Model Predictive Control of the Discharge Distribution of the Rhine River in the Netherlands

M. Xu[1], P.J. van Overloop[1], R.M.J. Schielen[2], H. Havinga[2]
[1] *Section of Water Resources Management, Faculty of Civil Engineering and Geosciences, Delft University of Technology*
[2] *Rijkswaterstaat, Water Dienst en Directie Oost-Nederland*

Introduction

The river Rhine is the one of the most important rivers in Europe. The river enters into the Netherlands from Germany at a small village called Lobith. After a few kilometres the river bifurcates into the Waal and Pannerdens canal. The water in the Pannerdens canal flows into the Nederrijn and IJssel at a second bifurcation point. At the moment the discharge distributions are regulated by the geometry of the bifurcation points. At high flow, the approximate distribution is 2/3 to the Waal, 2/9 to the Nederrijn and the remaining 1/9 to the Ijssel, assuming the total flow is 1. Figure 1 shows a schematic view of the water system.

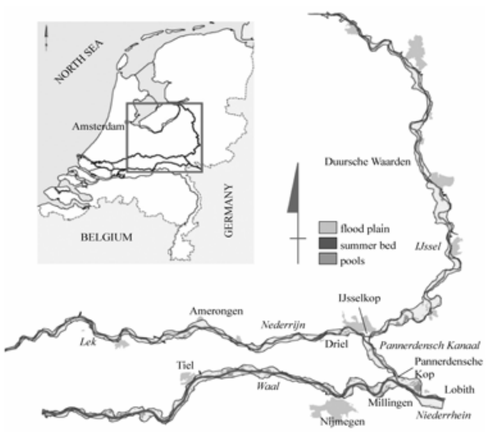

Figure 1. Schematic view of water system

It is important to maintain the discharge distribution during high flows otherwise it may create problems to the dikes and protected areas. This is because the dikes are designed for a specific design flood discharge. In addition, there exists an uncertainty of about 550 m^3/s in the assumed and actual discharge due to errors introduced by the estimation of roughness, morphological change, wind and model uncertainties. On the other hand the IJssel river branch has a function of navigation as well as it is used to flush the saline water in the northern part of the country. Therefore, during low flows the minimum flow towards the IJssel should be maintained. Based on the above-mentioned purposes, several bypasses are going to be constructed near the bifurcation points. Previous studies by Rijkswaterstaat and Delft University of Technology (Schielen R.M.J), proposed a dynamic control of the discharge to undertake these uncertainties. Particularly the Model Predictive Control (MPC) configuration is proposed for steering the discharge distributions, to manage extreme (low and high) flows and to counteract the effects of the uncertainties. The research aims at designing Model Predictive Control (MPC) in the Dutch Rhine water system. In this proceeding, MPC only applies on the first bypass between Bovenrijn and Pannerdens canal.

Method

MPC is an advanced control technique. The reason of choosing it is due to the factor of multi-objective water system subject to certain constraints. MPC can take advantage of the prediction with simplified model (Schuurmans, Bosgra et al. 1995) and optimization, and then allow the flexible management of the system. The schematic view of MP is shown in Figure 2.

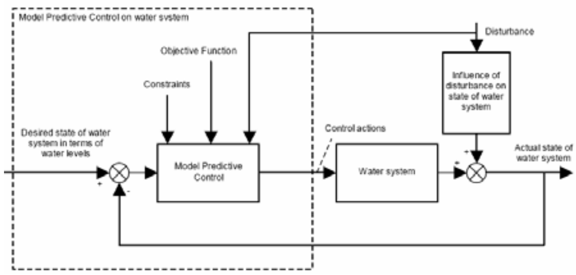

Figure 2. Schematic view of MPC (Van Overloop 2006)

The general objectives of the controller are:

1. eliminate uncertainties in the river during high flows until the design flow;
2. achieve the limited amount of water during low flows;
3. efficiently divert extra water into bypass during extreme flows above the design flow.

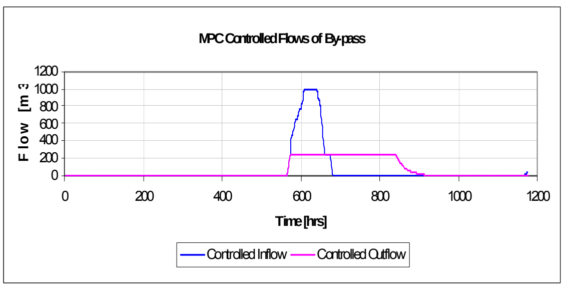

Figure 3. In and out flow through bypass

Results

The simulation runs for the extreme flow condition. Their results are illustrated through Figure 3 to 6. It is clear that MPC can divert certain peak flow into bypass under the constraints of river design flow, maximum in and out flow and maximum water level in the bypass. Although there are still some flow violations in the river shown in Figure 5, it is unavoidable, due to the limited bypass capacity (Figure 4). When comparing with feedback control, MPC cuts off the peak flow of 500m3/s more. See Figure 6. The reason behind it is that feedback acts when the river flow goes above the threshold, but when the real peak comes, there is no capacity to divert in the bypass. While MPC can predict the peak flow and optimally used the bypass capacity. The advantage of MPC is significant in this case.

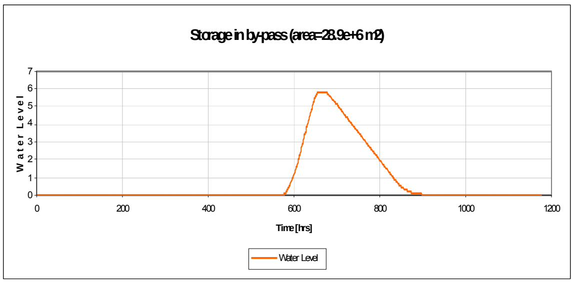

Figure 4. Water level in bypass

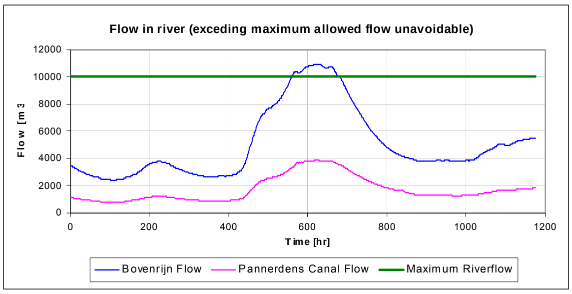

Figure 5. River flows

Reference

Schielen R.M.J, H. H., Lemans M. "Dynamic Control of the Discharge Distributions of the Rhine River in the Netherlands. (Draft)."

Schuurmans, J., O. H. Bosgra, et al. (1995). "Open-channel flow model approximation for controller design." Applied Mathematical Modelling 19(9): 525-530.

Van Overloop, P. J. (2006). Model Predictive Control on Open Water Systems, IOS Press.

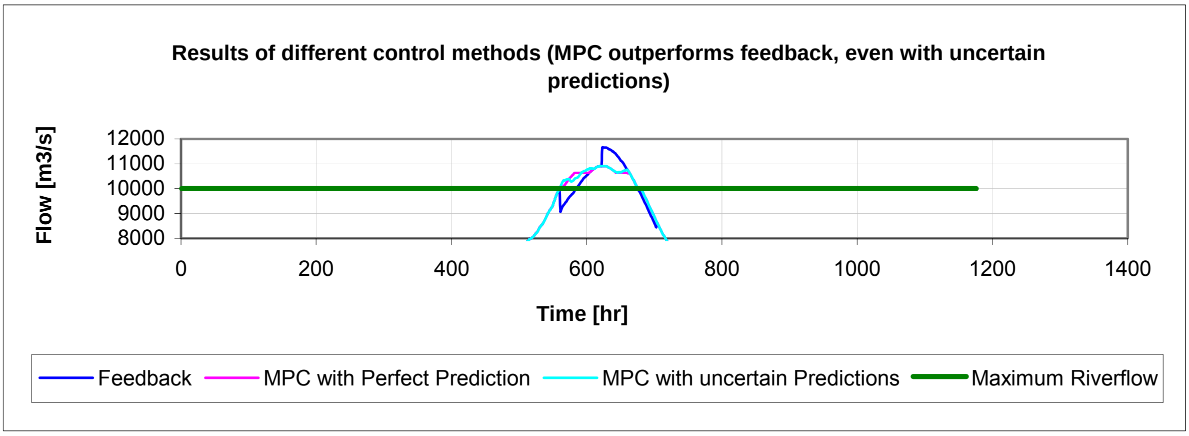

Figure 6. Feedback and MPC