

# Comparison of Physical and Numerical Simulations of Currents

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**ABSTRACT:** The effects of river works and harbor constructions under tidal flow conditions are determined using numerical and physical models. For the harbor extension Altenwerder, now being under construction, and the reconstruction of the Hansahafen both in Hamburg, Germany, different designs of harbor geometries were analyzed with respect to flow characteristics and sedimentation conditions. A comparison of the results reveals a good agreement of the flow conditions between numerical and physical models.

## 1 INTRODUCTION

Design or reconstruction of tidal harbor entrances require an analysis of the flow conditions of different layout alternatives in order to minimize effects on navigation (Giszas, 1984)

and sedimentation, arising from sediment carried with the passing river flows. Areas of sedimentation are locations of large eddies, induced by passing flows at the harbor entrance and which change directions for ebb and flood tide (Christansen, 1996).

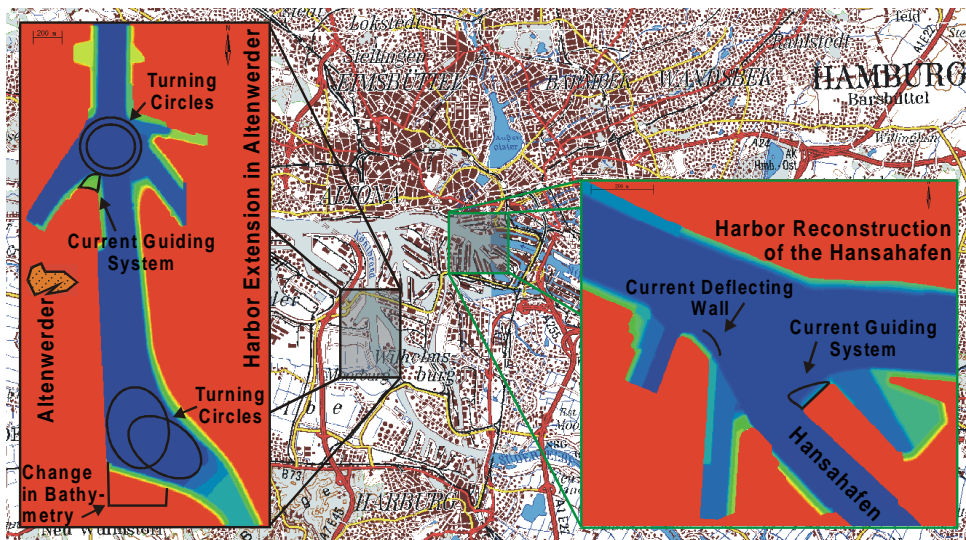


Figure 1: Location of the harbor extension Altenwerder and the reconstruction of the Hansahafen.

The sedimentation rate depends on the size of the eddy and the radial gradient in eddy flow velocities and the rate of sediment carried in the river. The navigability in the harbor is influenced by magnitude of eddies' cross flow components in navigation channels.

Characteristics of an optimized layout are negligible cross flow velocities and minimized eddies within the navigation channels. For different alternatives, developed in pre-feasibility studies (Schwarze et al., 1988), the size of turning circles, bathymetry changes with current guiding systems and additional structures with current deflection walls, the influence of variations was analyzed in two case studies - the reconstruction of the Hansahafen and the harbor extension in Altenwerder at the Port of Hamburg.

Figure 1 shows the Hamburg harbor and the locations investigated. For both harbors physical and numerical model tests were carried out at the FRANZIUS-Institut of the University of Hannover, Germany in 1996 and 1997 in order to optimize the harbor design.

## 2 BOUNDARY CONDITIONS

The Elbe river passing through the Port of Hamburg has an upstream discharge between 145 m<sup>3</sup>/s and 3,620 m<sup>3</sup>/s with a mean of 710 m<sup>3</sup>/s. The tidal range is 3.6 m with a maximum of 5.0 m under storm water surge conditions.

Four design proposals are given for the Hansahafen model, varying in the combination of bathymetry changes and integration of additional structures like flow deflecting systems. For the Altenwerder model five design proposals were developed, varying in the size of the turning circles and the layout.

Besides the bathymetries of the different alternatives for the two model areas (Figure 1) physical and numerical models require two types of boundary conditions for tidal flows (Abott et al., 1981):

- water-level boundaries (WL)
- discharge boundaries (Q)

### 2.1 Hansahafen model

The model of the Hansahafen was set up with water-levels (WL) at the downstream boundary in the river (Norderelbe) and the discharge (Q) at the upstream boundary. The physical and numerical simulations were carried out with the same steady flow boundary conditions corresponding to the maximum flood current.

The inflow into the Hansahafen basin due to rising tidal water-level was modeled by a steady flow discharge at the southern boundary (Figure 2).

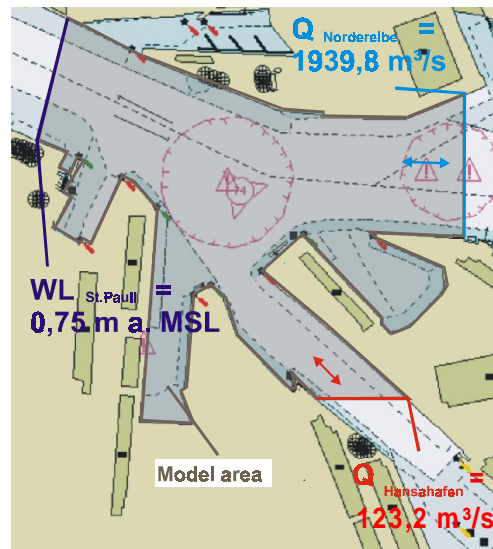


Figure 2: Boundary conditions for the Hansahafen model.

### 2.2 Altenwerder model

The analysis of the harbor extension Altenwerder was carried out by simulating a complete mean tidal cycle with water-levels (WL) at the downstream boundary and the discharge (Q) at the upstream boundary of the river (Süderelbe) in the numerical and physical model.

The influence of connected harbor basins, like the Rethe, is represented by the tidal discharge, due to the volume effect. Figure 3 shows the tidal curves of water level and discharge at the boundaries.

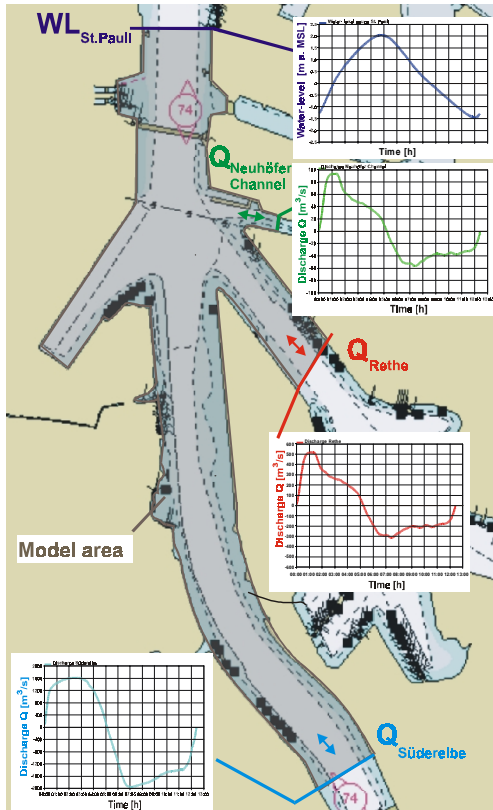


Figure 3: Boundary conditions for the Altenwerder model.

### 3 PHYSICAL MODEL

#### 3.1 Hansahafen model

The model area of Hansahafen, covering 1250 m x 700 m in nature, has been scaled 1:75 in an undistorted manner. The flow velocities were measured by tracking the movement of surface floaters.

Figure 4 shows the flow characteristics of today's layout and of a layout with flow guiding structures to destroy eddies and reduce sedimentation in the harbor entrance and the navigation channel.

The reconstruction comprises the installation of a current deflecting wall at the downstream and a current guiding system at the upstream corner of the harbor entrance (Winterwerp et al., 1994).

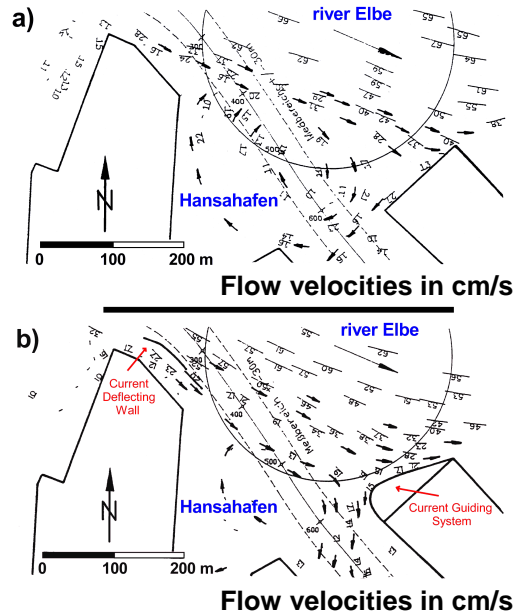


Figure 4: Flow velocities of today's harbor design (upper part) and a design with flow guiding structures (lower part).

The effect of the current deflecting wall comes from the inflow through the current deflecting wall channel which is larger than the tidal inflow, so that a flow component directed out of the harbor can shift the separation zone of the harbor entrance with minor inflow into the harbor at the downstream corner of the harbor entrance (Schwarze et al., 1995). This effect is increased by the current and flow guiding system.

#### 3.2 Altenwerder model

The model area of Altenwerder covers 1700 m x 3400 m in nature and has been scaled 1:85 in an undistorted manner. The flow velocities were also measured by tracking the movement of surface floaters.

Figure 5 shows an example of flow velocities in the new Altenwerder harbor during maximum ebb current, approximately 2 hours and 30 minutes after mean high water at the gauge St. Pauli near the northern boundary (Schwarze et al., 1997).

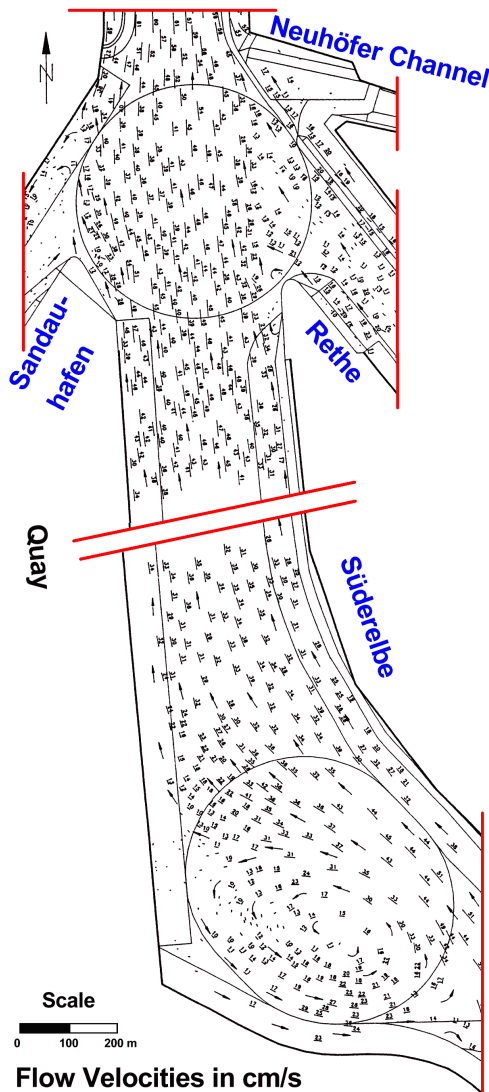


Figure 5: Flow velocities in the Altenwerder harbor during maximum ebb current, approximately 2 hours and 30 minutes after mean high water at the gauge St. Pauli.

#### 4 NUMERICAL MODEL

The modeling system MIKE21<sup>®</sup> HD for 2D free surface flows was used for the numerical simulation of the flow conditions in the harbors Hansahafen and Altenwerder. The finite difference grid was chosen to be 2.0 m x 2.0 m in the Hansahafen and 2.5 m x 2.5 m in the Altenwerder model.

The model parameters eddy viscosity and bottom friction were calibrated using on-site data, measured by radar tracked surface floaters, in the harbor Köhlfleet near Altenwerder. Field measurements were carried out for a harbor layout with and without a current deflecting wall (Berkenkamp et al., 1991).

The following calibration was chosen:

- Eddy viscosity (Smagorinsky, 1963)  
Smagorinsky factor:  $C_s = 0.5$
- Bottom friction (Falconer et al, 1991)  
Manning-Number:  $M = 25 \text{ m}^{1/3}/\text{s}$

#### 4.1 Hansahafen model

The flow velocities obtained from MIKE21<sup>®</sup> simulations are plotted for the same boundary conditions, as presented for the physical model, in Figure 6.

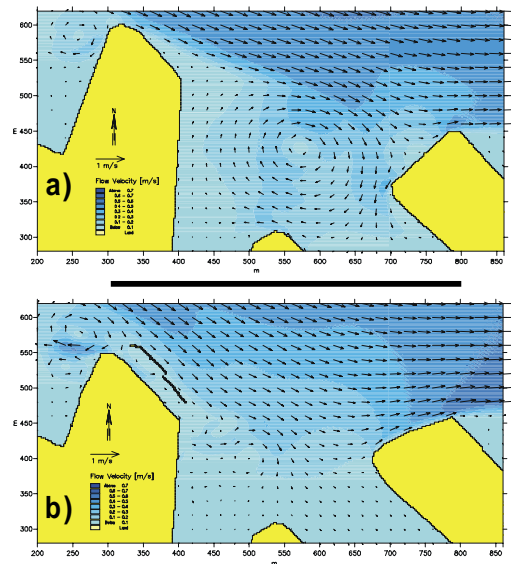


Figure 6: Flow velocities of today's harbor design (upper part) and a design with flow guiding structures (lower part).

The large eddy in the entrance of today's harbor layout is located at almost the same position as in the physical model. Also an improvement due to the current deflecting wall is revealed, i.e. the size of the eddy is significantly reduced.

#### 4.2 Altenwerder model

For the Altenwerder harbor the flow velocities simulated with the numerical model MIKE21<sup>®</sup> are given in Figure 7.

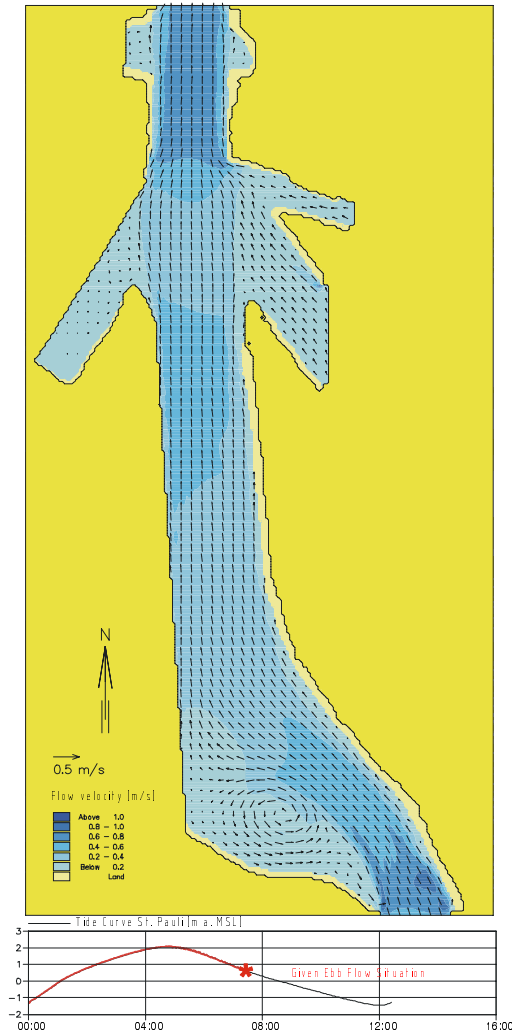


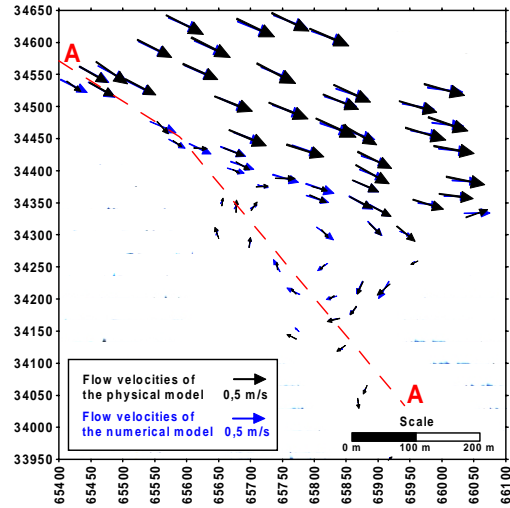
Figure 7: Flow velocities in the Altenwerder harbor during maximum ebb current, approximately 2 hours and 30 minutes after mean high water at the gauge St. Pauli.

During the maximum ebb current an eddy occurs at the upstream expansion of the river Elbe in the southern turning circle. Flow velocities of the eddy do not exceed 0.17 m/s. The cross flow velocities in the navigation channel are also negligible.

### 5 COMPARISON

#### 5.1 Hansahafen model

A comparison of the flow velocities obtained from physical model with the calculated from MIKE21<sup>®</sup> HD model is shown for today's harbor layout in Figure 8 and for the layout with the flow deflection systems in Figure 9.



#### SECTION A-A:

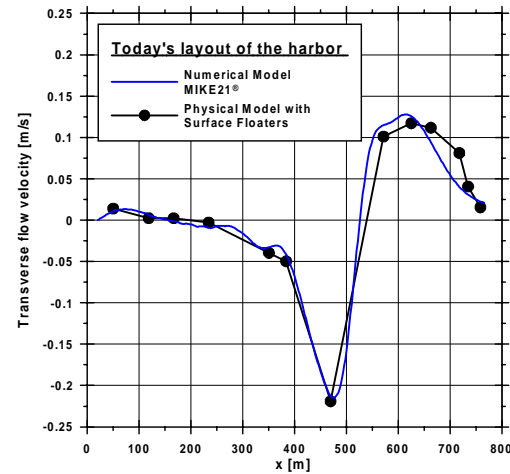
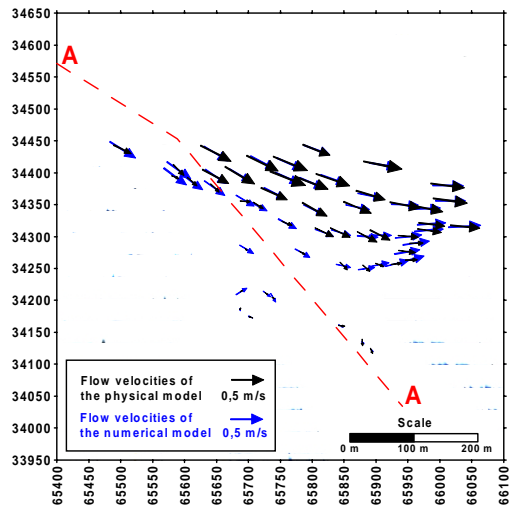


Figure 8: Comparison of the flow velocities from physical and numerical model for today's harbor layout.

The upper parts of the mentioned Figures show a 2-D sketch of the flow velocities measured with surface floaters in the physical



model (black arrows) and those calculated (blue arrows). For the cross-section A-A shown in the 2-D sketch the cross flows are given in the lower parts of Figure 8 and 9.



SECTION A-A:

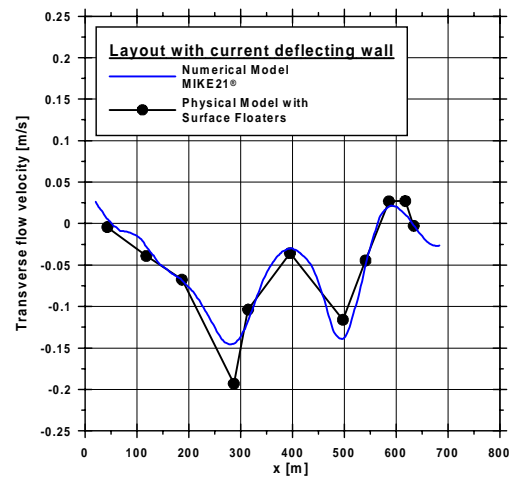


Figure 9: Comparison of the flow velocities from physical and numerical model for the reconstruction layout.

The results of the physical and numerical model correlate well with respect to the flow directions and flow velocities. The deviation of the maximal cross-flow is smaller than 5 % for today's harbor layout (Figure 8). The 25 % deviation for the reconstruction layout maybe caused by an incorrect measurement of a single surface floater.

## 5.2 Altenwerder model

A comparison between the results of the numerical and physical model of the harbor extension in Altenwerder, shows a good agreement of the flow velocities. The difference of velocities in both models is less than 0.08 m/s as given in Figure 10. Flow directions and positions of the eddies in the numerical and physical model are almost identical.

The lower part of Figure 10 shows a cross-section (A-A) through the eddy near the turning circle for the harbor extension, now being under construction, representing the flow velocities of the physical and the numerical model.

## 6 SUMMARY

The influence of the harbor geometry on the sedimentation conditions estimated by the existence of eddies and the navigability estimated by the magnitude of the cross-flow was exemplarily worked out for two different harbor geometries.

Both the physical model and the numerical model (MIKE21®) gave almost identical results, although small scale structures like current deflecting walls were modeled. This shows the applicability of the numerical model MIKE21® in harbor design. Obviously numerical models become more important in pre-feasibility studies, because they are time saving and easy to handle with respect to changes in bathymetry and layout. Also the advantages in the demonstration of results have to be mentioned. Nevertheless physical models will remain important investigating the final design of a planed construction in future.

Last but not least it should be remarked that both, numerical and physical model used in this investigation, are two dimensional flow simulations. With a grid spacing < 2.5 m large eddies can be reproduced with sufficient accuracy, allowing good estimates on the sedimentation and effective methods for reduction.

Improvements can be expected from three dimensional modeling of the local flow situa-

tion which has to be verified with detailed prototype flow measurements, e.g. using ADCP and calibrated e.g. with physical models (Figure 10).

ACKNOWLEDGMENT

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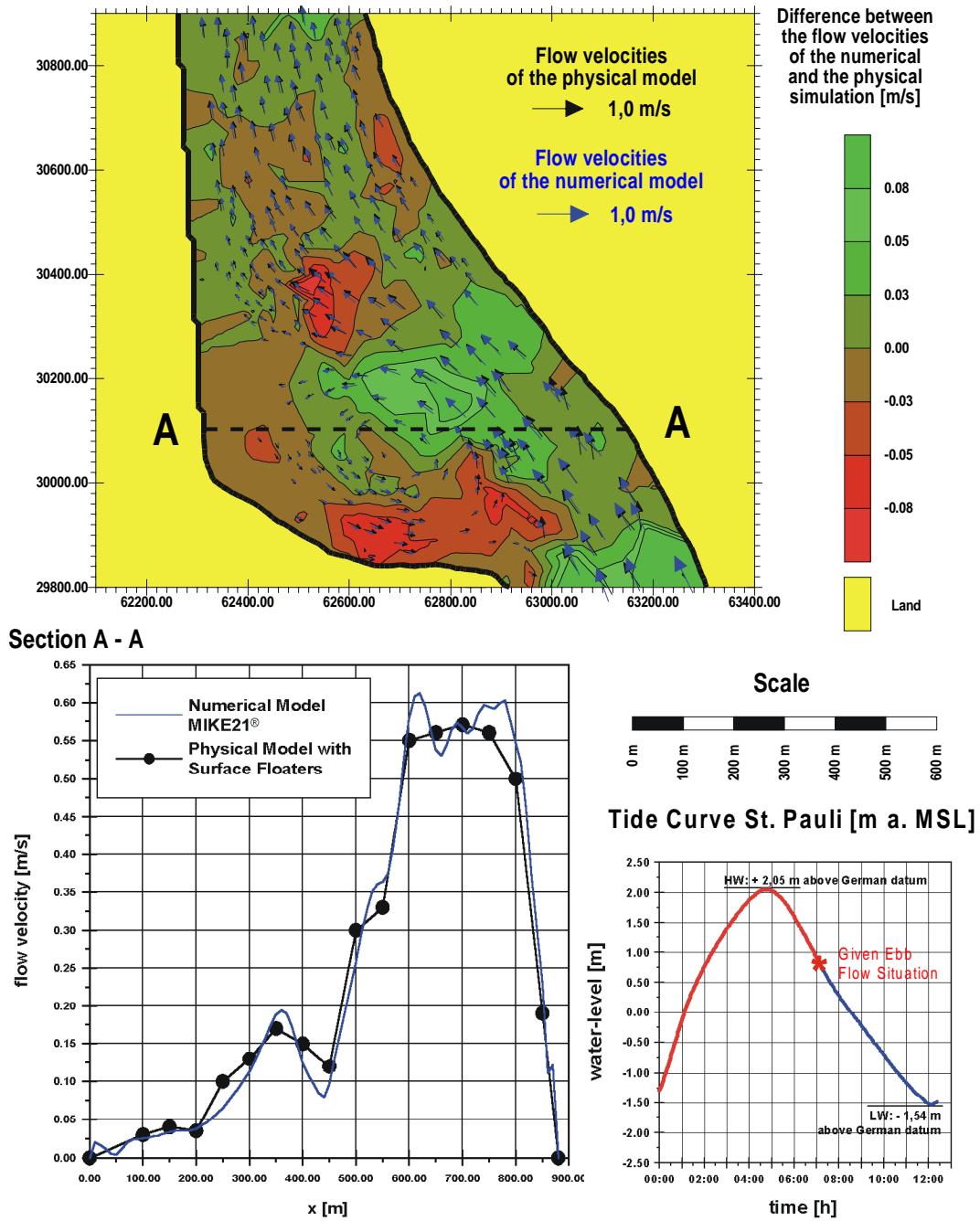


Figure 10: Comparison of the flow velocities from physical and numerical model for the Altenwerder harbor.

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