# HYDRO-NUMERICAL MODELING STUDY FOR "WASSERSTADT KOEPENICK"

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## Abstract

"Wasserstadt Koepenick" should become a residential area with a marina and canals and a direct connection to river Dahme. Due to water quality problems, an exchange of the water of this artificial system with Dahme water should be ensured. The objective of the work was to apply a 2D hydro-numerical model to design and optimize this artificial water system concerning the number, locations and discharges of various pumps. A favorite variant has been determined in an iterative way with five continuously discharging pumps (two in marina, one in each of the three canals), a mild slope and a continuous transition between canals and marina. The water exchange rates with river Dahme and the corresponding pump discharges leads to very small flow velocities in the range of several mm/s except the surroundings of the pumps. The bottom material, i.e. the bottom friction has a significant influence on the results.

## Introduction

Our area of investigation is located in Berlin, Germany, close to the new airport Berlin-Brandenburg. The "Wasserstadt Koepenick" should become a special kind of residential area with small canals and a marina with a direct connection to the river Dahme and should be built on a 10 hectare large area that was used by the chemical and pharmacy industry in the past and has been remediated (see Figure 1). The idea follows the trend "Living near water" and should provide attractive living space in the big city. The specific character of this building area should be an artificial water system, which exchanges the water with the river Dahme, with three small canals and a marina. The extracted water from Dahme should flow through a water treatment plant before injection into the water system, it will flow through the water system and then back into the Dahme. With respect to the water quality, it has to be ensured that the water will be completely exchanged within a few days and that it flows through all areas of the artificial water system, so that dead zones do not occur, i.e. that the flow velocity should not be closed to zero at any point in the system.

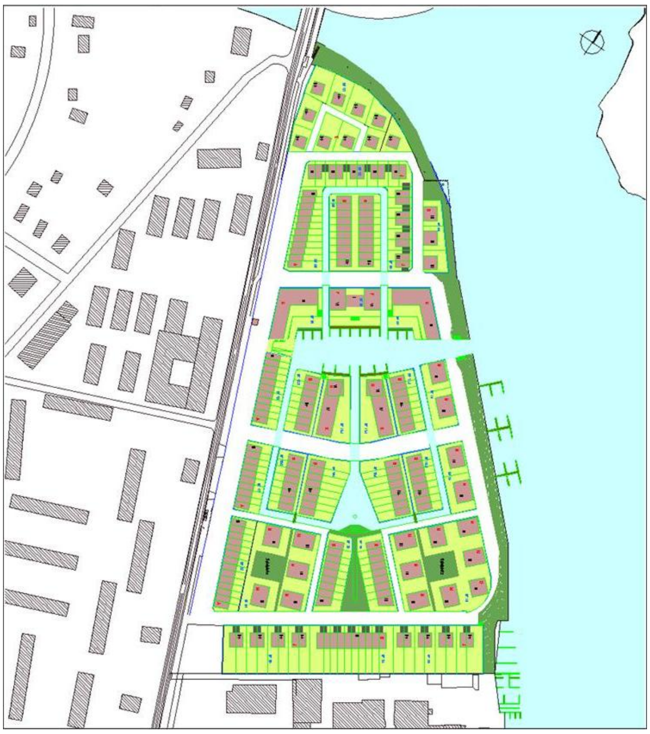

Figure 1: Detailed project plan of the building area (Meermann Invest Nr.7 GmbH, 2008)

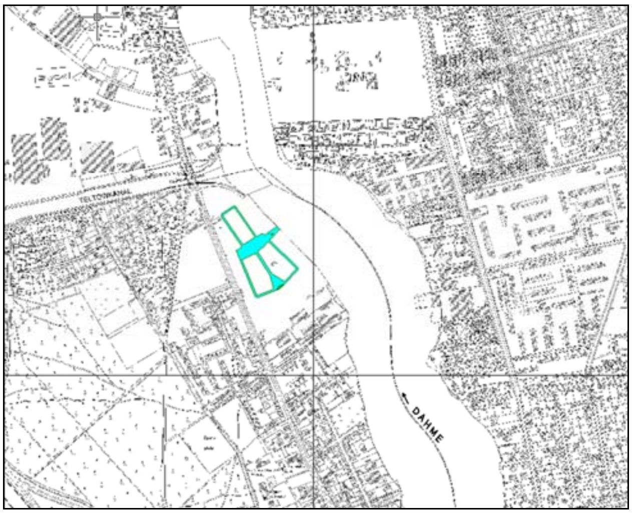


Figure 2: Location of the investigation area in Berlin-Koepenick (Senatsverwaltung für Stadtentwicklung, 2007; modified)

To ensure a continuous water flow through the artificial system without dead zones and by this to ensure good quality of the water was the major aim of this hydro-numerical study.

To achieve this aim, recommendations for the required number, locations and flow rates of the pumps and for the design of the canals, especially the slope and transitions between canals and marina as well as for the bottom material should be given. In addition, the water system should be operationable only in parts, possibly during construction phases or maintenance activities. Furthermore, the influence of water table fluctuations on the flow in the study area was investigated. The focus of the project was the best possible transport of the water through the system under consideration of hydraulic efficiency and economy.

The project was a part of the joint project "Integrated Water Management ´Puerto Verde´" and was carried out in a close collaboration with two partners, which were working on water treatment and rainwater management (Seemann, 2008; Seemann et al, 2009).

## Model Description

The 2D-hydrodynamical model package HYDRO_AS-2D (Nujic, 2006) was chosen for flow modeling. This model is based on the solution of the two-dimensional shallow water equations.

### Two-dimensional shallow water equations

The flow in rivers and creeks can be described by the depth-averaged two-dimensional unsteady shallow water equations:

$$\frac{\partial h}{\partial t}+\frac{\partial uh}{\partial x}+\frac{\partial vh}{\partial y}=S \qquad (1)$$

$$\frac{\partial uh}{\partial t}+\frac{\partial}{\partial x}\left(u^2h+\frac{1}{2}gh^2-\nu h\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(uvh-\nu h\frac{\partial u}{\partial y}\right)=-gh\left(I_{Rx}-I_{Sx}\right) \qquad (2)$$

$$\frac{\partial vh}{\partial t}+\frac{\partial}{\partial x}\left(uvh-\nu h\frac{\partial v}{\partial x}\right)+\frac{\partial}{\partial y}\left(v^2h+\frac{1}{2}gh^2-\nu h\frac{\partial v}{\partial y}\right)=-gh\left(I_{Ry}-I_{Sy}\right) \qquad (3)$$

h is the water depth, u and v are the velocities in x- and y-direction. S is a source or sink term in the continuity equation (1), which can, for example, account for the effective rainfall. The gravity acceleration is denoted with g, $I_{Sx}$ and $I_{Sy}$ are the bottom inclinations. Friction is taken into account by Strickler's law. Turbulence is determined with an algebraic turbulence model. Several empirical formulas for taking hydraulic structures into account (e.g. pipes, culverts, bridges, weirs) are available.

### Numerical scheme

The numerical scheme is based on an explicit Finite-Volume Method and can be applied on structured and unstructured grids. This very robust numerical scheme combines an ENO method (essentially Non-Oscillatory) in space with a predictor-corrector scheme in time. The model provides an efficient algorithm for wetting and drying. A detailed description is found in Nujic (1999, 2006).

## Model Setup

For setting up the model, at first the plan of the area (Figure 1) was used to determine a geo-referenced and detailed elevation model. The outline of the planned water system was oriented to the north and included in the topographic map of the urban area (see Figure 2).

### Computational domain and mesh

The spatial extension of the investigation area is about 296 m by 162 m, thus a small domain. The canals were planned with a width of 6 m and an average depth of about 0.7 m, the marina with a maximum width of about 42.5 m and a water depth of 1.3 m. The connection between marina and river Dahme has a width of 12.5 m.

A mesh has been generated with SMS (EMS-I, 2008), which can be chosen as pre-and postprocessor for HYDRO_AS-2D. It mainly consists of rectangular elements of about 3 m by 1 m together with a few triangular elements (see Figure 3).

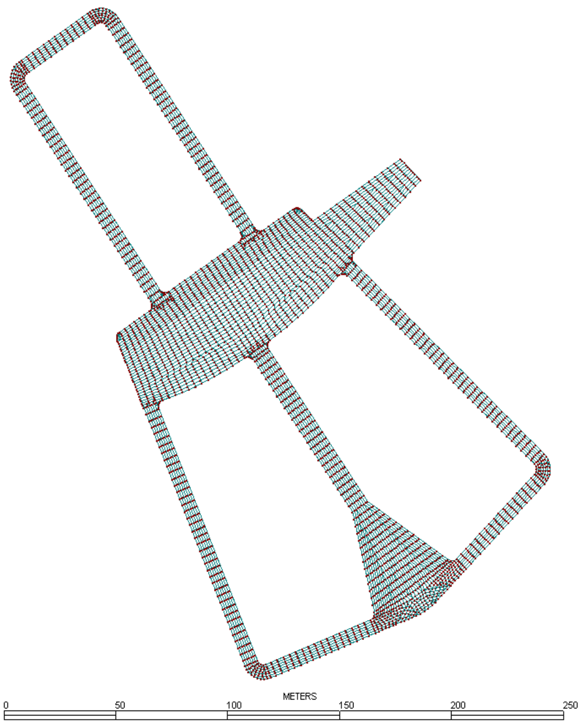


Figure 3: Structured mesh

## Model Application

### Relevant parameters

Various parameters have an influence on the flow conditions in the artificial water system. Some of them are in close interactions, so that they have to be varied in several steps and therefore the flow conditions have to be optimized in an iterative process.

The following parameters were investigated:

- number and positions of the pumps in each canal,
- number and positions of pumps in the harbor,
- angles for injection into the water system,
- distribution of the discharge among the pumps,
- time variation curves for pumps,
- slope in the canals,
- design of transitions between canal and harbor,
- bottom material.

### Variations of pumps

For investigations to optimize the pumps, a system without slope in the canals and with continuous transitions between canals and marina as well as a Strickler coefficient of 70 was chosen.

The first step of the optimization was to determine the necessary number and best positions for pumps in the system. To ensure an effective flow in every three canals, there must be at least one pump in each canal. Several simulations with different suitable locations and combinations were performed (see Figure 4) and evaluated with figures of flow velocity fields and particle tracking. The figures of flow velocity fields were produced by SMS, where the vectors and values of flow velocity in each cell of the grid are illustrated. The program SMS includes an application to visualize the tracks of the flow, too. The particle tracking tool enabled an estimation of the exchange of the water body. After evaluating these results it was concluded that pumps in the marina are necessary, too.

Various obviously suitable positions were combined systematically, angles of inflow were modified and the pumps had different stationary discharges. These parameters were gradually adapted to find the best possible solution by evaluating the figures of flow velocity fields and particle tracking.

From all of these simulations in an iterative process a favorite constellation was determined to be the most effective and economic solution. In this favorite variant one pump is installed in each canal and two pumps in the marina (see Figure 5).

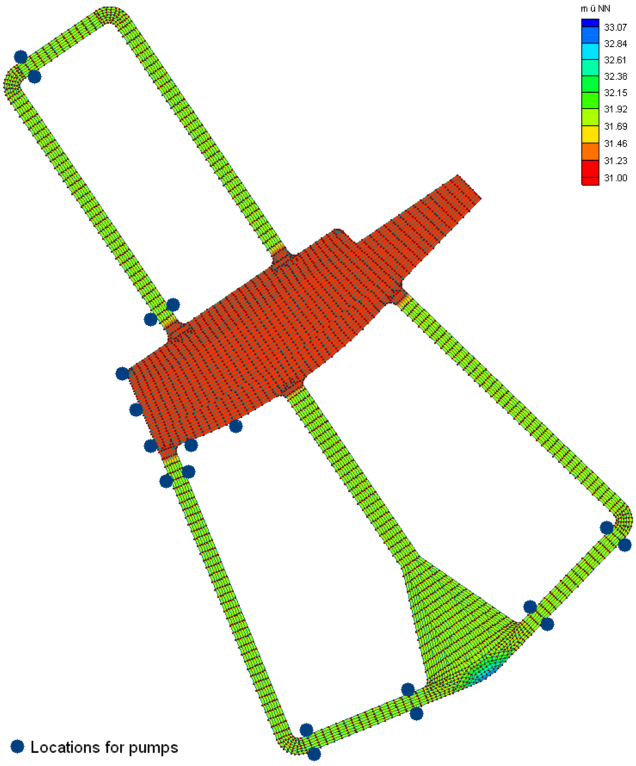


Figure 4: Pre-selected locations for pumps

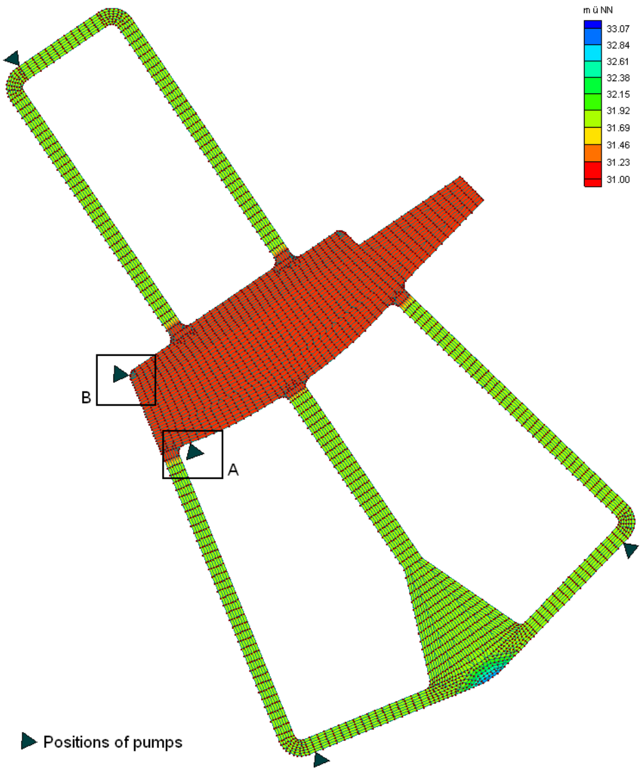


Figure 5: Positions of pumps in the favorite variant

The Figure 6 shows the flow field for the selected favorite variant. In the green and yellow areas the flow is sufficiently high. The flow in the red areas is critical, as the velocities are less than 0.5 mm/s. The water system can be considered as almost standing water. The occurrence of external influences, for example caused by wind, boats, animals or bathers, will probably enhance mixing of the water body.

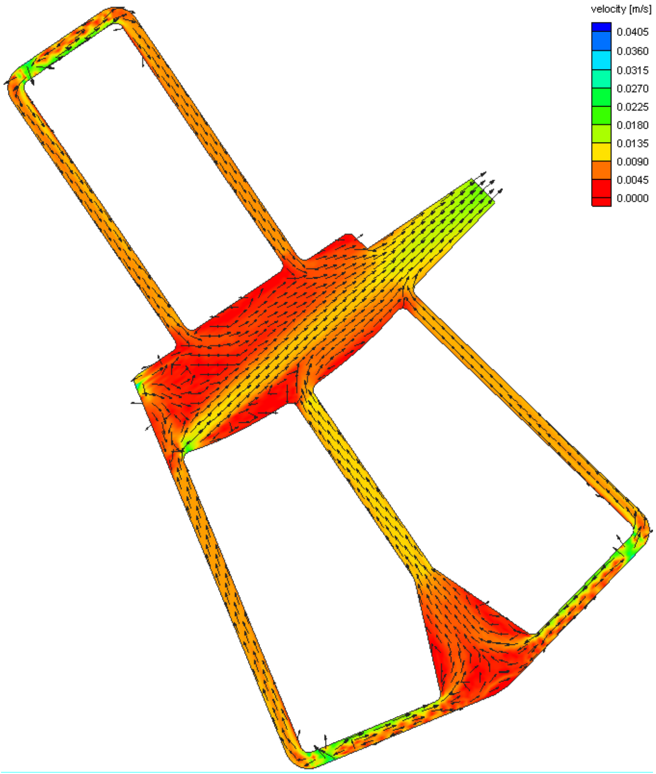


Figure 6: Flow velocity field for the favorite variant

The injection angle in the marina has a great influence on the flow conditions, because very small variations of this parameter delivered results with large variations. The best results were obtained with water injection into the marina under the angles as shown in Figure 7. The inflow in the canals perpendicular to the walls provided a sufficiently good flow in these areas.

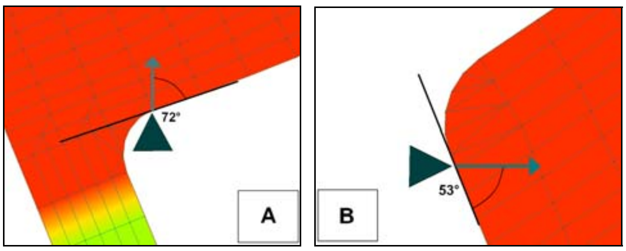


Figure 7: Angles for inflow of the pumps into the marina in detail A and B (cf. Figure 5)

The inflow into the whole artificial water system should be equally distributed among the five pumps. Injections with time variation curves are less favorable than continuous operation of the pumps. Although the flow is becoming more rapid in the phases of operation due to the higher flow rate, it had a significant adverse effect on the exchange of the water body in phases of downtimes.

After selecting a favorite variant for the whole system, the isolation of single canals from the system was simulated to get information about the flow in such cases. Especially the marina and the upper canals should be constructed first and be operational as early as possible.

The flow conditions were acceptable for this case, the results are shown in Figure 8.

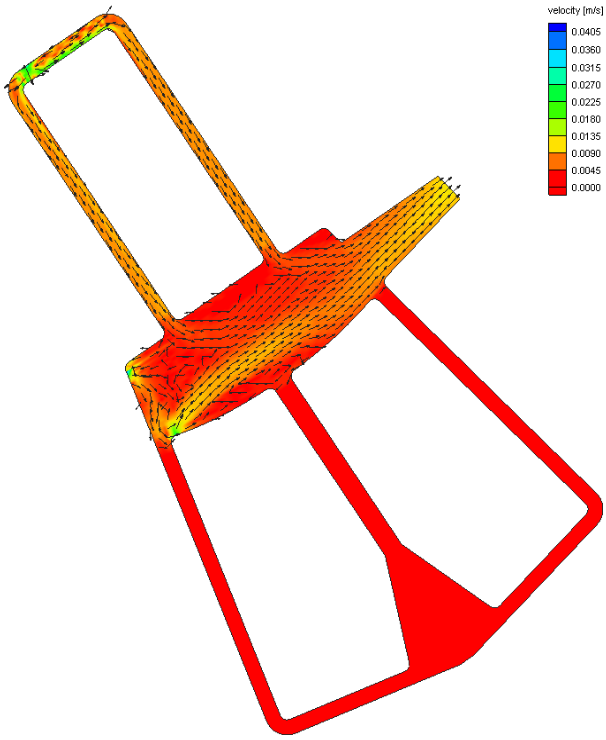


Figure 8: Vectors and values of flow velocities for the first construction part

**Variation of canal geometry and roughness**

In the favorite variant the canal geometry was modified. The canals got a very mild slope regarding the restrictions concerning the water depth, which was adapted to the injection points.

Generally, a slope in the canals has an advantageous effect on the flow. However, boundary conditions did not in this work allow a bigger slope and therefore, this impact was minor.

Another option to improve the flow conditions was the design of the transitions between canals and marina, which can be continuous or a step (see Figure 9). In principal the continuous transition has a positive effect, especially in areas with very small velocities.

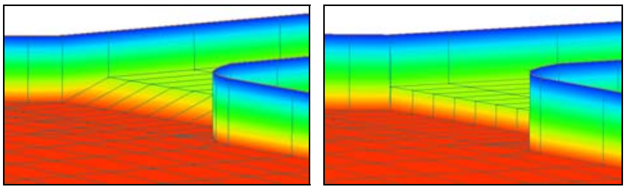

Figure 9: Continuous transition and step between canal and marina

Finally, the influence of the roughness on the flow in the system was investigated. The results of computations with different roughness values of walls and bottom, i.e. different Strickler coefficients, were compared to get information about their impact.

A rough surface is inappropriate for the flow as expected. The calculations have shown that the roughness of the bottom has clearly much more influence on the flow than the one of the walls due to the larger surfaces.

### Simulation with variable water levels

Water level variations in river Dahme have been investigated, too. As the Dahme and the whole Berlin water system is strongly regulated, the water level variations are small with a few decimetres in the last decades. Consequently, their impact on the design of "Wasserstadt Koepenick" can be neglected.

## Conclusions

A shallow water model was applied to design and optimize an artificial water system for a planned project to construct a "Wasserstadt Koepenick". In an iterative approach, an optimal solution for the number, locations and continuous discharges of various pumps has been determined. In the favorite variant, there is one pump in each canal and two in the marina, see Figure 5 for further details. The flow velocities are less than 1 cm/s in large areas of the water system, except the surroundings of the pumps. The roughness of the canal bottom, i.e. the construction material, has a significant influence on the flow field. The canal slope, canal transitions to the marina and water level variations have only minor impact.

Due to unexpected financial difficulties, the marina and the canals have not been built yet.

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