Simulating the Impact of Changes in Drainage Design on Hydrologic Response using a One-dimensional Flow-routing Model

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Abstract : Inundation of sugar cane fields in the Ripple Creek catchment is perceived by some cane farmers to be a major contributor to loss of production. To alleviate this inundation, drainage systems have been designed which are capable of removing surface water with astonishing rapidity. However, when the Herbert River is in flood this water may have nowhere to go. This combination of an efficient drainage system, the lack of an outlet for the water, and the growing of cane on land which may be unsuitable, has led to some farms facing extended periods of inundation. For this reason, proposals have been made to the Drainage Board to modify the drainage system to produce a more equitable distribution of inundation. To predict the hydrologic impact of these proposed modifications, we are utilising a 1-dimensional flow-routing modelling system, Mike-11. This modelling system produces a fully dynamic model that is capable of modelling water moving as either sub-critical or super-critical flow. It does this by solving the Saint-Venant equations for open channel flow, or else solving the equations describing flow as a diffusive wave, kinematic wave, or in a quasi-steady state. It also allows for the inclusion of structures such as broad-crested weirs, culverts, or flood gates in the drainage system. This paper will examine the application of the Mike-11 modelling system to the Ripple Creek catchment, and its calibration to the streamflow reference points established as part of an intensive CSIRO monitoring program. The model will then be used to examine the hydrologic impact of opening a new channel to divert flow into the Seymour River.

Keywords : Mike-11; Sugar cane; Hydrologic response; Drainage design

1. INTRODUCTION

Mike-11 is a widely used 1-dimensional flow routing modelling tool developed by the Danish Hydrologic Institute [DHI Water and Environment, 2000]. While this modelling system is used extensively by the engineering industry and numerous hydrologic consulting groups they normally do so without comparing the model to observed data [Manivasakan et al., 1995 for example]. In this study in the Ripple Creek and Seymour River sub-catchments of the Herbert River delta, we have assessed the resultant model by comparing model outputs to data collected as part of a CSIRO stream monitoring program.

This study was initiated in response to proposals by the drainage board to make changes to the local drainage system in order to alleviate the inundation of sugar cane fields in the Ripple Creek catchment, particularly in the so-called 'Ripple Sump'. It is part of a broader study investigating opportunities for optimisation of surface drainage at regional and farm scales, whilst minimising environmental impacts from runoff.

The major works proposed to alleviate flooding are the construction of a channel to carry excess floodwaters into the Seymour River catchment. Interestingly, much of the water that currently flows down Ripple Creek originally flowed into the Seymour River. Around 100 years ago, water flowing from rainforest feeding the Seymour River was diverted into Ripple Creek in order to provide water to a sugar mill that was operating in the Ripple Creek catchment. The proposal now is to effectively reverse this diversion, sending a maximum of 20 cubic metres per second of water back into the Seymour River, albeit in a slightly different location.

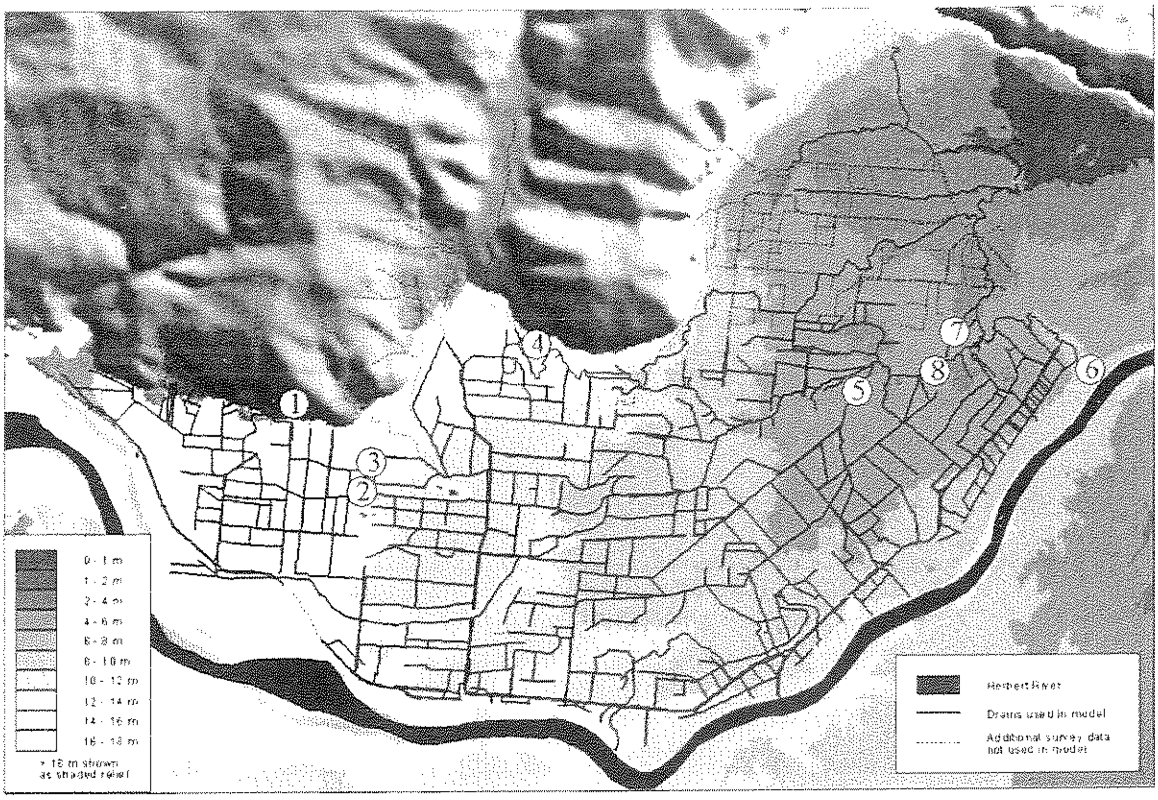

Figure 1 : Network file, DEM, and location of key points in the Ripple Creek catchment.

2. INPUT DATA

2.1 Drain Survey

As part of the broader study on integrated surface drainage, an extensive drainage survey of the Ripple Creek catchment was conducted. Over 300 km of drains were surveyed, covering a total area of 53 km^2. Note that this is the area under cane. The area covered by rainforest comprises another 37 km^2 (Figure 1).

The drain survey data was then incorporated into the Mike-11 model. The resulting network file has 1059 drain segments, 3412 cross-sections and 389 culverts. Figure 1 shows the network file used in this study. Cross-sections for each drain were automatically generated and incorporated into Mike-11 using the surveyed drain dimensions and shapes.

The survey data included information on slope for all drains but did not include information on absolute elevations. Thus, the elevation of every drain in the survey was calculated by finding the base elevation of the lowest drain (site 6 in Figure 1), and back-calculating the elevation of every other drain using their slopes. There were problems with this calculation in that drops in elevation between drains were not recorded in the drainage survey. To incorporate these drops in the Mike-11 model, the main drains were lowered in elevation by between 0.5 and 3.0 m. This was considered an adequate fix as most of the drops occur where minor drains flow into major drains.

2.2 Digital Elevation Model (DEM)

Figure 1 also shows the DEM derived for the Ripple Creek catchment. This DEM was derived from detailed spot heights and has an absolute accuracy of +/- 5 metres, but has a much greater relative accuracy for adjacent points.

Elevations for each cross-section in the Mike-11 model had to be calculated as accurately as possible and needed to be consistent with the surveyed slopes to allow flow routing to proceed correctly in Mike-11. We took a two-step approach. Firstly, the elevation of the drains as calculated above were adjusted for surveyed drain depth to give an approximation of surface elevation at each point. Secondly, we compared these elevations to the DEM (whose heights show only headlands and other surface features) and the iterated data was fitted to the DEM using the resulting linear relationship. Although there was good correlation (r^2=0.9), the iterated elevations had to be reduced by 15% to fit with the DEM. As a final adjustment, we "rubber sheeted" the DEM to be in agreement with the Mike-11 cross-sections. This removed localised warping which, while all within the DEM error, was in conflict with the model data and would have adversely affected any attempts at flood mapping.

2.3 CSIRO Monitoring Sites

The location of the CSIRO monitoring sites are shown on Figure 1. They are :
1. Post Creek @ Bananas;
2. Ripple Drain @ Outlet;
3. Prosser Drain @ Outlet;
4. Ripple Creek @ Swimming Hole;
5. Ripple Drain @ Croc City.

Other sites of importance are :
6. Flood gates where Ripple Creek discharges into the Herbert River;
7. Site of proposed Seymour overflow channel;
8. Ripple Sump.

Continuous depth data has been collected at each of the monitoring sites for the 1999/2000 and 2000/2001 wet seasons. In addition, velocity and turbidity data has been collected at sites 2, 3, and 4, while event based velocity data has been collected at site 1. Crocodile hazards prevented us from collecting event based velocity data at site 5. The depth and velocity data was combined with cross-sectional information to calculate discharge at sites 1, 2, 3, and 4.

Two of these sites (1 and 4) were used to provide input to the Mike-11 model, while the other three sites were used as model validation points, where the depth, discharge and velocity predicted by the model were compared to the observed data. No other model calibration was undertaken.

In addition to the in-stream monitoring, runoff from both furrowed and unfurrowed cane fields was monitored [Mitchell, 2001]. A unit hydrograph was fit to this data in order to derive generic runoff hydrographs that could be applied across the catchment. Soils and runoff characteristics are relatively uniform across the catchment, making this a reasonable extrapolation; the main difference in terms of runoff characteristics is due to the presence/absence of water furrows.

After examining the two years of data collected, the rainfall/runoff event that spanned the period 23 December 1999 to 1 January 2000 was chosen as the period over which to base our modelling. A total of 206 mm of rainfall occurred over the 5 day period 23 to 28 December. Runoff and localised flooding then continued for a number of days. This rainfall event is of the size expected to occur around once per year.

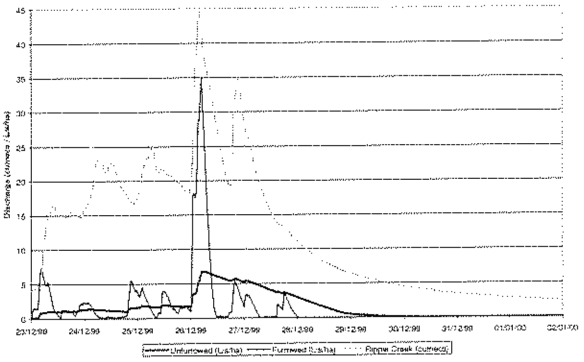

Figure 2 : Mike-11 input data - observed discharge for site 4, furrowed, and unfurrowed fields.

Figure 2 shows the measured discharge at site 4 and predicted runoff from an unfurrowed and furrowed cane field for this 10 day event. Note the units on this graph, where the discharge at site 4 is in m^3/s (cumecs) and is therefore much larger than the runoff from cane fields (L/s/ha). The observed discharge at site 1 looks very similar to that at site 4, but is much smaller, reflecting the fact that site 4 drains an area of 31 km^2, while site 1 drains an area of 0.7 km^2.

The observed discharge for sites 1 and 4 was used directly as inputs into the Mike-11 model. It may be seen from Figure 1 that there are a number of other streams draining from the rainforest onto the cane land which are similar in size to the area being drained by site 1. The observed discharge at site 1 was thus simply scaled by area to provide the input for these other ten streams. This was considered adequate as the rainforest here is very homogeneous and we have no reason to believe that these other streams behave significantly differently to Post Creek.

Finally, the area of cane land (and proportion of furrowed/unfurrowed fields) contributing to each drain was estimated from aerial photography and the discharge hydrographs shown in Figure 2 were scaled by this area and used as inputs for each drain.

3. EVALUATION OF MODEL RESULTS

3.1 Local Feedback

The results of the model runs were presented to cane growers in a workshop in April 2001. Overall, the growers were very happy with the modelling, stating that the model results reflected their knowledge of the observed hydrologic response of the catchment. Maps of flood inundation were presented for the 10 day period being modelled, which the farmers felt reasonably accurately represented both the area being inundated, as well as the duration of inundation. In addition, maps of the catchment showing depth of water in the drains, discharge of water, and velocity of water were presented. The farmers felt that these maps were accurately representing the pattern that they observed. In particular, the Mike-11 modelling system allowed us to zoom in on particular farms and demonstrate the hydrologic response of individual drains. This allowed detailed examination of the model to take place by farmers intimately familiar with the hydrologic response of their own farm.

Three main areas where the model was providing a poor representation of reality were pointed out at this workshop :

- Ripple Creek breaks its banks at high flows. This was incorporated in the model by taking the highest flows from Ripple Creek and adding them into the appropriate drains;
- The floodgates at site 6 provide a significant impediment to flow. This was incorporated into the model by increasing the resistance in the culvert at site 6;
- Water currently overflows into the Seymour River at site 7 during flood events. This was incorporated into the model in the same way as point 1.

This illustrates the usefulness of presenting model results to non-specialists who are nonetheless familiar with the area being modelled – too often modellers neglect to provide this feedback to members of the public (and receive valuable feedback in turn).

3.2 Comparison with Observed Data

Figure 3 shows observed and modelled depth at Site 5. It can be seen from Figure 1 that site 5 integrates much of the discharge from the cane area, thus modelling the depth correctly at this point indicates that we are reproducing the observed hydrologic response of the entire system with a high degree of accuracy. Unfortunately we could not obtain velocity measurements at this site and are therefore unable to compare modelled discharge and velocity with observed data.

Figure 4 shows observed and modelled discharge at site 2. The model is doing a remarkable job of predicting discharge at this site – the peak discharge is almost exactly the same, however the modelled discharge does lag behind the observed discharge slightly, and the rate of recession is also slightly too long. The prediction of depth and velocity at this site are similar in quality to those shown in Figures 3 and 5.

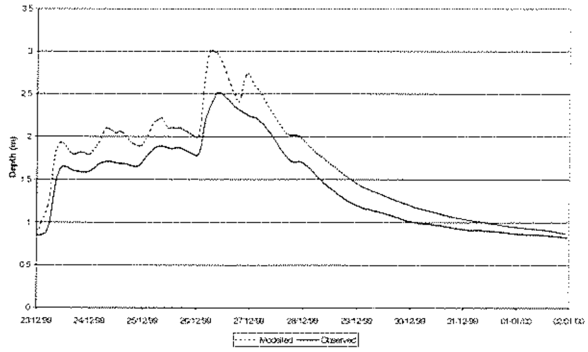

Figure 3 : Observed and modelled depth at site 5.

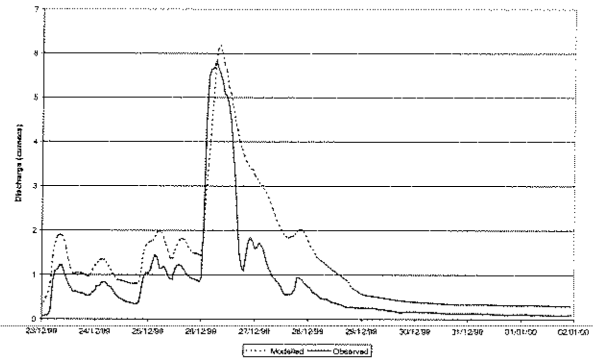

Figure 4 : Observed and modelled discharge at site 2.

Figure 5 shows observed and modelled velocity at site 3. The model is representing the magnitude of the velocity reasonably well, however it fails to reproduce the variations seen in the observed velocity. This is of little concern as these variations in the observed velocity may be due to

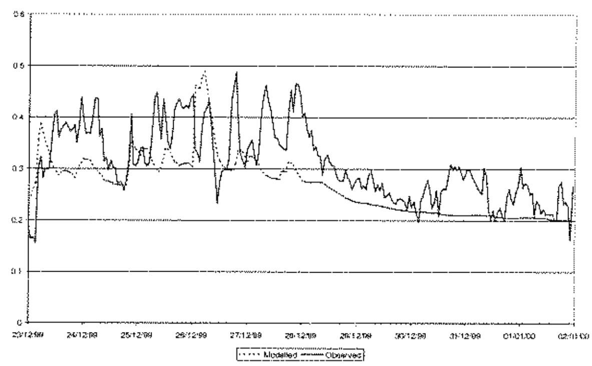

Figure 5 : Observed and modelled velocity at site 3.

the instrument used, rather than reflecting real conditions in the drain. In any case, the modelled velocity does represent the overall trend in observed velocity very well. The prediction of depth and discharge at this site are similar in quality to those shown in Figures 3 and 4.

In summary, despite some differences, the model is representing the hydrologic response of the catchment reasonably well. This comparison with observed data, combined with feedback from locals and BSES staff familiar with the catchment, allows us to state with some confidence that the model is capturing the observed hydrologic response of the catchment.

4. SCENARIO MODELLING

Having demonstrated that the model is representing the observed hydrologic response of the catchment with a reasonable degree of accuracy, we will now apply the model in order to determine the hydrologic impact of establishing an overflow channel from Ripple Creek to the Seymour River.

In this paper, only the most basic impacts on hydrologic response such as flood inundation times will be considered. However, one of the major advantages of the Mike-11 modelling system is that it allows detailed examination of the changes in hydrologic response. This includes changes in discharge, velocity, depth and overbank inundation for every one of the 1059 drain segments in the catchment. Some of these responses will be illustrated in the accompanying presentation.

In Section 3.1, we mentioned that during flooding, water can move overland and join the Seymour channel (site 7 in Figure 1). The drainage board has proposed digging an overflow channel between Ripple Creek and the Seymour River at this location in order to channel this overflow and thus enhance flow capacity. This was modelled by inserting a new branch in Mike-11 at this site and allowing water to pass through this branch when it reached the appropriate water level.

Figure 6 shows the impact of this channel on inundation in the catchment when the Herbert River is low, while Figure 7 shows the impact when the Herbert River is high. The light area in Figures 6 and 7 represents that area which is currently inundated for 3 days or longer and that will no longer be inundated for 3 days or longer after the channel is open.

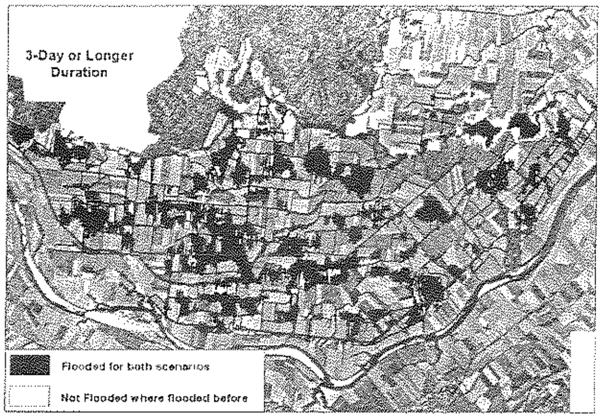

Figure 6 : Impact of the proposed Seymour channel on inundation when the Herbert River is low.

When the Herbert River is low and water can also escape through Ripple Creek, 45 ha of cane land and 30 ha of crown land will no longer be inundated for 3 days (Figure 6). When the Herbert River is in flood and all of the water has to pass down the Seymour River, the reduction in inundated area becomes 95 ha of cane land and 40 ha of crown land (Figure 7).

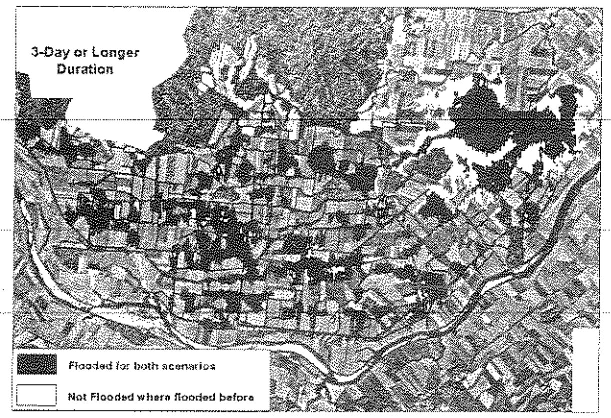

Figure 7 : Impact of the proposed Seymour channel on inundation when the Herbert River is in flood.

The Mike-11 model also allowed us to determine that the volume of water (36 cumecs at maximum flow) passing down the proposed Seymour channel will not be sufficient to cause the Seymour River to break its banks. Therefore, farmers in the Seymour River catchment should not be unduly affected by the proposed re-routing of water from Ripple Creek into the Seymour River. Interestingly, we found that the Queensland Department of Natural Resources and Mines (DNRM) estimate of a maximum discharge of 20 cumecs may be an underestimate. This is because the maximum predicted velocity in the channel is 1.15 m/s rather than the 1.0 m/s predicted by DNRM. If desired, this effect could be eliminated by increasing the roughness of the proposed channel.

5. CONCLUSIONS

The Mike-11 model has been successfully applied to the Ripple Creek catchment in the Herbert River delta. The outputs of the model have been compared to observed data and found to represent the hydrologic response of the catchment to an acceptable degree of accuracy. In addition, the outputs of the model have been presented to cane growers with an intimate knowledge of the local hydrologic response and they also believe that the model is providing an accurate representation of the hydrologic response, both at a catchment scale (in terms of inundation of land), and at a local scale (in terms of representing the hydrologic response of individual drains on their farms).

The effect of opening a channel from Ripple Creek to the Seymour River has been investigated. The model results show that this proposed channel will have a significant impact on reducing both the extent and period of inundation in the so-called 'Ripple Sump'. The economics of building this channel are beyond the scope of this study, but it would be a relatively easy problem to solve, given that the area of cane land no longer inundated has been determined in this study, and the cost of building the channel has presumably been determined by DNRM in planning the works.

The model used in this study is very complex, with 1059 drain segments. Future work will focus on simplifying the model by removing all of the first order drains. This will tell us what level of model complexity is required to adequately represent the hydrologic response of the Ripple Creek catchment. Once this is known, the model will then be applied to similar cane growing areas where the same level of drain data is not available.

6. ACKNOWLEDGMENTS

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