5 UNET Model Comparison to Illinois Waterway Backwater

Description of Illinois Waterway Backwater

To demonstrate the applicability of UNET to actual backwaters, UNET was compared to a backwater on the Lagrange Pool of the Illinois Waterway where measurements were taken in 1996 by Pratt and Fagerburg(draft). The prototype backwater channel (Figure 20) is on the left bank at River Mile 98.7 and connects the river to Panther Slough. At the connection to Panther Slough, a rectangular sheet pile structure having a sill width of about 9.1 m and sill elevation of about 0.8-0.9 m below the Lagrange normal pool elevation of 429.0. The “about” in the above sentence results because the width observation was based on similar independent estimates by two individuals who passed through the structure in a boat and the sill elevation estimate is based on bottom elevations taken upstream of the structure and the fact that the boat that passed through the structure had a known draft.

Bathymetry data and aerial photography were collected in about 1989 and resulted in an average channel top width of about 30 m along the length between the structure and the river. In 1993, the Illinois Waterway experienced a major flood. Four members of the 1996 field survey team independently estimated the channel top width to be from 12- 15 m wide during the field data collection. A fifth member of the field team collected GPS measurements that showed the top width to be 12 m in the middle of the reach between the structure and the river. Cross-sections were not collected during the 1996 field trip but depth checks at the water level and velocity measurement station near the structure and depths at sediment sampling points in the backwater showed the maximum depth during the 1996 trip was about 1.7 m. This depth is consistent with depths measured during the 1989 measurements. This disparity between the widths and the lack of cross-section data mean that this comparison will be more of a demonstration than a verification. Widths and depths upstream of the sheet pile structure are based on the 1989 measurements. One UNET model run will be conducted using widths in the reach below the sheet pile structure that are typical of the 1989 measurements to see how results are affected.

Pool elevation during the 1996 field measurements was 430.0 and flow rate in the backwater channel was near zero based on the velocity measurements which were less than 2 cm/sec. The upbound tow used in this demonstration of UNET, referred to as boat #2 in Pratt and Fagerburg (draft) is the M/V Tennessee which had a speed over ground V_g = 1.8 m/sec. The measured time history of water level at the mouth of the backwater (cross-section 0.00 in the UNET simulation, range 2 in the field data) is shown in Figure 21. Passage of the bow past the mouth of the backwater channel was at 10.14 hours for boat 2. Boat #2 was a loaded tow typical of the largest tows using the waterway having a length of about 340 m although the speeds were less than the fastest tows on the waterway. The measured time history of water level at the upper end of the backwater channel at cross-section 0.496 (range 1 in the field data) is shown in Figure 22 for boat 2. Cross-section names on Figure 20 refer to miles above the mouth of the backwater. Measured time history of velocity at UNET cross-section 0.496 is shown in Figure 23 for boat 2.

UNET Simulations of Illinois Waterway Backwater

The cross sections used in the Illinois Waterway backwater channel simulation are shown in Figure 24 and extended from the mouth to 2.0 miles upstream with the field measurement section at cross section 0.496. One of the limitations of applying the UNET model to actual backwaters is that most backwaters have a gradual decrease in depth all the way to zero whereas the UNET model must have a finite depth (a vertical wall) at the upstream end so that the depth will never be zero. A vertical wall reflects almost all of a wave whereas the mild slopes at the upstream end of an actual backwater reflect much less of the drawdown event compared to a vertical wall. The simulation used herein of the Illinois Waterway backwater has the measurement section far downstream of the upstream limit of the backwater so the reflection problems in UNET are not present. For backwaters where the water level is desired to be known where the backwater depth gradually diminishes to zero, it is recommended that the UNET simulation have a depth at the location of the actual upstream end of the backwater that is slightly greater than the drawdown and that the UNET simulation reach be extended far upstream of the actual upstream end of the backwater using the smallest depth that the model will run. This approximation will prevent the reflection problems at the location in the model that represents the actual upstream end of the backwater.

As in the physical model, none of the main channel of the Illinois Waterway was used in the UNET simulation. The drawdown time history from Figure 21 was discretized for input as the downstream stage hydrograph in the UNET model using a 30 sec time increment. While the 30 second discretization of a visual smoothing of the prototype time history did not capture all the variations in the prototype data, comparison of the observed data and the input downstream stage hydrograph in Figures 21 and 25 show a nearly identical shape.

Barkau (1992) states “...any model application should be accompanied by a sensitivity study, where the accuracy and the stability of the solution is tested with various time and distance intervals.” Sensitivity experiments were conducted to determine the maximum distance between cross sections Δx and computational time step ΔT. Courant numbers determined herein were based on a depth of 1.5 m. The sensitivity runs for Δx of 64 m, 32 m, 16 m, 8 m, and 4 m showed similar results for all Δx less than or equal to 32 m when comparing runs having the same Courant number. Sensitivity runs for ΔT were conducted with Δx = 32 m for ΔT of 16 sec, 8 sec, 4 sec, 2 sec, and 1 sec giving Courant numbers of 2, 1, 0.5, 0.25, and 0.125, respectively. A time step of 16 secs (Courant number of 2) resulted in smearing (amplitude decreases, wavelength increases) of the drawdown time history compared to the observed time history. Time steps of 4 sec, 2 sec, and 1 sec (Courant numbers of less than 1) resulted in increasing oscillation of the computed time history which was not present in the observed data.

A time step of 8 sec, and Δx = 32 m, giving a Courant number of 1 and Manning's n = 0.030, resulted in computed water level drawdown that had a shape similar to the observed data and is plotted in Figure 25. The computed velocity from UNET is shown in Figure 26. The times in Figures 21-23 are the actual time of day the prototype data was measured. The time on the UNET plots like Figure 25 and 26 differ because UNET was run with a starting time of zero. Comparing Figures 22 and 25, a UNET time of 0.093 hours is equal to a prototype measurement time of 10.14 hours. The important time to note is the difference in time between passage of the minimum drawdown, equal to about 0.071 hours from both the observed data and the UNET calculations. The two input files for UNET are shown in Figures 27 and 28.

A Manning's n value of 0.030 was used in all previous runs. Two members of the 1996 field team looked at photographs of channels with known n values from Barnes (1967) and estimated that the n value for the backwater channel was from 0.026 to 0.035. Water level and velocity were computed for n = 0.026 and 0.035 and are shown in Figures 29 and 30, respectively. This range of n value had only a small impact on computed elevations and a larger impact on computed velocity. The small effect of n value changes is likely due to the low average channel velocity (less than or equal to 0.41 m/sec) that occurs as a result of the vessel drawdown.

A final sensitivity run was conducted using a channel bottom width that was twice the bottom width of the channel used in the previous sensitivity runs (depth over the bottom remained the same due to the similarity of depth measurements in 1989 and 1996) to determine the importance of the contraindication between the 1989 measurements and the 1996 field observations. The doubling of the channel width was only in the reach below the sheet pile structure and used Δx = 32 m, ΔT = 8 sec, and n = 0.030. Results showed that doubling the channel width increased the maximum drawdown at the measurement station by about 50 percent. The explanation for the increased drawdown lies in how the width was doubled. The side slopes were left alone and the doubling of width was placed in the middle of the channel. For cross-sections 0.057 to 0.496 (Figure 24), the hydraulic radius of the original cross-section was 1.13 m. The hydraulic radius of the wider channel was 1.32 m which was one of the causes of the increase in drawdown. Another possible cause of the increased drawdown is that the cross-section at the weir and upstream remained the same in both runs. The increased contraction (wave going upstream) or expansion (wave going downstream) at the weir could also contribute to the increased drawdown.

Application of UNET Model

Another use of the UNET model output is to determine the amount of flow or volume leaving the backwater during the passage of a commercial vessel.

UNET also has modelling features that allow simulation of a large backwater lake (storage area) connected to the main channel by a channel. Although data was not found to evaluate this configuration, results from this study show that the UNET model simulates a worst case physical model backwater and a prototype channel backwater and should be applicable to the backwater lake/connecting channel.

One of the inputs to UNET is the time history of drawdown at the mouth of the backwater which was measured in the two cases studied herein but is rarely known. The NAVEFF model (Maynord, 1996) can be used to estimate the maximum drawdown along the edge of the main channel. Table 1 provides a dimensionless time history of drawdown developed based on prototype data. Knowing the vessel speed and length and the maximum drawdown from the NAVEFF model, the dimensionless parameters in Table 1 define the duration and magnitude of the drawdown event. The dimensionless time parameter is time at any instant / total time required for the barges to pass a fixed point on the river. The dimensionless drawdown parameter is the drawdown at any instant / maximum drawdown during vessel passage.

Table 1
Dimensionless Drawdown Time History

Time Time for Tow Passage*	Drawdown Maximum Drawdown
0.00	0.00
0.25	-0.32
0.50	-0.63
0.75	-0.83
1.00	-1.00
1.25	-0.82
1.50	-0.55
1.75	-0.33
2.14	0.00

* Time for tow passage = (Total Length of Barges)/(Vessel Speed)

UNET provides an easy way to evaluate variation of water level in navigation backwater channels, but because it is a 1-D model, the effects of many of the channel features such as alignment must be lumped into the resistance coefficient. For more detailed study of drawdown effects, the HIVEL2D model (Berger, Stockstill, and Ott 1995) is a two-dimensional depth averaged model that can be used to determine the effects of various channel alignments, shapes, and does not require a vertical wall at the boundaries of the backwater. Although the 2-D model requires more effort to setup and run, it requires less experience on the part of the modeller because channel features such as alignment are part of the model rather than lumped into an empirical resistance coefficient which the user must specify. The advantage of UNET is that is easier to set up and run.