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EDITORIAL155

TECHNICAL PAPERS

Shore Attachment of Buoyant Effluent in Strong Crossflow.
V. H. Chu and M. S. T. Abdelwahed157

Interfacial Mixing in Estuaries and Fjords.
John P. Grubert176

Hydraulic Transients in Rock-Bored Tunnels.
Lisheng Suo and E. Benjamin Wylie196

Reliability-Constrained Pipe Network Model.
Ian C. Goulter and Francois Bouchart211

Reliability Analysis of Pumping Systems.
Ning Duan and Larry W. Mays230

Optimal Reliability-Based Design of Pumping and Distribution
Systems.
Ning Duan, Larry W. Mays, and Kevin E. Lansey249

TECHNICAL NOTE

Accounting for Density Front Energy Losses.
Richard A. Denton270

DISCUSSIONS

Kinematic Wave Routing and Computational Error. T. V.
Hromadka II and J. J. DeVries.
By David R. Dawdy. By David Goldman.
By William H. Merkel. By Carl L. Unkrich
and David A. Woolhiser. By David A. Woolhiser
and David C. Goodrich. Closure by authors278

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applicability of approximate flood routing models ("Computer Program" 1983; Ponce et al. 1978).

The SCS is currently comparing selected approximate flood routing models with a full dynamic solution of the routing problem. The linear and variable parameter diffusion models show very promising results for conditions present in many SCS flood routing applications. These models have the potential to replace both the complex and modified Att-Kin procedures for SCS use.

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Discussion by Carl L. Unkrich⁶ and David A. Woolhiser,⁷
Member, ASCE

The authors used the HEC-1 computer program to evaluate the "standard kinematic wave (finite difference) routing method" for several open channel test cases. They reported mainly on the slow-flow case, and concluded that the method is far too sensitive to the choice of computational increments. However, two major assumptions are incorrect: (1) The slow-flow case, contrary to the authors' claim, does indeed attenuate due to kinematic shock; and (2) not all kinematic wave finite-difference algorithms are as sensitive to the choice of dx and/or dt as HEC-1. To illustrate the second point, the Kineros program (Smith 1981), which uses a four-point implicit numerical scheme with centered time differences and a weighting factor of 0.8 for the space differences at the advance time step, was used to simulate the same slow-flow case. Solutions were obtained for the same combinations of dx and dt as shown in Fig. 4. These solutions are shown in Fig. 9 along with the HEC-1 solution for $dt = 6$ min and $dx = 8,333$ ft (2,540 m). The Kineros solution for $dt = 2$ min and $dx = 500$ ft (152 m) plots virtually on top of the partially analytic solution obtained by the method of characteristics with a shock following scheme. It is clear that the finite-difference scheme in Kineros exhibits much less numerical diffusion than that in HEC-1 and that with a reasonable number of dx increments (>10) it provides quite acceptable numerical results.

The ranges of peak discharge obtained from Kineros for dx ranging from 1,000 to 8,333 ft (3.5 to 2,540 m) and $dt = 5$ min are shown in Fig. 10

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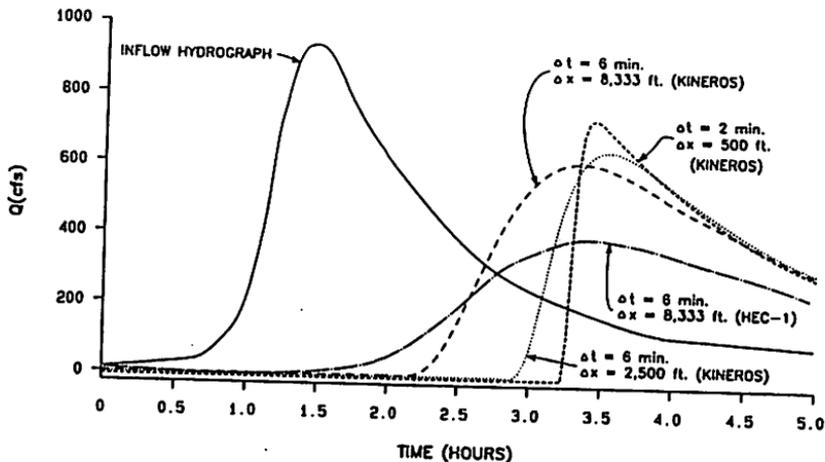


FIG. 9. Kineros Results for $L = 25,000$ ft (7,620 m)

along with the range for the convex method and a line showing the true KW solution (obtained by the method of characteristics with a shock following scheme). The resulting variation for peak flow rates is 8% at $L = 25,000$ ft (7,620 m) compared with the 130% (really 80% because the authors incorrectly assumed that there would be no attenuation) for HEC-1.

It should be noted that Kineros has built-in limits on the number of spatial increments (which were overridden for this study). The size of dx increments is based on an input "characteristic length" for the watershed defined as the length of the longest cascade of overland flow planes or the longest channel, whichever is greater. This characteristic length is divided into 15 dx increments and shorter elements have proportionally fewer, with a minimum of five dx increments. Therefore the allowable range of dx increments for Kineros is from 1,786 to 6,250 ft (544 to 1,905 m) for a 25,000-ft (7,620-m)

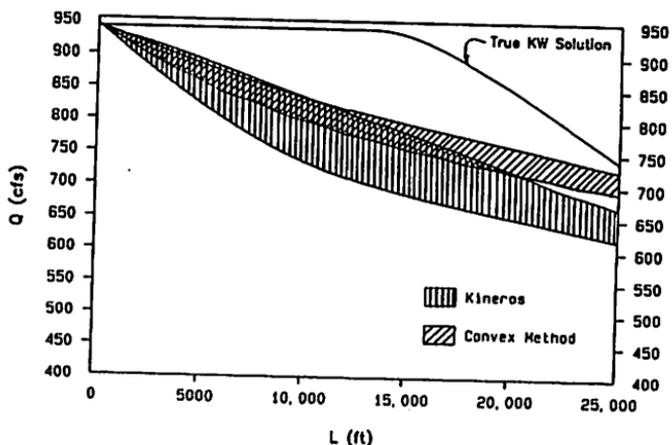


FIG. 10. Variation in Kineros and Convex Method Modeling Results of Q_p for Various L Values from 0 to 25,000 ft (7,620 m)—Slow-Flow Case

reach. For a dt of 5 min, which is sufficient to define the inflow hydrograph, the range of Q_p was 626–666 cfs (17.7–18.9 m³/s), a variation of only 6.4%.

The authors' choice of references regarding KW channel routing performance is highly selective and may lead to incorrect conclusions by the reader. For example, the cases examined by Akan and Yen (1981) involved back-water conditions so it is not surprising that KW routing procedures did not work well. Katapodes and Schamber (1983) were investigating dam-break problems that lead to kinematic shocks. Since it is precisely in the vicinity of shocks that the kinematic approximation breaks down, KW routing would normally not be recommended for this problem. Weinmann and Laurenson (1979) point out that for slowly rising hydrographs and moderately steep slopes KW routing will give results that compare favorably with solutions of the St. Venant equations. Ferrick (1985) provided a comprehensive analysis of river wave types, developed a set of scaling parameters and used case studies to define the appropriate scaling parameter range for each wave type. His criteria should provide useful guidelines for choosing the appropriate approximation for a given channel.

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Discussion by David A. Woolhiser,⁸ Member, and David C. Goodrich,⁹ Student Member, ASCE

Although we agree with the authors' conclusion that there is a need for better guidelines for choosing Δx and Δt in some kinematic wave (KW) routing models and for internal checks regarding the appropriateness of the KW formulation from the physical point of view, we find that their analysis is misleading. An analysis of their "slow-flow" case, which leads to the information shown in Figs. 1–7, reveals that according to current criteria the (KW) model should not be used for this case. Ponce et al. (1978) showed that for 95% accuracy of the kinematic wave solution after one propagation period, the dimensionless period $\hat{\tau}$ should be greater than 171. This translates into

$$T \geq \frac{171d_0}{(U_0S_0)} \dots\dots\dots (4)$$

where T = the wave period of the perturbation to steady uniform flow; U_0 = the steady velocity; d_0 = the steady depth; and S_0 is the slope. If we relate U_0 and d_0 to the mean variables at the upper boundary, we find that T should

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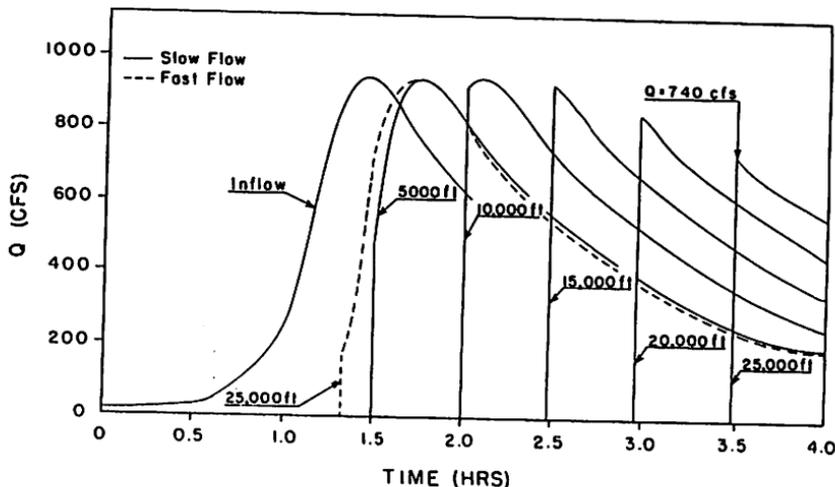


FIG. 11. Characteristic Solutions for Hydrographs

be greater than three days, yet the period of input at the upper boundary is approximately 4 hr. The "fast-flow" case meets the preceding criterion and we see that the numerical errors introduced by the KW model are in fact smaller than those in the convex method (Fig. 8).

The authors state that they are evaluating only numerical errors introduced by the HEC-1 KW program rather than those due to the KW fundamental assumptions. Yet by using an example that violates the fundamental assumptions they leave the reader with the impression that the numerical errors are more serious than they really are. If the finite difference equations in the HEC-1 model are expanded in Taylor series, we find, for example, that the error terms for the conservation form are $(\Delta x/2)(\partial^2 Q/\partial x^2) + \Delta t(\partial^2 Q/\partial x \partial t) + (\Delta t/2)(\partial^2 A/\partial t^2) + O(\Delta x)^2$.

If the Courant condition is exactly satisfied, this scheme can give exact results, but in general it is of first-order accuracy and is more dispersive than some alternative schemes. It is worth noting that for flows meeting the criteria for kinematic flow, the second-derivative terms are very small over most of the solution domain and, if reasonable Δx and Δt increments are chosen, this finite difference scheme will give quite accurate results.

When performing an empirical examination of the accuracy of rectangular grid finite-difference schemes it is always wise to have a more accurate solution for comparison. Both examples used will lead to a kinematic shock emanating from $x = 0, t = 0$, and traversing the channel with a shock velocity equal to the local velocity. Kinematic characteristics will be straight lines emanating from the line $x = 0$ and some will intersect the shock front. A numerical shock following scheme similar to that used by Kibler and Woolhiser (1970) was used to develop accurate hydrographs for both examples. Discharge hydrographs at various distances along the channel are shown in Fig. 11. For the slow flow case, the hydrograph peak overtakes the shock front at $x = 12,490$ ft (3,797 m), so for this case the peak does attenuate due to the peak overtaking the shock. Therefore, the line shown in Fig. 7 as the true kinematic solution is incorrect after that distance and