MODELLING COMPLEX INDUSTRIAL CATCHMENTS

USING THE SPIDA PACKAGE

A. Baldwin, Integrated Hydro Systems, Ilkley, W Yorks

1. INTRODUCTION

Integrated Hydro Systems were invited by I.R. Robertson and Partners (Consulting Engineers to B.P. Chemicals Ltd, Grangemouth) to carry out a drainage study of the storm, oily, and chemical drainage systems of the B.P. Chemical works at Grangemouth, Scotland. An integral part of the study was the construction and verification of a complex hydraulic model using the SPIDA software package. The purpose of the study was to investigate some unusual problems associated with the drainage network:

a) Flooding associated with the application of fire water on processing equipment is of major concern with regard to risks and hazards of fire fighting. The model of the system identified the locality and magnitude of flooding, as well as the maximum fire water rate allowable before the onset of flooding.

b) The drainage network contains a range of sediment deposits reducing the hydraulic performance of the system. The flows and depths from the SPIDA model, plus empirical sedimentation formulae, were used to estimate the quantity and location of sediment deposits.

c) The model was also used to assess the overall system performance under design rainfall conditions, identifying flooding, surcharging, hydraulic restrictions, maximum pipe flows etc.

This paper describes various techniques used to model the complex hydrological and hydraulic problems associated with the industrial catchment, and demonstrates how computational modelling can be used to solve unusual drainage problems in other sectors of industry.

2. DESCRIPTION OF CATCHMENT

The BP Chemicals catchment comprises of two sites (North and South sites) covering an area of 70 hectares. The land use for both sites comprises of chemical processing plants, storage tanks, service buildings, access roads, service and pipe ducts, and open access areas covered with a fine gravel material. The catchment is drained by 4 systems:

1) Storm water system
2) Foul system
3) Oily system
4) Chemical system

The flows are partially treated on-site with the use of large oil and chemical separator units. The final effluent is collected at 2 main drainage basins from which the flow is pumped to a sea outfall located on the Firth of Forth. Ancillary structures in the catchment consisted of the following types:

1. Drainage Basins : Major pumping station comprising of wet-well, multiple pumps, and overflow pipe. Circulation pumps and manual pump control are often special features of these ancillaries.

2. Oily Separators : Large tanks with multiple weirs and baffle boards designed to collect oily /chemical substances.

3. Valve Chambers : Manually operated valves located in chambers or manholes.

4. Septic Tanks : Small tanks treating foul flow before entering storm water system.

5. Pumping Stations : Comprising of small wet-well and pumps designed to transfer flows over short distances.

3. MODEL BUILDING USING SPIDA

Using data supplied by I.R. Robertson Ltd, a SPIDA model of the B.P Chemical catchment was constructed. The model consisted of 327 modelled pipes ranging from 150 to 900 mm diameter, and 9 ancillary structures. Particular features of the constructed model were:

1) Contributing areas were defined with the use of aerial photographs and drawings; these were digitised and entered into the Drainage System Data (DSD) file using specially developed model building software.

2) Dry weather flows consist of oily and chemical inflows from the process plant, ground water infiltration, and treated foul flows from septic tanks. Data obtained from a tracer study and the short-term flow survey identified a varied distribution of DWF; this was modelled by applying local DWF to the nodal data in the DSD file.

3) Complex flow regimes such as reverse flows, back-water effects, rapid variation in water levels etc, were often caused by the operation of the ancillaries. (eg; drainage basins, separator units etc). The SPIDA simulation program was ideal for modelling these complex conditions as it allowed the ancillaries to be modelled using a combination of fixed rate pumps, weir and orifice controls, and nodal storage volumes.

4) The separator units and main drainage basins often had a recirculation valve arrangement; this comprised a variable outlet valve controlled by the water level in the wet-well. At the time of the study, SPIDA did not have the facility to directly model this arrangement and instead a series of discrete pumps with different switching levels were used to model the variable pumping effect.

4. SURFACE RUNOFF CALIBRATION

The catchment comprises a complex range of surfaces which contribute runoff to the storm water and oily drainage systems. These surface areas, identified from the drawings and aerial photographs, were grouped and classified as follows:

a) Paved areas: Roads, pavements, and car parks
Pitched / flat roof premises
Storage tanks

b) Plant areas: Chemical process plant
Pipe work / service ducting

c) Blaes areas: Fine gravel material covering clay sub-soil

The hydrological runoff processes were modelled using a series of equations built into the SPIDA simulation program. The model calibration involved the selection of the following runoff parameters for each surface type.

a) Depression storage coefficient (K)

b) Fixed percentage runoff (PR)

c) Routing constant (c)

The runoff parameters were calibrated using small sub-catchment models of each surface type with associated flow and rainfall data. The short term flow survey provided 4 storm events, 3 were used to calibrate the runoff parameters, and 1 used to test the final runoff model. The calibration exercise revealed the following parameter values specific to the B.P. Chemicals catchment:

Runoff Parameter	Paved	Plant	Blaes
Surface type index	10	15	20
Depression storage constant	0.01	0.01	0.02
Percentage runoff	70	60	30
Routing constant	-1.0	30.0	30.0

5. MODEL VERIFICATION

As for any hydraulic modelling study it is necessary to compare the model predictions against observed data to obtain a high degree of confidence with the model results. This study was no exception, in fact, verification was essential due to the complex hydrological and hydraulic features present in the catchment.

A short-term flow survey recorded flow, depth and rainfall data for 4 suitable storm events and dry weather flow data. The verification used data collected from 15 flow monitors, 7 depth monitors, and data supplemented from BP outfall flow gauges. Overall, the flow survey data was good especially as various logistical problems such as operational requirements prevented regular cleaning and sensor replacement.

A notable feature of the verification was the requirement to model the initial water levels to ensure correct representation of storage at the beginning of each storm event. Unlike WALLRUS, initial water levels in ancillaries cannot be defined in the DSD file for SPIDA. Instead, initial water levels were modelled using the 'state' file facility. Further problems encountered during the verification are listed below:

1) Complex plant operation producing irregular inflows over varying time periods.

2) Irregular surface runoff.

3) Manual operation of pumping equipment causing irregular flows and depths.

4) Linkage between storm and oily drainage systems.

5) Un-identified restrictions, blockages, pipe conditions etc.

6. FIRE WATER ANALYSIS

The SPIDA model predicted the magnitude and location of flooding caused by the application of fire-water to the chemical processing sites. The fire-water rates were provided by the Chief Fire and Security Officer for BP Chemicals and varied up to a maximum of 15,500 IGPM (Imperial gallons per min.) providing the worst case scenario.

The main objective was to determine the maximum fire-water application rate without causing surface flooding. This was achieved by gradually increasing the application rates until the model predicted flooding at each site. The model predicted 14 out of the 18 sites with varying degrees of flooding up to a maximum flood volume of 1050 m^3 for a 90 minute duration event.

The model generally predicted flooding local to the fire application sites and identified various hydraulic restrictions causing the flooding. These included insufficient capacity in the pipes connecting the surface areas to the main drainage lines, backing-up from downstream ancillaries, and large dry weather flows taking up a large proportion of the capacity.

7. SEDIMENTATION PREDICTIONS

The hydraulic data generated from the model was used to estimate the location and quantity of sediment deposits within the drainage network. The complexities of the drainage system and varying degrees of sediment types made a detailed study impractical. However, a more general approach of assessing sedimentation was implemented providing sufficient detail for the purpose of the study.

Flows and depths obtained from the HYQ and HYD files were input into specially developed software designed to predict erosion and deposition using empirical formulae developed at HR Wallingford. The sediment 'transport capacities' were compared with a typical sediment concentration to determine the magnitude of sediment eroded or deposited from the pipe invert. Sediment transport capacities ranged from 0 to 60 ppm.

The study identified major deposition occurring upstream of drainage basins where frequent back-water and surcharging occur. Evidence of major deposition is seen from the 'full' catch-pits present in the system. The results from the sedimentation analysis will assist in identifying operational maintenance requirements.

8. CONCLUSIONS

The study described in this paper clearly demonstrates how hydraulic modelling is an essential technique for analysing the performance and operation of complex drainage systems.

The complex hydrological and hydraulic processes associated with the BP Chemicals industrial site required sophisticated modelling techniques including runoff calibration, sedimentation analysis, complex ancillary modelling etc. Above all, the study demonstrated the reliability and flexibility of SPIDA for modelling complex systems.

Finally, the study has demonstrated the need to model industrial catchments, and identified a specific drainage modelling application outside the field of standard drainage area planning.

Industrial Modelling Case Study
Andy Baldwin **Integrated Hydro Systems**

Question John Packman Institute of Hydrology

I am particularly interested in the runoff from the Plant areas and the Blaes. Does the Plant runoff go across the Blaes?
30% runoff from the Blaes seems high, is it seasonal?

Answer

It was mixed in some areas direct connection from Plant to pipes, in others Blaes to pipes and in others Plant to Blaes to pipes. The client felt that 30% from the Blaes was too low, the calibration of the runoff model did indicate this value. The flow survey work was in October November so it was "winterish".

Question Robin FitzGerald Reid Crowther

Was the model building made easier by the good quality of the data.

Answer

Yes this did help but it was still a very complex layout