The Hydrodynamic-numerical model of the river Rhine

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Abstract

Based on the computer CARIMA programme which is developed by SOGREAH (Prof. Cunge, France), the Hydrodynamic-Numerical Model of the River Rhine (HN-Model Rhine) is constructed. It includes 500 km length of the river from Iffezheim, the last weir on the Upper Rhine, to Lobith, the hydrological station at the border between Germany and The Netherlands and the main important tributaries of the section including Neckar, Main, Nahe, Lahn, Moselle, Ahr, Sieg, Ruhr and Lippe.

The calibration and verification of the model were carried out with three different types of floods on the River Rhine: The flood of March 1988 occurred on the whole Rhine, The flood of December 1993 occurred on the Lower Rhine and the flood of February 1999 occurred on the Upper Rhine. The results obtain very good agreement between measured water level and computed water level, the computed peak discharges were very good fit with the natural observed once.

For simulating the actual and the future situations of the River Rhine with different flood regulation measures, the HN-Model Rhine is able to predict the response of the river to imposed changes. It can give a whole picture of the variation of the water levels effected by these changes and the advices for flood management purpose. Depending on the studies required, the entire model or simply a part of it may be used for different simulations. The HN-Model Rhine has been used for the projects of assessing the effects of dyke displacements and polder systems on The Lower Rhine into flood situation and given many practical results.
1 Introduction

During the last centuries the river Rhine underwent a major regulation process which divided the river-bed from its flood plains and reduced the available areas for flooding. The river is straightened, consequently, many recorded flood events were occurred. The flood that previously were likely once every 200 years can now be expected every 50 years (Bernhart, 1990). [1]. Serious floods at the river Rhine in 1993 and 1995 resulted in the policy “Room for the Rivers” and in 1998 in the “Action Plan Flood Defence” by the International Commission for Protection of the Rhine. The “Action Plan Flood Defence” aims at improving the protection of people and goods against flood while integrating ecological improvements of the Rhine and its flood plains. Targets include the enlargement of flood plains through dyke displacement, the protection of valuable flood plains and flood plain restoration. Further targets are the re-connection of the rivers backwaters, the restoration of hydrological and ecological interactions between river and flood plains and the restoration of the riparian zone [2]. Different criteria for flood retention areas will altogether contribute towards a more natural river landscape with a higher flood regulation capacity and larger biodiversity.

In order to quantitatively assess the effectiveness of those measures into flood situation, the Hydrodynamic-Numerical Model (HN-Model) for the whole Rhine of the free flowing section from Iffezheim, the last weir in the Upper Rhine, to Lobith, the hydrological gauge at the border between Germany and The Netherlands is constructed. It includes 500 km length of the River Rhine and the main important tributaries of the river (Neckar, Main, Nahe, Lahn, Mosel, Ahr, Sieg, Ruhr and Lippe).

2 Model construction and calibration

The upstream boundary of the model is the discharge curve at the gauging station Maxau while the water level curve and the rating curve at the gauging station Lobith is the downstream boundary. The main tributaries are simulated as lateral inflows. The length of the reach is different from 100m to 1000m depending on the specific of the river morphology. For each calculation point, the programme calculates the water level and flow rate during any chosen hydrological event.

The results of calibration and verification of the model have a very good agreement with measured data: The difference between computed water level and measured water level is smaller than ±0.20 m at the steady flow calibration in cases of middle and flood discharges (see Table 1).

At the unsteady flow computations, the time when the peak discharges appeared at the main stations are almost the same with the observed once (Fig. 1). The difference of water level was never exceed ±0.10 m except at the station Mainz
in case of flood discharge because the influence of the big tributary Main (see Table 2).

Table 1: The Difference between Calculated and Measured Water Level at Steady Flow Condition.

<table>
<thead>
<tr>
<th>Gauge</th>
<th>Worms</th>
<th>Mainz</th>
<th>Bonn</th>
<th>Cologne</th>
<th>Düsseldorf</th>
<th>Ruhrort</th>
<th>Emmerich</th>
</tr>
</thead>
<tbody>
<tr>
<td>MQ(m³/s)</td>
<td>0.1</td>
<td>0.1</td>
<td>0.07</td>
<td>0.09</td>
<td>0.05</td>
<td>0.05</td>
<td>0.08</td>
</tr>
<tr>
<td>HQ(m³/s)</td>
<td>0.1</td>
<td>0.2*</td>
<td>0.08</td>
<td>0.07</td>
<td>0.09</td>
<td>0.05</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Figure 1 The Unsteady Flow Calibration, Gauge Bonn, Flood 1988

Table 2 Differences between computed & measured water level, time, flood 1988

<table>
<thead>
<tr>
<th>Gauge</th>
<th>Cologne</th>
<th>Duesseldorf</th>
<th>Ruhrort</th>
<th>Emmerich</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak 1</td>
<td>Peak 2</td>
<td>Peak 1</td>
<td>Peak 2</td>
</tr>
<tr>
<td>ΔH (m)</td>
<td>0.06</td>
<td>0.20</td>
<td>0.04</td>
<td>0.02</td>
</tr>
<tr>
<td>ΔT (h)</td>
<td>1.75</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
3 Effect of flood plain restoration works into flood regulation

Along the Rhine in Germany, retention areas – large polders beside the river, which inundate only at times of flood – are being created. These will be able to store up to 270 million cubic metres of water and are planned in the state of Baden-Württemberg, Rhineland-Palatinate, Hessen and North Rhine-Westphalia. About a 100 million cubic metres of capacity is already available [2]. By diverting water into these retention areas, it was possible to reduce the water level at downstream.

In order to assess the effect of polders on the Upper Rhine into flood regulation along the river, the model is simulated with 13 polders situated on the Upper Rhine from Maxau (Rhine km-362,2) to Bingen (Rhine km-528,4). The computed flood is February 1999.

Table 3 The effect of Upper Rhine polders, flood event 1999

<table>
<thead>
<tr>
<th>Gauge</th>
<th>Worms</th>
<th>Kaub</th>
<th>Mainz</th>
<th>Bonn</th>
<th>Cologne</th>
<th>Duesseldorf</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔH m</td>
<td>0,18</td>
<td>0,18</td>
<td>0,14</td>
<td>0,20</td>
<td>0,20</td>
<td>0,18</td>
</tr>
<tr>
<td>ΔT (h)</td>
<td>7,25</td>
<td>9,75</td>
<td>9,25</td>
<td>10,25</td>
<td>11,75</td>
<td>11,50</td>
</tr>
</tbody>
</table>

Figure 2 shows very clear the results obtained from simulation run. Under the effect of the polders on the Upper Rhine, the water level at the gauging stations reduced up to 20 cm at the peak flood and the time when the peak appeared were also up to 12 hours later. They also show that the impacts of the polder system on the Upper Rhine is not only for the local area but also for the region downstream of the area (Table 3).

Figure 2 Water level comparison, with and without polders, flood event 1999
4 Conclusions and remarks

Proper management of rivers and their watersheds involves balancing a host of resource uses of the river and the ability to predict the response of the river to imposed changes. The HN-Model is a helpful tool for the management of the River Rhine, especially for the flood management. Depending on the studies required, the entire model or simply a part of it may be used for different simulations.

The HN-Model of the River Rhine can help political people and common understanding the role of the wetlands on flood mitigation; The HN-Model is required for design of flood control works and assessing the impacts on water levels of alternative dyke configurations and floodplain storage options; And last but not least, the results obtained from HN-Model is the boundary condition for 2-D, 3-D numerical model, physical model and also one of very important data for GIS application on water resources management. For the whole, the HN-Model of the River Rhine develop a clear understanding how the river water levels adjusted to previous designs and plan implementations.

The results of the simulations of the HN-Model Rhine show that by using the different types of polders along the river can help to reduce the flood peak and also the time coming of the peak discharge. The best solution for fighting with the flood by using polder system is polders with flood controlled structures [3].

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References