 3. Predicted distribution of the temperature increase (ΔT) for continuous discharge in the middle of the channel at point Z_1 while the off-diagonal elements of dispersion tensor are omitted.

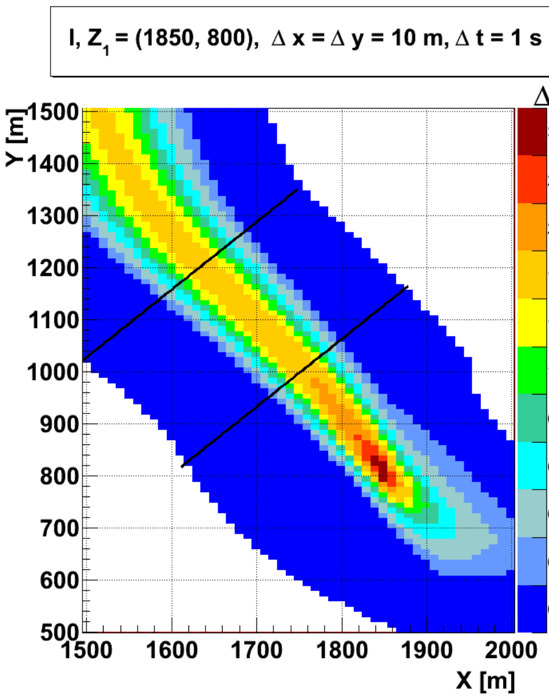

Figure 2. Predicted distribution of the temperature increase (ΔT) for continuous discharge in the middle of the channel at point Z_1 with the proper way of dispersion tensor computation – the enlargement of discharge area. The diagonal black lines denote the cross-sections located 250 and 500 m from the source.

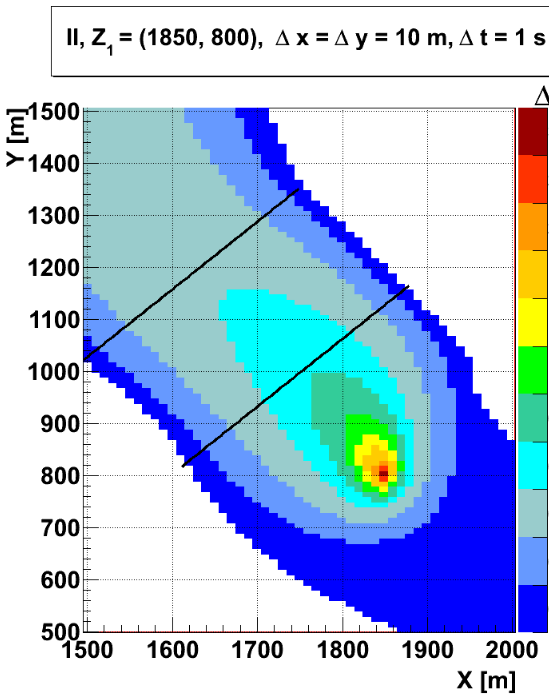

Figure 4. Predicted distribution of the temperature increase (ΔT) for continuous discharge in the middle of the channel at point Z_1 while the off-diagonal elements of dispersion tensor are omitted – the enlargement of discharge area. The diagonal black lines denote the cross-sections located 250 and 500 m from the source.

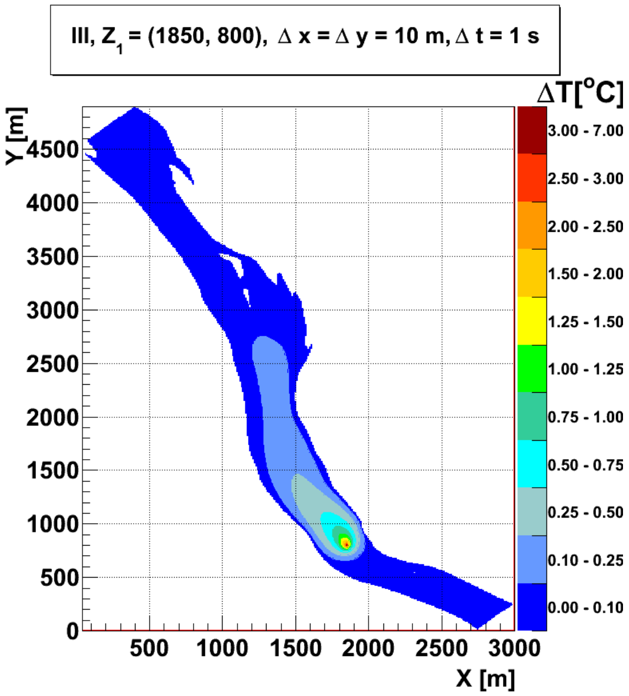

Figure 5. Predicted distribution of the temperature increase (ΔT) for continuous discharge in the middle of the channel at point Z_1 while the dispersion coefficients D_L and D_T are treated as a vector.

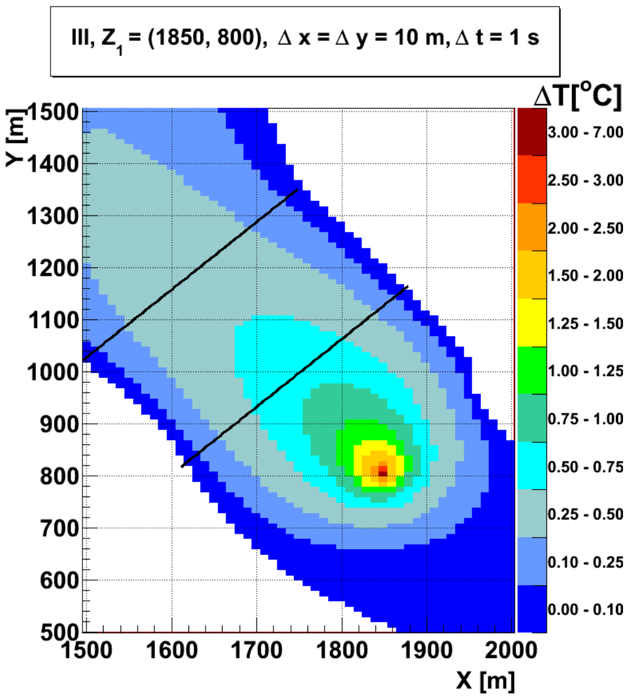

Figure 6. Predicted distribution of the temperature increase (ΔT) for continuous discharge in the middle of the channel at point Z_1 while the dispersion coefficients D_L and D_T are treated as a vector – the enlargement of discharge area. The diagonal black lines denote the cross-sections located 250 and 500 m from the source.

the dispersion coefficients D_L and D_T are treated as a vector (for detailed definition see Rowiński & Kalinowska 2006). All simulation have been performed for the proper selected grid spacing $\Delta x = \Delta y = 10$ m and time step $\Delta t = 1$ s. We can easily observe the difference between the results with the full dispersion tensor and with the simplified variants, both in temperature distribution shapes and in the values of temperature increase. While using the full dispersion tensor, the so-called mid-field zone is much longer than in cases with omitted off-diagonal tensor elements and the increase of the temperature in the middle of the channel is much bigger which could be very important in case of EIA (see Figure 7, and Figure 8). Figure 9 and Figure 10 present

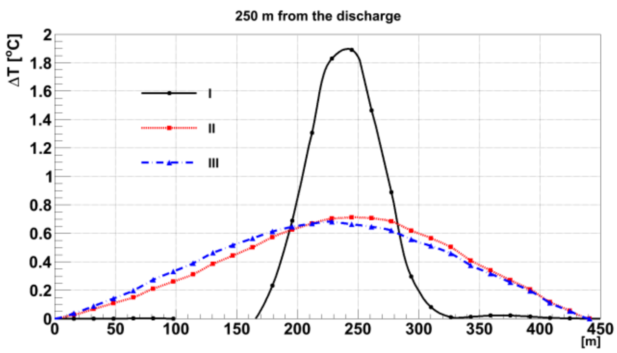

Figure 7. Temperature change distribution in case of continuous discharge in the middle of the channel at point Z_1 = (1850m, 800m) across the cross-section located at 250 m from the discharge point: I – with the proper way of dispersion tensor computation, II – while the off-diagonal elements of dispersion tensor are omitted, III – while the dispersion coefficients DL and DT are treated as a vector.

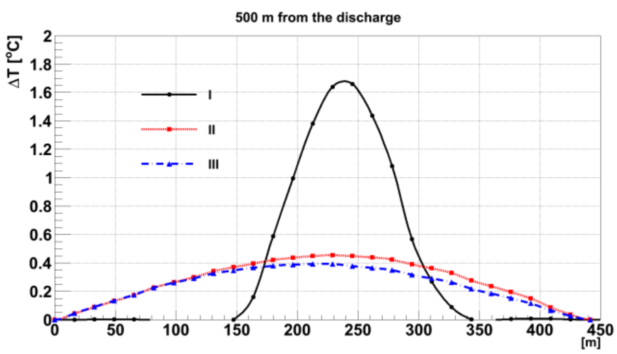

Figure 8. Temperature change distribution in case of continuous discharge in the middle of the channel at point Z_1 = (1850m, 800m) across the cross-section located at 500 m from the discharge point: I – with the proper way of dispersion tensor computation, II – while the off-diagonal elements of dispersion tensor are omitted, III – while the dispersion coefficients DL and DT are treated as a vector.

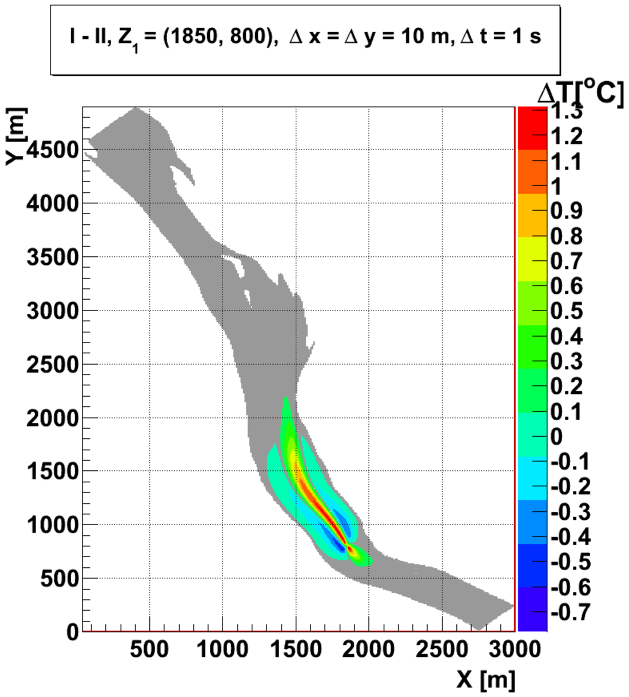

Figure 9. Difference between the results with the proper way of dispersion tensor computation (Figure 1) and the results in which the off-diagonal elements of dispersion tensor are omitted (Figure 3) for the whole computational area.

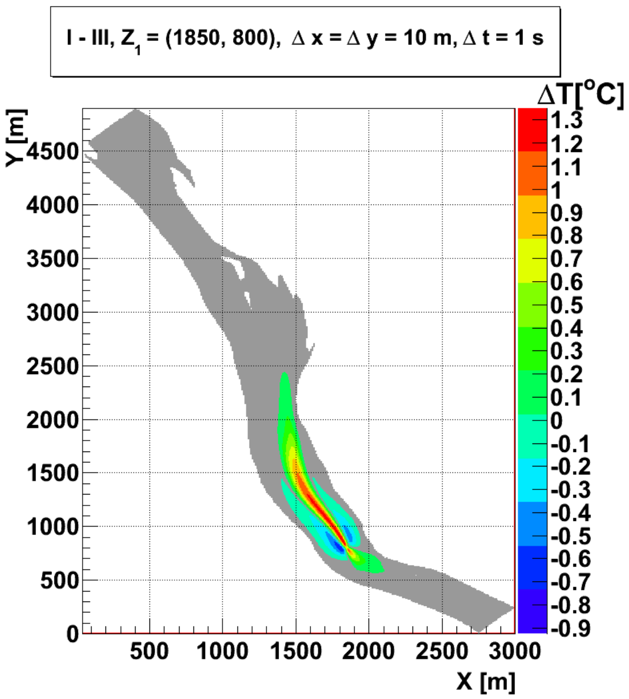

Figure 10. Difference between the results with the proper way of dispersion tensor computation (Figure 1) and the results in which the dispersion coefficients D_L and D_T are treated as a vector (Figure 5) for the whole computational area.

the difference between the correct and the simplified solution for the whole computational area while the off-diagonal elements of dispersion tensor are omitted and while the dispersion coefficients D_L and D_T are treated as a vector respectively. In both cases the difference is of the order of 1°C. In the considered case, the longitudinal and transverse dispersion coefficients values were: D_L = 34.425 m^2/s, D_T = 0.04 m^2/s (see Kalinowska et al., 2012 for details about theirs computation). But the determination of those coefficients could be very difficult (Czernuszenko, 1990) and then it became another source of uncertainty in the solution obtained. The best source of information about them could be a tracer test performed for the actual river. Since usually it is not possible to perform such experiment, there are many formulae in literature to compute those coefficients. But choosing the proper one could be extremely difficult. As an example the value of the transverse dispersion coefficient calculated for considered case using different relationships (collected e.g. in the articles: Jeon et al., 2007; Seo and Baek, 2008; Deng et. al, 2001) are presented in Figure 11.

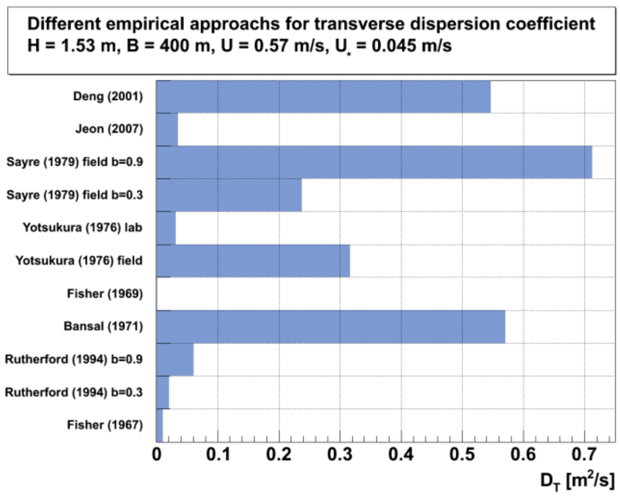

Figure 11. Transverse dispersion coefficient D_T for the considered reach of the Vistula River calculated using several formulae (taking into account different hydraulic parameters including: H – averaged river depth, B – averaged river width, U – averaged velocity, U_* – averaged shear velocity).

Conclusions

Solving practical problems concerning the threats caused by heated water discharged into a river usually we deal with the limited data, time and finance, therefore the simplifications of the problem are often inevitable. Some of those simplifications are admissible under certain conditions, but some cause unacceptable errors. This study is based upon a case investigation of the spread of warm water discharged in to a river. The paper presents the analysis how the simplifications of dispersion coefficients may influence the obtained results. It has been shown that the resulting error appears both in temperature distribution shapes and in the values of temperature increase when the dispersion tensor is not compute in the proper way. Also it has been noted that the determination of longitudinal and transverse dispersion coefficients may be difficult in particular case.

Acknowledgments

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