Revista de Investigación de Física **23(3)**, (2020)

VICERRECTORADO DE INVESTIGACIÓN Y POSGRADO
eISSN:1728-2977

Use of HEC-HMS in floodwave propagation simulations

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Recibido 05 febrero 2020 – Aceptado 02 diciembre 2020

Abstract

A delicate feature of the flood propagation simulation performed by the program HEC-1 with the option of the modified Puls method with normal flow approximation is constituted by the estimation of the quanta parameter NSTPS. While it is recognized to be a parameter that one should calibrate, it is usually recommended that it be estimated as the ratio (wave travel time/integration time step). In this paper it is shown that numerical experiments conducted with the program FEQ, retained as standards, when compared with HEC-1 solution, do not confirm the above estimate. The preliminary results presented here suggest that the ratio (time to peak of outflow hydrograph/time to peak of inflow hydrograph) may be a more meaningful, but strongly event dependent,parameter.

Keywords: Hydraulics.

Uso del HEC-HMS en la simulación de ondas de avenida

Resumen

Una característica delicada en la simulación de propagación de inundaciones realizada por el programa HEC-1 con la opción del método Puls modificado con aproximación de flujo normal está basado en la estimación del parámetro de cuantia NSTPS. Si bien se reconoce que es un parámetro que se debe calibrar, generalmente se recomienda estimarlo como la relación (tiempo de viaje de onda / intervalo de tiempo de integración). En este trabajo se muestra que los experimentos numéricos realizados con el programa FEQ, considerados como estándares, cuando se comparan con la solución HEC-1, no confirman la estimación mencionada lineas arriba. Los resultados preliminares presentados aquí sugieren que la relación (tiempo al pico del hidrograma de flujo de salida / tiempo al pico del hidrograma de flujo de entrada) puede ser un parámetro más significativo, pero fuertemente dependiente del evento.

Palabras clave: hidráulica

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Introduction

The program HEC-HMS has been designed to simulate the response of a watershed to precipitation events. One of the components of the river network is the channel reach or river reach where the process of wave propagation can be simulated by several routing methods. One method in particular is the object of this research: the modified Puls method **(Puls, 1928)** with normal depth storage vs. outflow relationship, which has its basis in hydraulics concepts. We will call this method "modified Puls method #2" for short, to distinguish it from the homonimous method #1, where the storage vs. outflow relationship is given from empirical data. In this method one assumes that a river reach can be simulated globally and that the inflow hydrograph I(t) and outflow hydrograph O(t) are related to the storage S(t) in the reach via the continuity equation

$$\frac{\partial S(t)}{\partial t} = f(t) - O(t) \qquad (1)$$

Since this equation is not sufficient to solve the problem of wave propagation through the reach, another relationship between S, I, 0 should be found. This can be given only by hydraulics (correctly the de Saint-Venant equations), but other drastic simplifications (as the Muskigum method) are usually introduced in hydrology for the sake of expediency. A method that approximates the dynamic behavior of the system.is the one that assumes that S and 0 are indirectly related through the outflow cross section area A., via the momentum equation as written for normal flow.

$$O = \frac{4.186}{n}\frac{A_o^{5/3}}{P_o^{2/3}}\sqrt{Sf} \qquad (2)$$

where *S*r is the "energy slope" at the outflow cross section, n is Manning's friction coefficient, Ao, is the outflow cross section area at the depth yo; Po is the length of its wetted perimeter, and yo(Ao) is the inverse function of A(yo); Ao, is related to Sf either via the equation S = LA, where L is the reach length, or via other more sophisticated relationships which introduce the inflow water area. The first published reference to this method of numerical approach to floodwave propagation has been found by the authors in **(De Marchi, 1945)** who gives credit to **(Fantoli, 1925)** for the "concetto informatore" (conceptual framework).

It is obvious that this type of routing has considerable simplifications with respect to a strict applications of the full de Saint-Venant equations, but one must admit that the application of HEC-HMSis sufficiently easy, with respect to full equation programs, to warrant a search for the limits within which HEC-HMS could be used for wave propagation studies of hydraulic consequence.

In the present project we specify the channel cross section (via 8 points, which is what the HEC-HMS modified Puls method #2 requires), the channel's length, and the channel's slope, and we will consider several normal How conditions corresponding to normal depths varying from 5 ft to 40 ft at intervals of 5 ft. We will achieve this by varying the "unperturbed" flowrate Qo according to the Chezy-Manning Equation (2). We superpose then to each unperturbed normal How various hydrographs with variable characteristics of peak How ΔQi and time to peak Tp. By varying the only HEC-HMS parameter NSTPS for the simulation of the hydrograph propagation we will explore the region within which the results of HEC-HMS applications are reliable. In order to do this we need "standard" solutions against which to compare the HEC-HMS solutions. We will assume that these standard solutions are the solutions of the Full Equation Model (FEQ), developed by **(Franz, 1988)**.

Model Data

The The geometry of the channel reach to model is presented in Figure 1. The bottom slope is S=.0002 and the Manning's "n" values are n = 0.030 for the channel and n = 0.80 for the overbanks. The length of the channel reach is L = 10 miles. Since the initial conditions start from uniform How, we will choose as initial flowrates for our experiments, fractions of that flowrate which fills the channel in normal How conditions (*Qo* max = 128,046 cfs). The several unperturbed normal flowrate that are the object of our investigation are the normal discharges, for the same geometry, corresponding to depths that range from 5 ft to 40 ft. They are presented in column 1 of Table 2, paired with the corresponding normaldepths.

The resulting hydrographs (sum of the unperturbed flowrate Qo and of the perturbation hydrograph) have the analytic expression

$$Q = Q_o + \Delta Q_i\left[\frac{t}{\tau_p}\right]^2 e^2\left(t - \frac{t}{\tau_p}\right) \qquad (3)$$

Where: ΔQi is the perturbed hydrograph peak and Tp is the perturbation hydrograph. The resulting hydrograph peak is therefore Qo + ΔQi. The values of ΔQi have been established so that the normal depth corresponding to Q0 + ΔQi has a value between 5 ft and 40 ft, at intervals of 5 ft. This is tantamount to saying that, if we call Qoi the j-th value of the unperturbed normal discharge the following relationship issatisfied

$$Q_{o,j} + \Delta Q_{ij} = Q_{oi+j} \qquad (4)$$

This paper reports on the results of the experiments conducted with

$$Q_{o,2} = 10{,}525 cfs$$

[1]ΔQ_{12} = 10,921cfs, for several values of the parameters Δt (time increment of the numerical integration scheme), TP (time to peak), and NSTPS (number of sub-reaches used in the HEC-HM Ssimulation). The simulation deals with a flood wave which, starting from a normal depth of 10 ft, presents a peak stage of 15 ft. The values of the integration time step Δt used in the simulation are presented in the following matrix (Table 2), juxtapposed to the Tp values to which theyrefer.

Since the values of Q0 and ΔQi are kept constant throughout this presentation, we will refer to each one of the numerical experiments by the triplet Tp, Δt, NSTPS. We will denote, e.g., by "experiment(Tp= 2 hr, Δt = 15 min, NSTPS = 3)" the experiment whose parameters have the values given within the parentheses.

Table 2. Parameter for Input Hydrographs

Qoj (cfs)	Qoj+ΔQij (cfs)						
Yoj (feet)	ΔQ1j	ΔQ2j	ΔQ3j	ΔQ4j	ΔQ5j	ΔQ6j	ΔQ17
3,194 5	10,525 7,331	21,446 18,252	35,866 32,672	54,816 51,622	76,475 73,281	100,936 97,742	128,046 124,852
10,525 10	21,446 18,252	35,866 32,672	54,816 51,622	76,475 73,281	100,936 97,742	128,046 124,852	
21,466 15	35,866 32,672	54,816 51,622	76,475 73,281	100,936 97,742	128,046 124,852		
35,866 20	54,816 51,622	76,475 73,281	100,936 97,742	128,046 124,852			
54,816 25	76,475 73,281	100,936 97,742	128,046 124,852				
76,475 30	100,936 97,742	128,046 124,852					
100,936 35	128,046 124,852						
128046 40							

Table 2. Time Step for Simulation

Time To Peak (Tp) (Hours)	Time Step (Δt) (Minutes)				
1	15				
2	15	30			
4	15	30	60		
8	15	30	60	120	
16	15	30	60	120	240

Presentation of the results

By inspecting the results of the numerical experiments presented in the last column of Table 3, we discover that the value of Δt does not affect sensibly the results of the simulation, as far as the value of NSTPS is concerned. This can be seen clearly in comparing the Figures 5, 6, 7 where, for Tp = 4 hrs, Δt varies from 15 min to 60 min. Notice that in our simulations the value of Δt is always at most as large as Tp/4, and it is therefore reasonable that the above result be expected.

The results of the numerical experiment (Tp = 1 hr, Δt = 15 min) for several values of the parameter NSTPS, compared with the standard solution obtained by means of FEQ **(Bueno-Galdo, 1991)**, shows clearly that the parameter NSTPS affects dramatically the outcome of the simulation. The peak of the response and the time to peak of the response tend to increase as the value of NSTPS increases. Notice that for NSTPS = 1 the outflow hydrograph cuts the inflow hydrograph at the peak of the outflow hydrograph (because in this case the routing is identical to level pool routing). For this experiment it seems that a value of NSTPS = 3 fits best the standard solution, albeit the HEC-HMS result lags slightly with respect toit.

The several parameters defining the columns of Table 3 are described in detail below.

Columna I Tp, time to peak of the inflow hydrograph
Columna II Δt, time step of the HEC-HMSsimulation
Columna III T'p, time to peak of the outflow hydrograph as simulated by HEC-HMS, where the value of NSTPS isoptimal;
Columna IV NSTPSc = (T'p – Tp)Δt value of NSTPS that one would obtain by the peak travel time (from inflow cross section to outflow cross section) byΔt;
Columna V NSTPSv, value of NSTPS that one would obtain by dividing the reach length by the peak outflow water velocity multiplied by.Δt;
Columna VI NSTPSm, the value of NSTPS found experimentally;
Columna VII NSTPSp, the value of NSTPS given by the formula proposed below

NSTPSP = n +1 if T'p/Tp >n+.2

NSTPSP =n if T'h/Tp < n+.2,

where n is any integer.

Conclusions

The preliminary results of the investigation presented in this paper tends to suggest that the quanta parameter NSTPS used in the application of the modified Puls method #2 to the HEC-HMS simulation of a floodwave propagation depend exclusively on the peak delay factor T'p/Tp. If this is the case, the parameter is not only a characteristic of the macro and microgeometry of the river reach, but it depends also on the characteristics of the inflow hydrograph. This means that NSTPS is different for different flood waves. If the floodwave has a large value of Tp then NSTPS should have the value of 1. If Tp is small, NSTPS should have values larger than 1, according to the outcome of Equation (5). Since most floodwaves have several peaks, a choice of the value of NSTPS can be made to simulate more accurately single peaks or overall trends. The arbitrariness by which this process is clouded may constitute a major handicap for the use of the modified Puls method #2 in the HEC-HMS simulation of hydraulically meaningful problems.

Table 3 . Results of Numerical Experiments

Tp	ΔT	**T'p**	**NSTPSv**	**NSTPSv**	**NSTPSm**	**T'p/Tp**	NSTPSp
1.00	15	3.5	10	17	3.00	3.50	4.00
2.00	15	4.50	10	16	3.00	2.25	3.00
	30	4.50	5	8	2.00	2.25	3.00
4.004	15	6.75	11	16	2.00	1.63	2.00
	30	6.50	5	8	2.00	1.50	2.00
	60	6.00	2	4	2.00	1.34	2.00
8.00	15	10.75	11	15	2.00	1.34	2.00
	30	10.30	5	8	2.00	1.28	2.00
	60	11.00	3	4	2.00	1.38	2.00
	120	10.00	1	2	2.00	1.25	2.00

16.00	15	18.50	10	15	2.00	1.15	1.00
	30	18.58	5	8	2.00	1.15	1.00
	60	19.00	3	4	2.00	1.19	1.00
	120	18.00	1	2	2.00	1.13	1.00
	240	20.00	1	1	1.00	1.25	1.00

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