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**THE WAJIANZHAI YELLOW RIVER CONTROL AND  
FORECASTING SYSTEM – A REAL TIME OPERATIONAL AND  
FORECASTING APPLICATION**

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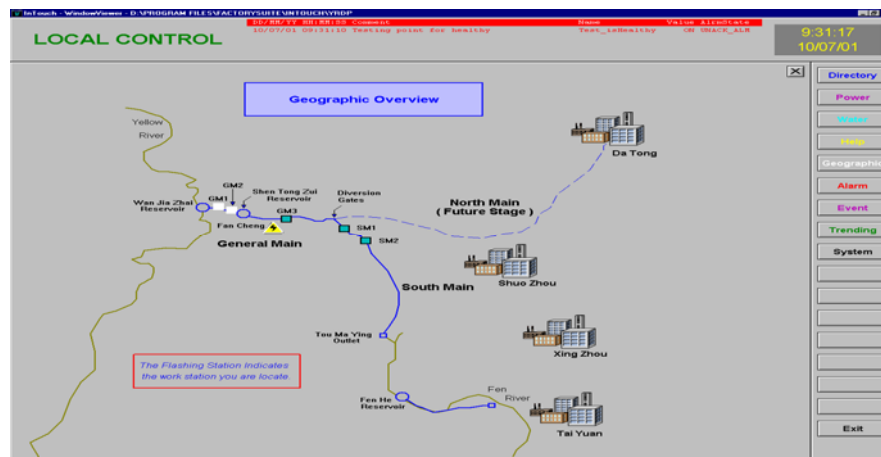
**Abstract:** The Wanjiashai Yellow River Diversion Project is a large-scale inter-basin water diversion project located in the northwest Shanxi Province of the People's Republic of China. DHI's MOUSE model has been applied as an application running in real time to provide short-term security checking and also to develop long-term optimal operational strategies to the entire conveyance system. A key aspect of the development of the system was the understanding of the differing control strategies between the process modelling and the SCADA system, as the model was required to be able to accurately predict the true operation of the system during emergency conditions and with operator intervention. The paper describes the applications development including the unique aspects of producing operational forecasting over a 7 day period to develop safe, economic and reliable operations in an hydraulically complex water diversion scheme.

**Introduction**

The Wanjiashai Yellow River Diversion Project is a large-scale inter-basin water diversion project located in the northwest Shanxi Province of the People's Republic of China. The project is one of many strategic measures to alleviate water shortage problems in the area, particularly for the three cities of Taiyuan, Datong and Shuozhou. The WYRDP covers more than 450 km of water conveyance system (combined pressurized

and open channels) and includes 5 large pumping stations which total over 500m lift at the design discharge of 48m<sup>3</sup>/s. A tailored application of the DHI MOUSE model (DHI Water and Environment [1]) was applied as the hydraulic engine to simulate the conveyance works. The MOUSE model has been applied as an application running in real time to provide short-term security checking and also to develop long-term optimal operational strategies to the entire conveyance system to minimise electricity consumption and ensure safe and reliable operation.

A schematic of the project is shown in Figure 1.



### The DIMS/MOUSE Model

The MOUSE model forms part of an integrated Computer Supervision and Control System (CSCS). The main objective of this system is to supervise and control the operation of all equipment to achieve water flow equilibrium throughout the water conveyance line. The CSCS consists of a real-time State Estimator which provides the operators with real time information on water levels and flows throughout the water dispatch system and providing automated leakage and tunnel clearance analysis. The state estimator includes a Look Ahead module giving information up to 12 hours ahead based on planned future operating of pumps during forecast period of operation transmitted. The CSCS also includes a Predictive Process Model (PPM) which allows the system operators to develop a plan for the optimum operating conditions of the entire water system for the coming 7 days.

A key aspect of the CSCS is that the system was developed in parallel with the development of the SCADA system (Drabarek, [3]) so that the hydraulic model would react to events in the same way as the SCADA system. This was necessary in order for

the DHI Applications to predict ahead what would be the reaction of the SCADA to future conditions.

The focal point of the design of the YRCFS is the system operator. The user-interface is therefore designed to provide data in an intuitive and meaningful fashion, a system that is easy to handle and enables the use of the system with a minimum of training requirements. An important issue in this context is the level of access to dispatch methods in the real-time environment. In a real-time situation the operator must have clear well-defined choices for both the data sources that can be used to perform the forecast and the different control strategies that can be activated and modeled. The overall strategy is to provide the operator with access to pre-defined sets of dispatch methods, model inputs and boundary conditions and to enable the operator to perform ‘what-if’ scenarios on the basis of different dispatch states (gate flows, pump operations etc). The operator is not allowed to directly alter the logical structure of the rules, but is able to adjust the parameters used in the application of the dispatch methods.

The user interface for the Hydraulic Engineer is DHI’s Dynamic Integrated Monitoring System, DIMS (DHI Water and Environment [2]). DIMS handles the interfacing with the SCADA system, and prepares the MOUSE simulations, and retrieves information from the MOUSE results and stores them for reporting and analysis. DIMS undertakes all data QA checks and preparation, reporting, statistics, leak detection and generation of alarms to the operators and hydraulic engineers. A typical DIMS screen is shown below in Figure 2, which is generally similar to the SCADA system operators console, but with specific windows and data entry screens for the DHI applications.

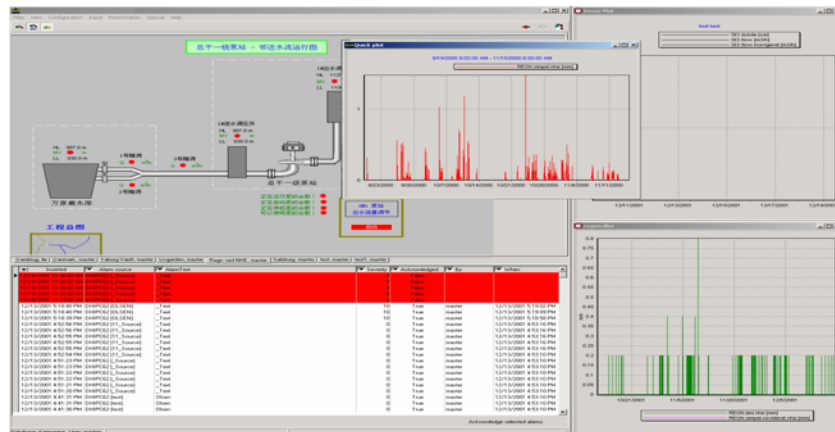


Figure 2 – DIMS interface

The YRCFS system consists of a number of modules which perform different tasks, summarised as follows:

**A real time model (State Estimator).** The State Estimator (SE) will provide the operators with real time information on water levels and flows throughout the water dispatch system. The state estimator includes a **Look Ahead** module giving water levels and flows during the next dispatch period based on:

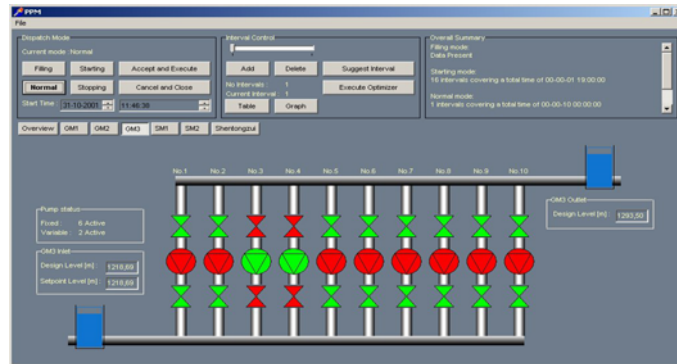
- Current operating conditions
- Planned future operating of pumps during the coming dispatch period transmitted from the Invensys I/A Series SCADA system, see Drabarek [3].
- Expected meteorological conditions and water off-take

The YRCFS launches State Estimator simulations with regular intervals (the estimated period for the operational cycle is less than 15 minutes).

**Predictive Process Model.** The basic concept for the use of the development of YRCFS is that a plan for the optimum operating conditions of the entire water system for the coming dispatch period should be developed on a regular basis. The YRCFS includes a Predictive Process Model (PPM), which the dispatcher can use as a decision support tool during the process of defining control strategies. By use of the PPM, the dispatcher can determine the operating plan with the objective of obtaining:

- An acceptable steady operation for the next dispatch period.
- Assurance that operating constraints (level limitations or pressure limitations) are unlikely to be violated during the operation period.

Control rules are implemented in the I/A Series SCADA system where the actual control actions of pumps and gates throughout the system are generated at the station computer and LCU level. However, the YRCFS system includes a replication of the I/A Series SCADA control rules so that the dispatcher can test operating plans before they are activated. These rules contain the timing and conditions by which flow regulation must be undertaken, which may include operation of gates or variable speed pumps. These scenarios can be undertaken in a training simulator, which allows the development and testing of various operational profiles, and also allows for the trainer to test the trainees with unexpected conditions such as leaks or sticking gates. The training interface is shown below in figure 3.



**Figure 3 – Training Interface**

The Water Conveyance line will be operated in 6 different hydraulic modes, and the DIMS/MOUSE system has been developed to simulate the actual method of operation of these modes. The modes are listed briefly below:

1. WATER FILLING PROCEDURES
2. STARTING PROCEDURES OF CONVEYANCE SYSTEM
3. STOPPING PROCEDURES OF CONVEYANCE SYSTEM
4. WATER DISPATCHING UNDER NORMAL OPERATION
5. REGULATION OF UNBALANCED DISCHARGE
6. DISPATCHING AT EMERGENCY SHUTDOWN OF PUMPS

The principles of the above six broad dispatching modes are implemented in the YRCFS system. The dispatch rules are implemented in terms of flow variables (for example flow through gates, pump stations, water level set points etc) and it is a key assumption of the system that the direct control of regulators is activated by the local controllers, which the DIMS/MOUSE facilitates but does not direct the operation.

### **Leak Detection**

The system includes a Leak Detection module based on mass balance calculations and comparison with measured and modelled values for water levels., incorporating known instrument accuracies. Time periods where leak detection is not possible are treated differently from degraded operation. The pipeline model may continue to run, but the response of the leak detection calculation is set to zero, and the case is defined as inhibition of detection.

Flow measurements are used in the leak detection algorithm which uses Mass Balance under steady state conditions. The Mass Balance routine calculates the difference between total inflow to and total outflow from a pipeline segment, taking into account dynamic storage effects in the pipeline:

Hence, if there is a leak in a tunnel segment, there will be a divergence of model-predicted water levels and measured water levels, and the flowmeters will show a lower flowrate than the model-predicted flowrate. Leak detection can only be undertaken in tunnel segments, as it is not possible to identify the precise location of leaks. Only one leak can be determined in any tunnel section where sufficient sensors are located.

Under unsteady state conditions another leak detection and quantification method is used. In a general sensor validation module several consecutive sensors showing lower values than simulated this indicate a leak which is then quantified and reported in DIMS.

### **Hydraulic Studies**

The model developed has been subjected to a wide range of hydraulic studies. Since the Water Conveyance line is not yet operational, it is not possible to calibrate the model, hence design roughnesses and parameters have been used to date. A wide range of model runs and tests have been used to validate the performance of the model compared to the system description and specifications. The test were divided into three groups:

Group 1. Tests of the design dispatch mode behaviour of the system, to validate performance and accuracy.

Group 2. Tests to demonstrate the behaviour of the system in response to variable flow control at the exit gates from the SHE reservoir.

Group 3. Tests to investigate situations of emergency shutdown of pumps at GM1, GM2 and GM3.

The Group 3 tests were designed to investigate the effects of surges in the pressurised tunnel sections between GM1 and GM2. In this section of the tunnels, failure of pumps will cause either large positive or negative pressure waves to be generated, depending on the mode of failure and the location of failure of the pump. The MOUSE model was set up with specially chosen parameters in order to simulate the pressure system under emergency shutdown procedures. The results were found to be very good, and compared favorably with other studies of the system using alternative analysis tools.

One of the tests is described below in detail, for the condition where there is complete Shutdown of 2 pumps at GM1. This test involves running the MOUSE model at a steady

condition with all 8 pumps running in GM1 and GM2. Then two pumps at GM1 are abruptly stopped. Figure 4 shows the performance predicted by the model from the time of the emergency shutdown of the pump at GM1.

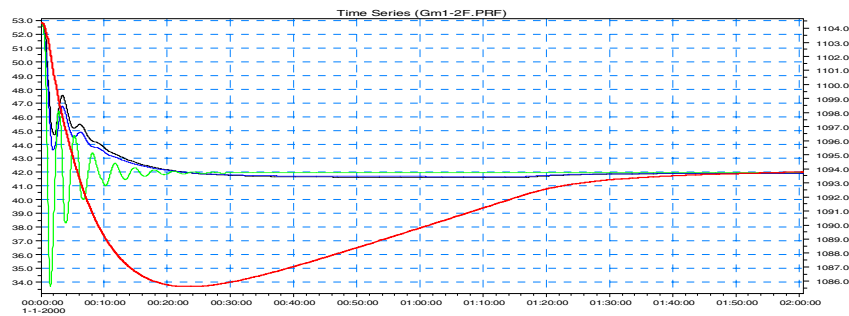


Figure4. Failure of 2 pumps at GM1.

The left hand axis is flow rate in  $\text{m}^3/\text{s}$ , from  $34\text{m}^3/\text{s}$  at the bottom to  $53\text{m}^3/\text{s}$  at the top. The right hand axis is water level, with  $1086\text{m}$  at the bottom and  $1104.5\text{m}$  at the top. The green line in Figure 4 is the flow rate in the tunnel leading into GM1. The blue line is the flow in on the GM1 side of the overflow shaft. The black line is the flow rate in the Tunnel on the GM2 side of the overflow shaft. The red line is the water level in the overflow shaft.

The time scale is in 10 minute major periods, the total plot covering about 2 hours.

Failure of 2 pumps in GM1 results in an immediate fall in the water level in the connecting tunnel because GM2 still pumps with 8 pumps. A negative surge wave is generated which oscillates between GM2 and GM1.

This test demonstrated that the rate of fall of pressure level in the tunnel is not directly calculated from the volume of storage in the risers and shafts of the line between GM1 and GM2, since the pumps are changing flowrate at the same time as the water level is changing. Hence the rate of lowering of the pressure level in the tunnel depends on the rate of change of flow in the pumps, and the pump curve.

The pressure level in the tunnel drops approximately  $19\text{m}$ , which causes the head to rise in GM2 and the flow rate in the pumps falls which eventually levels out to match the flow rate in GM1 with 6 pumps. The water level in the tunnel then again stabilises at a lower flow rate equivalent to 6 pumps.

The above scenario is simulated in significant detail in the MOUSE model, and serves to demonstrate the detailed hydraulic behaviour of the complex hydraulic system.

**Conclusion**

The DHI DIMS/MOUSE Suite provides the four functional elements required to ensure safe economic dispatch of the Yellow River Water Conveyance Line in this large-scale inter-basin water supply project. A safe realistic control and feedback loop between the instruments and the DHI Applications Software and the SCADA system ensures that any disturbance to the smooth operation of the tunnels and pumps can be quickly detected and assessed.

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