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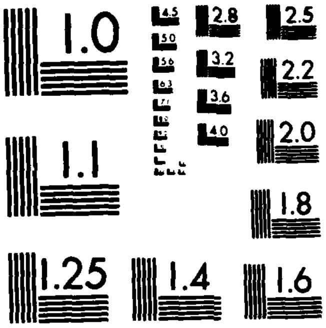

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FLOOD INUNDATION MODELLING USING MILHY

First Interim Report

by

M.G. Anderson and [illegible] Singleton

November 1987

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Dr M.G. Anderson

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Flood inundation modelling using MILHY

M.G. Anderson and L. Singleton

Contents

1. Objectives

The objectives for the work reported here are:

(i) the inclusion and evaluation of alternative geometric definitions for channel segment inter-flow;

(ii) the evaluation of the legitimacy of routing channel segments separately downstream, to better model in and out of bank flows;

(iii) the establishment of a working Fulda data set for evaluation of out-of-bank conveyance schemes;

(iv) the installation of SUN Work Station and transfer of HYMO to a UNIX operating system.

These objectives represent the continuation into the third year of the project stated under DAJA45-85-C-0011.

2. Work undertaken in the 6 months period to December 1984

2.1 Out-of-bank flood conveyance

Following the March 1987 report, work has continued on the research of improved out-of-bank flow estimation procedures. As suggested in the last report, work on the redefinition of channel geometry to include turbulent exchange between segments has been completed - section 2.2. The concept of the separation of segmented flow has now been extended to the flood routing models, to better model the discrete paths taken by out-of-bank flow.

2.2 Redefinition of channel geometry to incorporate in-and-out of bank flow

In the flow rating curves generated by the Manning equation, there is no provision for any interaction between computations undertaken in the specified channel sections, i.e. the channel cross sectional sub-areas (segments) are assumed independent in terms of the hydraulic calculations. Significant errors can occur in the discharge estimation, which is of particular importance at the point of flood plain inundation.

Chow (1959) suggested that redefinition of the area and wetted perimeter terms may be undertaken to provide an improved discharge estimate based on the Manning Formula. The four methods described in Table 2.1 have been incorporated into the CMPRC subroutine of MILHY, using the definition diagram, figure
2.1.

The trials were repeated with the fictional algorithm, equation 2.1, which assumes friction varies as a function of stage, removed:

$$n' = n - 0.0025 \text{ Area/wetted perimeter} \qquad 2.1$$

The results are shown in Tables 2.2 to 2.10. Table 2.10 compares results <u>with</u> the Manning adjustment (equation 2.1). Note that:

a = flood plane width : channel width ratio
b = ratio of flood plain : channel friction 'n' values

From these results it can be concluded that:-

(i) The four alternative geometric methods do make a significant impact on flow rates. Most produce lower flow rates indicating that some allowance for interaction in the flow between segments has been made.

(ii) The flood plain/channel width and friction ratios have an impact on flow rates. It would seem, therefore, that the optimum method depends on the individual geometry patterns.

(iii) The Manning 'n' adjustment, Table 2.10, produces flow rates varying up to 40% from computations without the adjustment, across all geometries, indicating the sensitivity of the Manning equation to n.

2.3 Application to hydrograph generation

As a preliminary study, the four alternative methods have each been incorporated into HYMO2 to generate a hydrograph. With a precipitation storm of 2" in 0.5 hours, in order to exceed bankfull conditions, the hydrograph was routed through a subcatchment, using each of the four methods.

Figure 2.2 shows the outflow hydrograph for HYMO2 and method 1, whilst figure 2.3 illustrates methods 3 amd 4, where in both cases a = 10, b = 4.

When the flood plain channel friction ratios were at their greatest, peak discharge values showed a variation of up to 25%.

The results demonstrate that segment turbulent exchange is significant and therefore how critical the rating curve generation method is, especially if flood inundation areas are to be predicted with acceptable accuracy. In figure 2.2, a discrepancy of $10m^3s^{-1}$, indicates an elevation difference in a typical German catchment of 15 cm. The optimum scheme for individual valley geometry and accuracy of inundation predictions needs to be investigated. For the present, based on Knight and Hamed's (1984) results, from a hardware application, method 3 seems the most appropriate and will be applied here.

2.4 Separate routing of channel and flood plain water

After consultation with HALCROW it became clear there is a discrepancy between the segmentation of water in the rating curve generation scheme and the lumping of all water in the routing routine. In a naturally meandering channel, there is a tendency for flood plain water to "short-circuit" along a more direct route (Fread, 1976). Most routing models treat the flood plain as stores of water only, or as in the HEC model generate an average routing length based on the proportion of flow on the flood plains and in the channel.

At the present time, the ROUTE subroutine is being investigated in order to treat each segment separately, coincident with the Chow methods, acknowledging the turbulent transfer between segments illustrated in figure 2.4. The PRTHY subroutine has been rewritten enabling it to recall a previously computed rating curve and thereby convert a discharge hydrograph to a stage hydrograph., A series of trials are now underway to pinpoint an acceptable discrepancy in stage levels between segments at any time interval. It is envisaged that the routing method will involve several "balancing checks" between stations to prevent the build up of water in any segment at any time.

Initial results, figure 2.5, illustrate the necessity of this investigation, where the outflow hydrograph for the same reach routed with the segments together (1) or divorced (2), are dramatically different. Figure 2.6 illustrates the same reach, routed with the flood plain segments, lengths reduced by 5% (1) and 30% (2). Figures 2.7 and 2.8 show a different rainfall storm, routed through the same reach. The necessity for the separation of flood plain flows are therefore clearly dependent on the degree of "short circuiting" taking place.

2.5 Establishment of The Fulda Data Set

The Fulda River data set has been established after a visit to West Germany earlier this year, figure 2.9. Data was collected from the Water Authority, Wasserwirtschaftsamt, Fulda, and the Meteorolgy Office, Deutcher Wetterdienst Zentralamt, Offenbach, Frankfurt.

For the eight gauging stations marked, the following data was collected:

- cross-sectional technical drawing of gauging site
- stage/discharge relationship
- stage hydrographs for six separate storms, recording of one week each

During the visits, the gauging sites were visited and valley cross-sectional sketches made, valley photographs taken, and Manning's 'n' estimates made.

Meteorological data includes:

- daily precipitation values for the period three weeks proceeding and the week of the stage hydrograph records
- continuously recorded precipitation for two stations. Bad Hersfeld and Kunzell-Dietershausen for five of the six storms identified
- daily maximum and minimum temperatures and snowfall records for one storm

Additional data already available consists of:

- topographic maps
- soil classification maps
- flood inundation maps

A full copy of this raw data has been forwarded to Environmental Laboratory, W.E.S., Vicksburg. Mississippi.

The Fulda data set is now running with the completion of:-

1) digitising stage hydrographs to 15 minute interval

2) parametric regression of the stage/discharge relationship and conversion of the stage hydrographs to discharge values

3) combination of valley and gauge site cross-sections with topographic map information to give cross-sectional data for direct input into HYMO

4) identification of sub-catchment and determination of the channel network in a logical manner for the routing procedures

5) identification of the proportional major soil groups for each subcatchment

6) computation of weighted, Theisson, precipitation inputs for each subcatchment, for each of the identified storms, figure 2.10

7) construction of 5 km, radar grid and preparation of precipitation data for moving storm analysis

3. The SUN Work Station

A considerable advance in the computing application of HYMO has been made with the transfer of all work to a SUN station, from a HONEYWELL mainframe. The 3 MIPS work station will speed the development of individual subroutines, and the numerous applications required for their validation.

Transfer to a UNIX operating system has involved minimal changes to the inherited Fortran code, and HYMO 2 and 3 are now up and running. The full Fulda data set has also been transferred, although it will probably be two months before the full potential of this machine is utilised.

4. Research plan for the next six months

(1) Continuing familiarization with the SUN work station.

(2) Determination of the acceptable discrepancy in water surface elevation between independently routed segments, using a hypothetical reach. This will be used to establish the intermediate reach routing interval, at which point transfer of water between segments will occur.

(3) The routing (ROUTE) and travel timetable generation (CMPTT) subroutines will be rewritten to incorporate the option of discrete segment routing.

(4) Sensitivity analysis of ROUTE, CMPTT abd CMPRC subroutines, combining the segmented routing and rating curve generation schemes. Thresholds in stream sinuosity, flood plain/channel geometry, and frictional 'n' values, will be investigated using the Fulda catchment data.

It is anticipated that by the 1 March 1988, the HYMO model will incorporate:

i) the five alternative cross-sectional geometry definitions to incorporate segment turbulent exchange

ii) discrete segment routing

iii) conversion of discharge hydrographs to stage hydrographs

The most appropriate technique (of, for example, cross sectional geometry) will wherever possible be selected by the program using the thresholds which will have been previously determined in the sensitivity analysis. The operator will have the option of selection but will be expected to specify the required accuracy of output data required.

A prototype of this model will be presented during a visit to Vicksburg in late March 1988.

References

Chow, V.T. (1959). Open Channel Hydraulics. McGraw-Hill.

Fread, D.L. (1976). Flood routing in meandering rivers with flood plains. Article in "Rivers" 1976. Symposium on Inland Waterways for Navigation Flood Control and Water Diversions. Proc. A,M. Soc. Civ. Engrs., Waterways, Harbours Coastal Engr. Div. pp.16-35.

Knight, D.W. and Hamed, M.E. (1984). Boundary shear in symmetrical compound channels. J. Hyd. Eng., ASCE 110, No. 10, pp.1412-1430.

Table 2.1

Alternative geometric definitions to incorporate segment intractions
Chow (1959)

Method	Flood Plain		Main Channel	
	Area	Wetted Perimeter	Area	Wetted Perimeter
1	(H-h) (B-b)	B-b + H-h	2bH	2b + 2h
2	(H-h) (B-b)	B-b + 2(H-h)	2bH	2b + 2H
3	(H-h) (B-b/2)	B-b + H-h)	b(H+h)	2b + 2h
4	(H-h) (B-b/2)	B-b + H-h	b(H+h)	2b + 2h + $2((H-h)^2+b^2)^{1/2}$

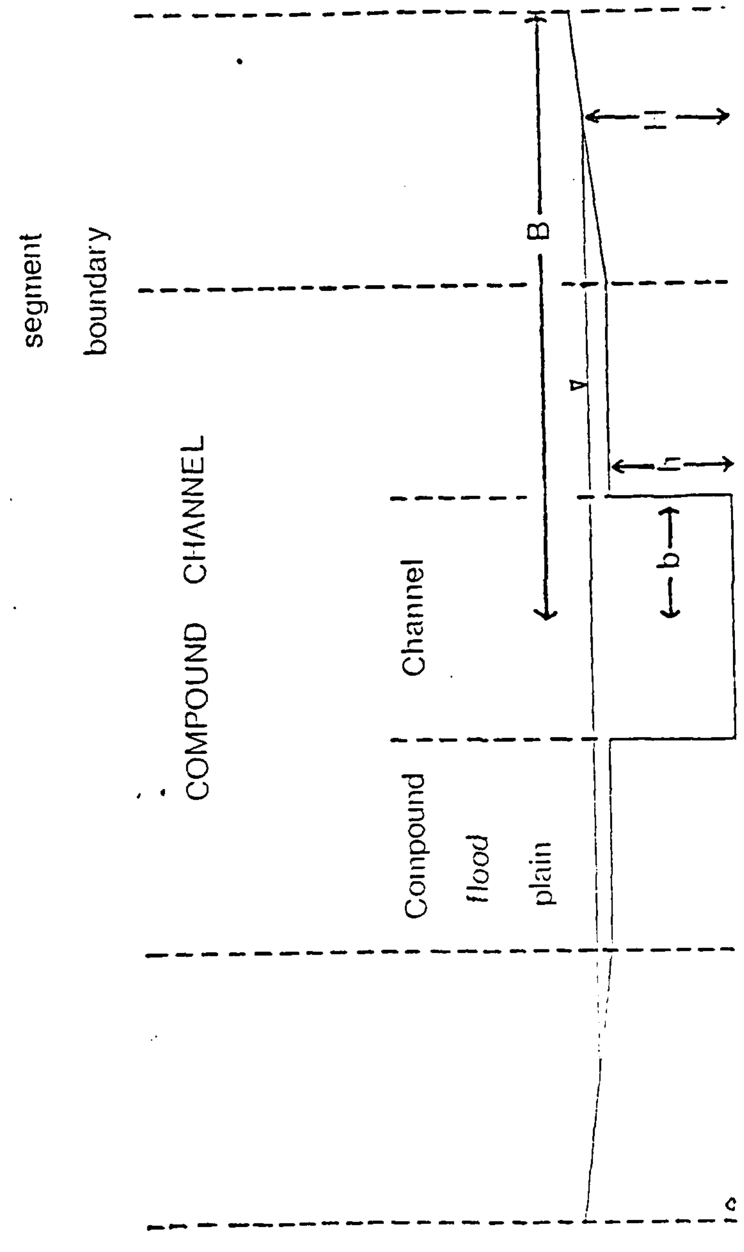

Fig. 2.1: Cross-sectional structure for rating curve computation

Table 2.2

DISCHARGE (cfs)

(Error calculated as % of manual estimate)

Water elevation above bankfull (feet)	Manning Manual Calculation	HYMO 2		HYMO 3 Method 1		HYMO 3 Method 2		HYMO 3 Method 3		HYMO 3 Method 4	
			%error		%error		%error		%error		%erro
0.21	417.2	423.9	+1.6	428.6	+2.7	428.6	+2.7	413.8	-0.8	296.5	-28.
0.63	617.2	624.0	+1.1	617.9	+0.1	617.2	0	582.0	-5.7	462.4	-25.
1.05	901.2	913.1	+1.3	892.0	-1.0	889.1	-1.3	842.6	-6.5	721.0	-20
1.47	1254.4	1276.2	+1.7	1235.3	-1.5	1227.9	-2.1	1178.2	-6.1	1055.0	-15.
1.89	1669.0	1705.3	+2.2	1639.1	-1.8	1624.6	-2.7	1579.5	-5.4	1455.1	-12.
2.32	2150.6	2195.2	+2.1	2097.6	-2.5	2072.9	-3.6	2040.0	-5.1	1914.8	-11.
Average error			+1.7		-0.7		-1.2		-4.9		-19

- Without Mannings 'n' correction factor
- a = 4
- b = 1

Table 2.3

DISCHARGE (cfs)

(Error calculated as % of manual estimate)

Water elevation above bankful 1 (feet)	Manning Manual Calculation	HYMO 2		HYMO 3							
				Method 1		Method 2		Method 3		Method	
			%error		%error		%error		%error		%erro
0.21	404.0	414.7	+2.7	419.4	+3.8	419.4	+3.8	403.5	-0.1	286.3	-29.
0.63	535.3	550.7	+2.9	544.9	+1.8	544.5	+1.7	500.8	-6.5	381.1	-28.
1.05	710.0	733.4	+3.3	713.8	+0.5	712.4	+0.3	644.3	-9.3	522.7	-26.
1.47	920.8	955.4	+3.8	918.3	-0.3	914.6	-0.7	825.3	-10.4	702.2	-23.
1.89	1163.4	1212.6	+4.2	1153.8	-0.8	1146.6	-1.4	1039.3	-10.7	915.0	-21.
2.32	1441.8	1502.3	+4.2	1417.5	-1.7	1405.2	-2.5	1283.1	-11.0	1157.9	-19.
Average error			+3.5		+0.6		+0.2		-8.0		-24.

- Without Mannings 'n' correction factor
- n = 4
- b = 2

Table 2.4

DISCHARGE (cfs)

(Error calculated as % of manual estimate)

Water elevation above bankfull (feet)	Manning Manual Calculation	HYMO 2		HYMO 3							
				Method 1		Method 2		Method 3		Method 4	
			%error		%error		%error		%error		%error
0.21	399.6	411.7	+3.0	416.4	+4.2	416.4	+4.2	400.1	+0.1	282.9	-29.2
0.63	508.0	526.2	+3.6	520.6	+2.5	520.3	+2.4	473.7	-6.8	354.0	-30.3
1.05	646.4	673.5	+4.2	654.4	+1.2	653.5	+1.1	578.1	-10.6	456.5	-29.4
1.47	89.6	848.5	+4.8	812.6	+0.4	810.1	+0.1	707.7	-12.6	584.6	-27.8
1.89	995.0	1048.4	+5.4	992.1	-0.3	987.3	-0.8	859.3	-13.6	734.9	-26.1
2.32	1205.6	1271.3	+5.5	1190.8	-1.2	1182.6	-1.9	1030.8	-14.5	905.5	-24.9
Average error			+4.4		+1.1		+0.9		-9.7		-28.0

- Without Manning's 'n' correction factor
- [illegible] = 4
- [illegible] = 3

Table 2.5

DISCHARGE (cfs)

(Error calculated as % of manual estimate)

Water elevation above bankfull (feet)	Manning Manual Calculation	HYMO 2		HYMO 3							
				Method 1		Method 2		Method 3		Method 4	
			%error		%error		%error		%error		%error
0.21	397.4	410.1	+3.2	414.8	+4.4	414.8	+4.4	398.4	+0.3	281.2	-29.3
0.63	494.3	514.0	+4.0	508.4	+2.9	508.2	+2.8	460.1	-6.9	340.5	-31.1
1.05	614.6	643.6	+4.7	624.7	+1.6	624.0	+1.5	545.1	-11.3	423.5	-31.1
1.47	754.0	795.0	+5.4	759.8	+0.8	757.9	+0.5	648.9	-13.9	525.8	-30.3
1.89	910.8	966.2	+6.1	911.2	0.0	907.6	-0.5	769.3	-15.5	644.9	-29.2
2.32	1087.4	1155.8	+6.3	1077.5	-0.9	1071.3	-1.5	904.6	-16.8	779.4	-28.3
Average error			+5.0		+1.5		+1.2		-10.7		-29.9

- Without Mannings 'n' correction factor
- a = 4
- b = 4

Table 2.6

DISCHARGE (cfs)

(Error calculated as % of manual estimate)

Water elevation above bankfull (feet)	Manning Manual Calculation	HYMO 2		HYMO 3							
				Method 1		Method 2		Method 3		Method 4	
			%error		%error		%error		%error		%error
0.21	437.1	436.2	-.02	488.5	-0.8	433.5	-0.8	419.5	-4.0	309.9	-2.9
0.63	821.4	826.4	+0.6	813.6	-1.0	812.9	-1.0	779.7	-5.1	668.3	-18.6
1.05	1419.4	1433.4	+1.0	1406.3	-0.9	1403.3	-1.1	1359.8	-4.2	1246.9	-12.2
1.47	2192.4	2219.4	+1.2	2173.4	-0.9	2165.9	-1.2	2120.0	-3.3	2005.9	-8.5
1.89	3120.2	3164.6	+1.4	3094.4	-0.8	3079.4	-1.3	3039.1	-2.6	2924.2	-6.3
2.32	42162.2	4256.1	+1.0	4155.7	-1.4	4130.0	-2.0	4103.0	-2.7	3987.6	-5.4
Average error			+0.8		-1.0		-1.2		-3.7		-9.0

- Without Manning's 'n' correction factor
- a = 10
- b = 1

Table 2.7

DISCHARGE (cfs)

(Error calculated as % of manual estimate)

Water elevation above bankfull (feet)	Manning Manual Calculation	HYMO 2		HYMO 3							
				Method 1		Method 2		Method 3		Method 4	
			%error		%error		%error		%error		%error
0.21	413.9	413.0	-0.2	410.3	-0.9	410.3	-0.9	395.3	-4.5	285.8	-3.1
0.63	637.4	641.8	+0.7	629.3	-1.3	628.9	-1.3	587.7	-7.8	476.2	-25.3
1.05	969.2	981.2	+1.2	955.6	-1.4	954.1	-1.6	890.1	-8.2	777.1	-19.8
1.47	1389.8	1412.0	+1.6	1369.9	-1.4	1366.1	-1.7	1285.5	-7.7	1168.4	-15.9
1.89	1889.0	1924.5	+1.9	1861.9	-1.4	1854.4	-1.8	1754.5	-7.1	1639.6	-13.2
2.32	2474.6	2512.1	+1.5	2424.8	-2.0	2411.9	-2.5	2299.0	-7.1	2183.6	-11.8
Average error			1.1		-1.4		-1.6		-7.1		-14.9

- Without Mannings 'n' correction factor
- a = 10
- b = 2

Table 2.8

DISCHARGE (cfs)

(Error calculated as % of manual estimate)

Water elevation above bankfull (feet)	Manning Manual Calculation	HYMO 2		HYMO 3							
				Method 1		Method 2		Method 3		Method 4	
			%error		%error		%error		%error		%error
0.21	406.2	405.2	-0.2	402.6	-0.9	402.6	-0.9	387.3	-4.7	277.7	-31.6
0.63	576.1	580.3	+0.7	567.9	-1.4	567.6	-1.5	523.7	-9.1	412.2	-28.5
1.05	819.2	830.3	+1.4	805.3	-1.7	804.3	-1.8	733.5	-10.5	620.5	-24.3
1.47	1122.2	1142.9	+1.8	1102.1	-1.8	1099.5	-2.0	1003.4	-10.6	889.3	-20.8
1.89	1478.7	1511.1	+2.4	1451.1	-1.9	1446.1	-2.2	1326.4	-10.3	1211.4	-18.1
2.32	1894.0	1930.7	+1.9	1847.8	-2.4	1839.3	-2.9	1697.7	-10.4	1582.3	-16.5
Average error			+1.3		-1.7		-1.9		-9.3		-23.

- Without Mannings 'n' correction factor
- a = 10
- b = 3

Table 2.9

DISCHARGE (cfs)

(Error calculated as % of manual estimate)

Water elevation above bankfull (feet)	Manning Manual Calculation	HYMO 2		HYMO 3							
				Method 1		Method 2		Method 3		Method 4	
			%error		%error		%error		%error		%error
0.21	402.4	401.4	-0.3	398.7	-0.9	398.7	-0.9	383.2	-4.8	273.7	-32.0
0.63	545.4	549.5	+0.8	537.2	-1.5	537.0	-1.5	491.6	-9.9	380.2	-30.3
1.05	744.2	755.0	+1.5	730.2	-1.9	729.2	-2.0	655.2	-12.0	542.2	-27.1
1.47	988.6	1008.3	+2.0	968.1	-2.1	966.2	-2.3	863.8	-12.6	749.7	-24.2
1.89	1273.6	1304.4	+2.4	1245.7	-2.2	1241.9	-2.5	1112.3	-12.7	997.4	-23.[illegible]
2.32	1603.8	1640.1	+2.3	1559.4	-2.8	1552.9	-3.2	1397.0	-12.9	1281.6	-20.1
Average error			+1.45		-1.9		-2.1		-10.8		-26.[illegible]

- Without Mannings 'n' correction factor
- a = 10
- b = 4

Table 2.10

Average errors (%) for water surface elevation 953.21-955.32

Summary		HYMO2		Method 1		Method 2		Method 3		Method 4	
		MANNINGS CORRECTION FACTOR									
		Y	N	Y	N	Y	N	Y	N	Y	N
4	1	+35.6	+1.7	+29.2	-0.7	+28.0	-1.2	+19.5	-4.9	-4.5	-1.9
4	2	+40.7	+8.5	+31.9	+0.6	+31.4	+0.2	_15.4	-8.0	-14.1	-24.9
4	3	+42.8	+4.4	+33.0	+1.1	+32.7	+0.9	+13.2	-9.7	-18.5	-28.0
4	4	+47.0	+5.0	+36.3	+1.5	+36.1	+1.2	+14.1	-10.7	-19.5	-29.9
10	1	+26.9	+0.8	+22.6	-1.0	+22.2	-1.2	+17.1	-3.7	+1.3	-9.0
10	2	+28.1	+1.1	-22.0	1.4	+21.8	-1.6	+11.4	-7.1	-10.0	-14.9
10	3	+30.9	+1.3	+23.5	-1.7	+25.1	-1.9	+9.8	-9.3	-14.5	-23.3
10	4	+33.2	+1.5	+24.9	-1.9	+24.8	-2.1	+9.1	-10.8	-17.2	-26.2
Average error[a]		+35.7	+2.4	+27.9	0.4	+27.8	-0.7	+13.7	-8.0	-12.1	-19.8

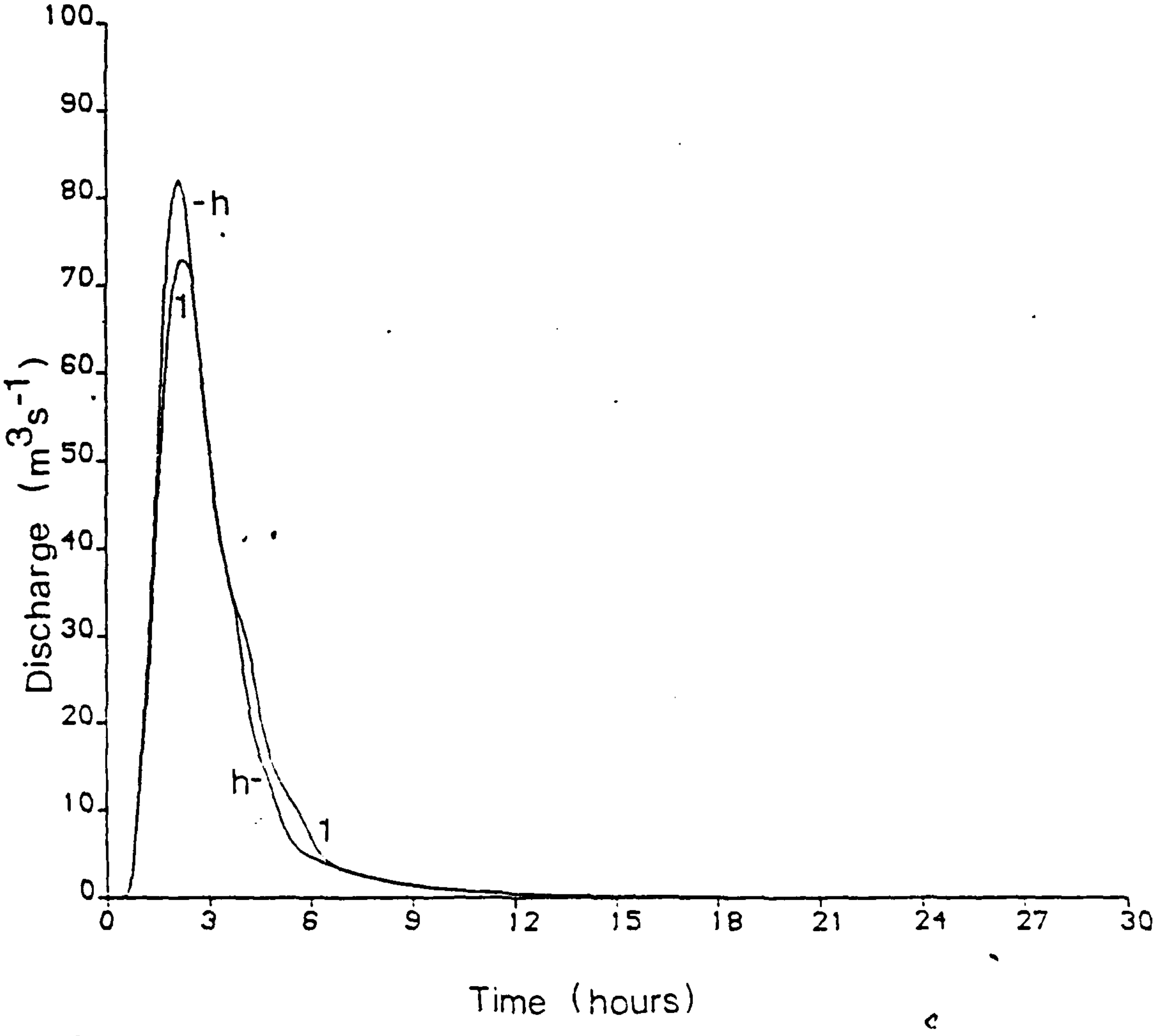

Fig. 2.2: Comparison of channel geometry redefinition
methods to incorporate inter-segment flow
h - HYMO2 method
1 - Chow method 1

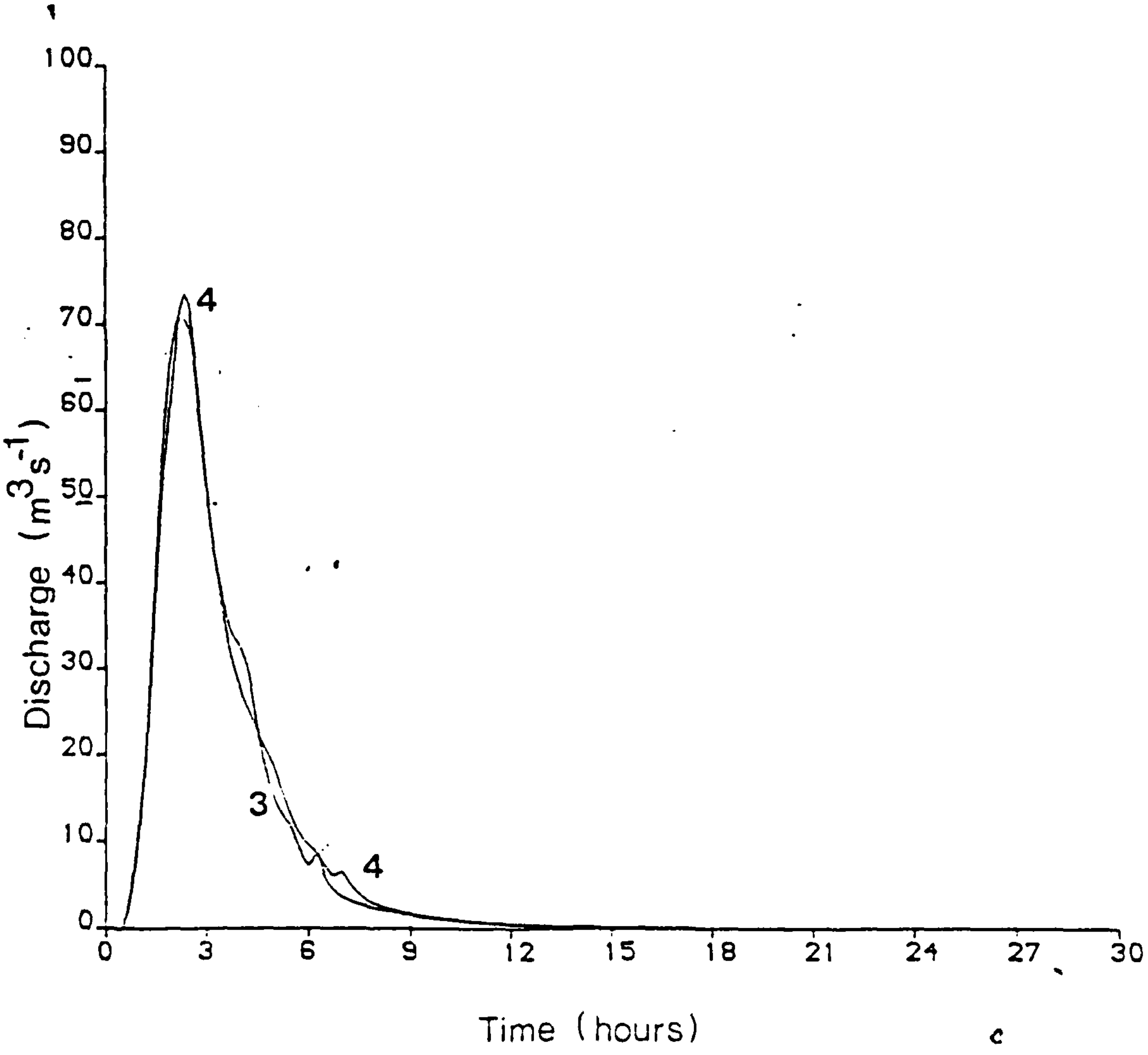

Fig. 2.3: Comparison of channel geometry redefinition methods to incorporate inter-segment flow
3 - Chow method 3
4 - Chow method 4

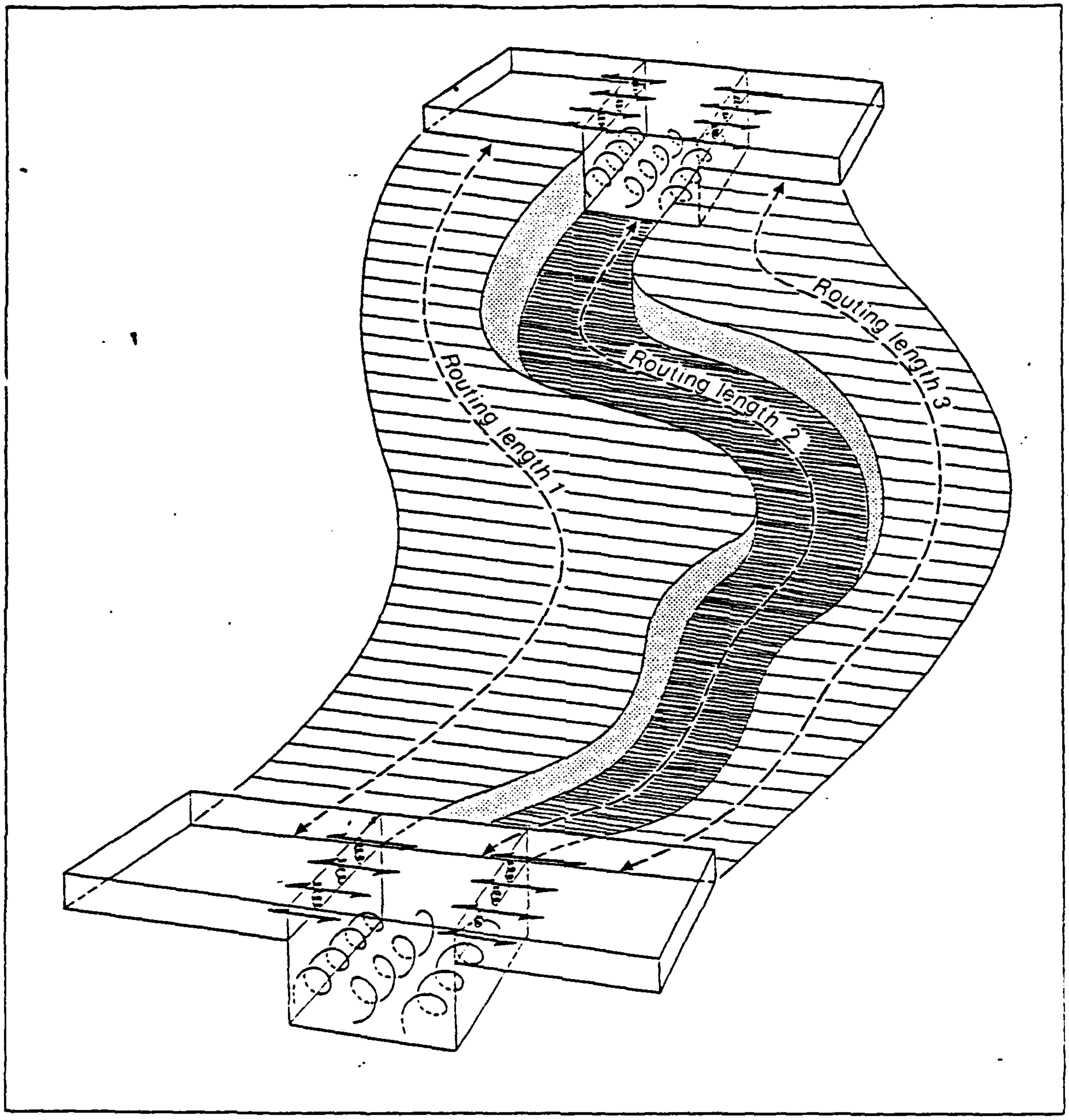

Fig. 2.4: Schematic representation of discrete segment routing paths incorporating segment turbulent exchange at gauging sites

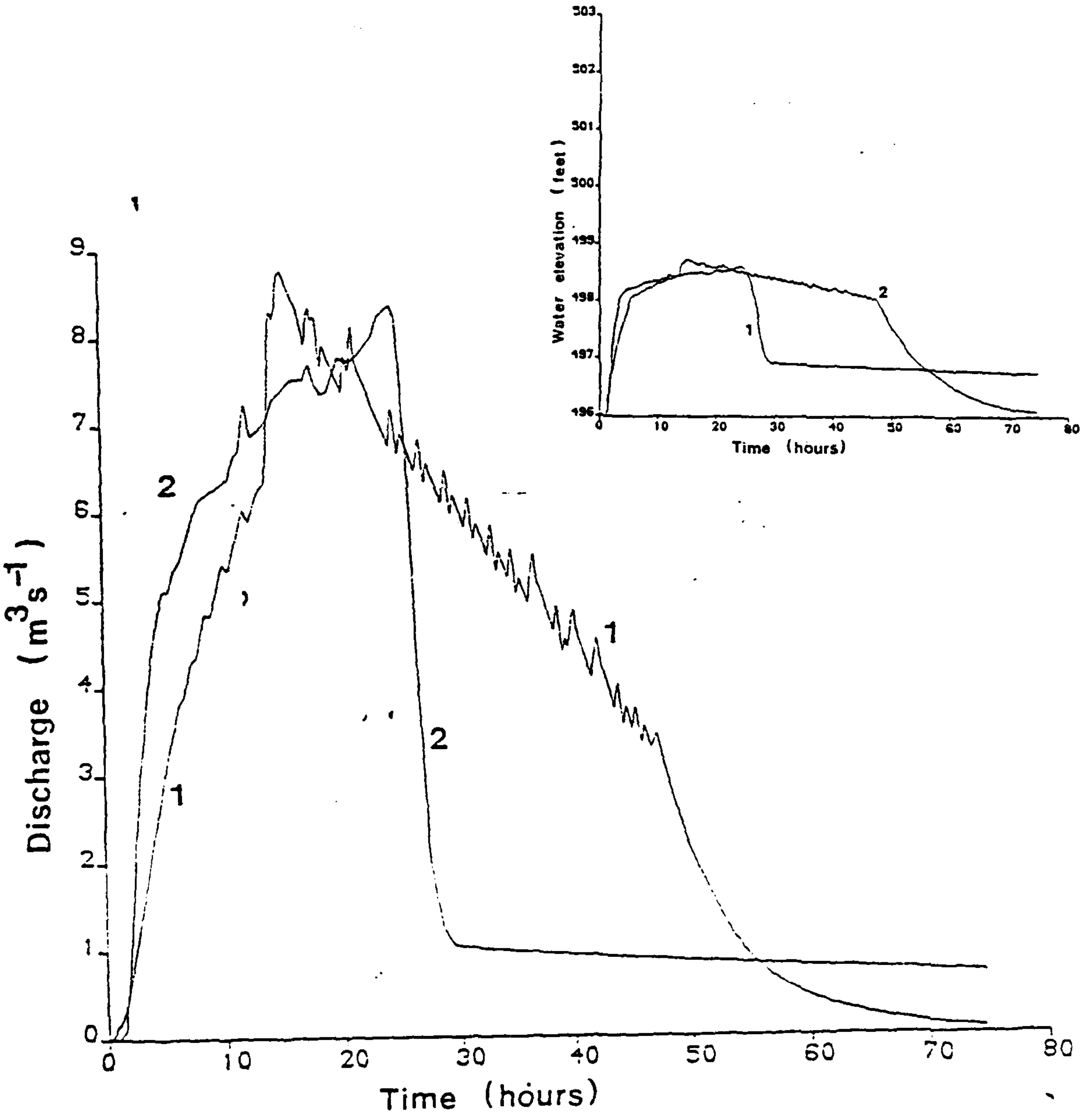

Fig. 2.5: Comparison of aggregate and discrete routing methods
1. Aggregate routed discharge hydrograph
2. Discrete routed discharge hydrograph
Inset: stage hydrographs for the same outflow hydrographs

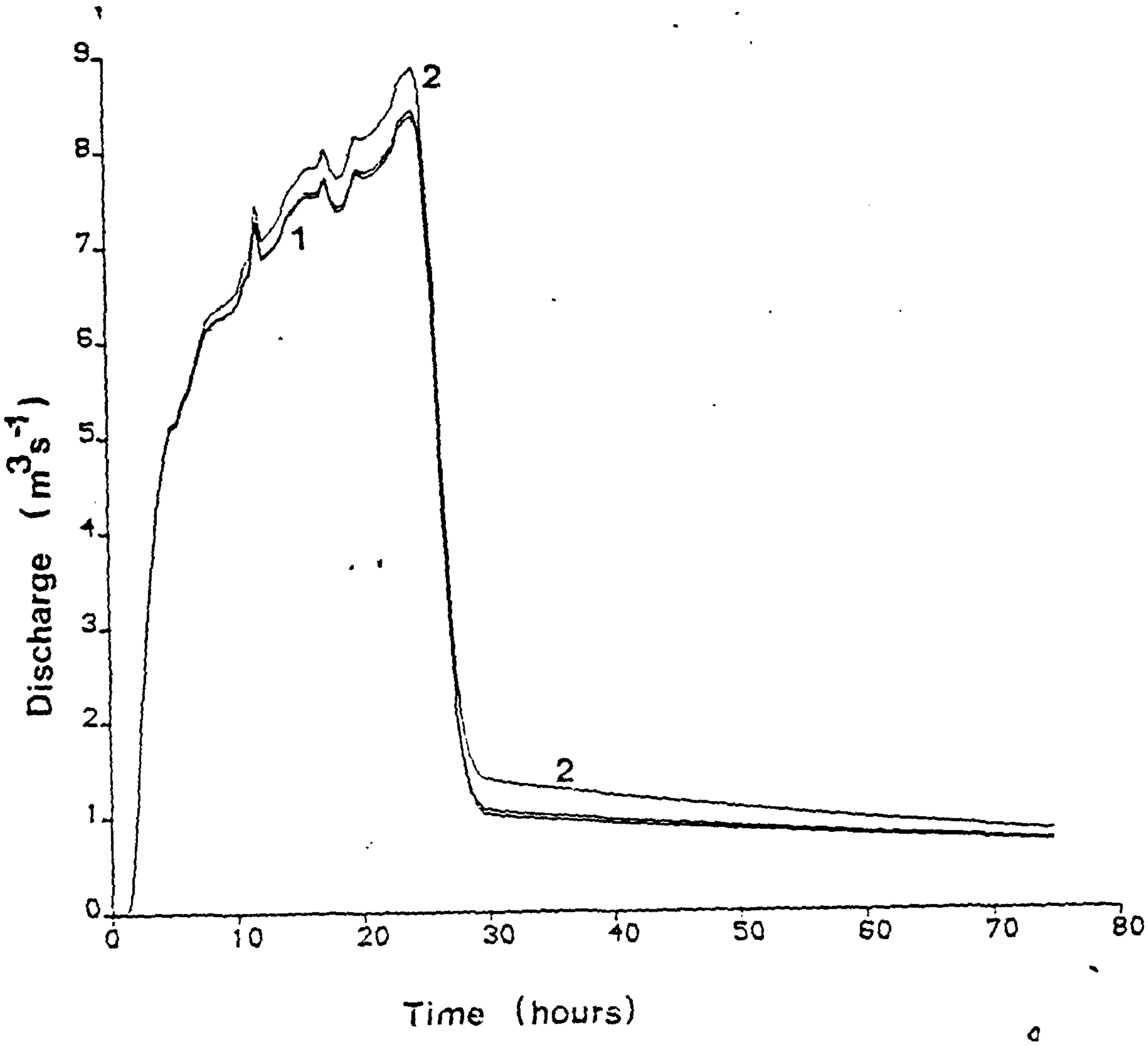

Fig. 2.6: The impact of the short-circuiting of flood plain water.
1 - Flood plain routing lengths the same, and 5% less than, channel routing length.
2 - Flood plain routing length, 30% less than channel routing length.

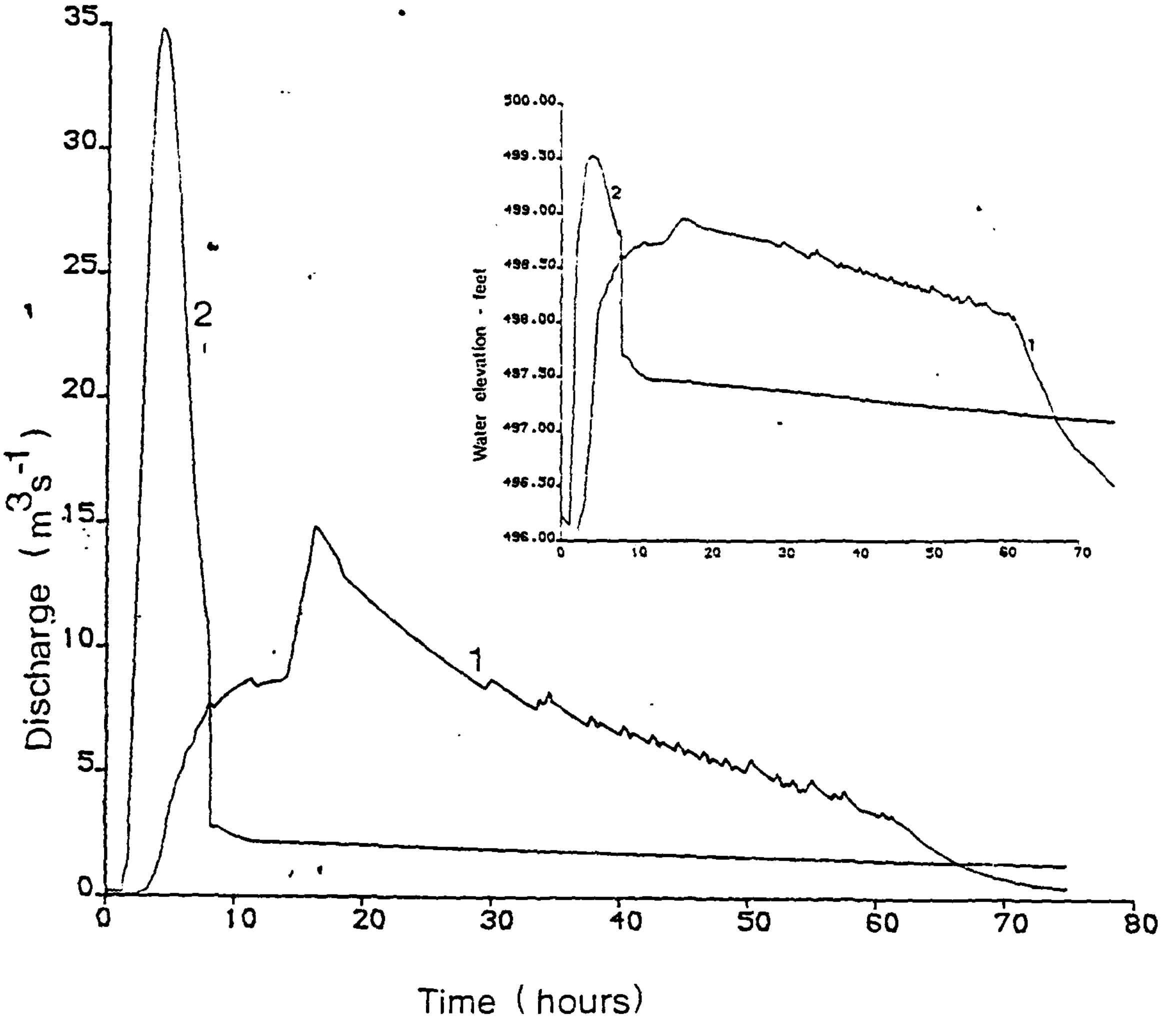

Fig. 2.7 Comparison of aggregate (1) and discrete (2) routing methods of 2" in 1 hour storm over subcatchment 406

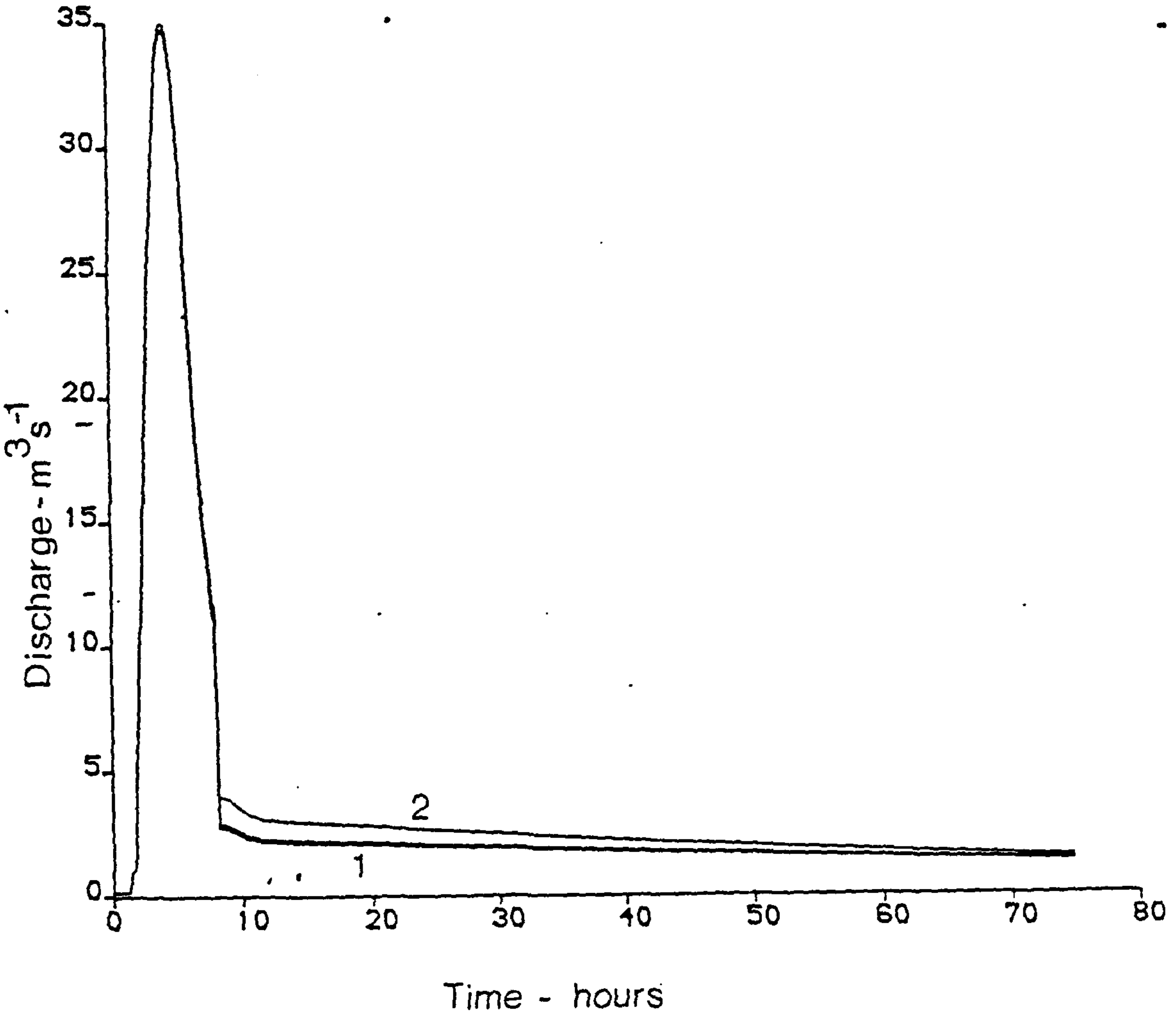

Fig. 2.8: Impact of the short-circuiting of 2" in 1 hour storm

(1) Flood plain routing reach length the same, or 5% less than the channel routing reach length

(2) Flood plain routing reach length 30% less than the channel routing reach length

Fulda Catchment, West Germany
containing the Haune sub-catchment.

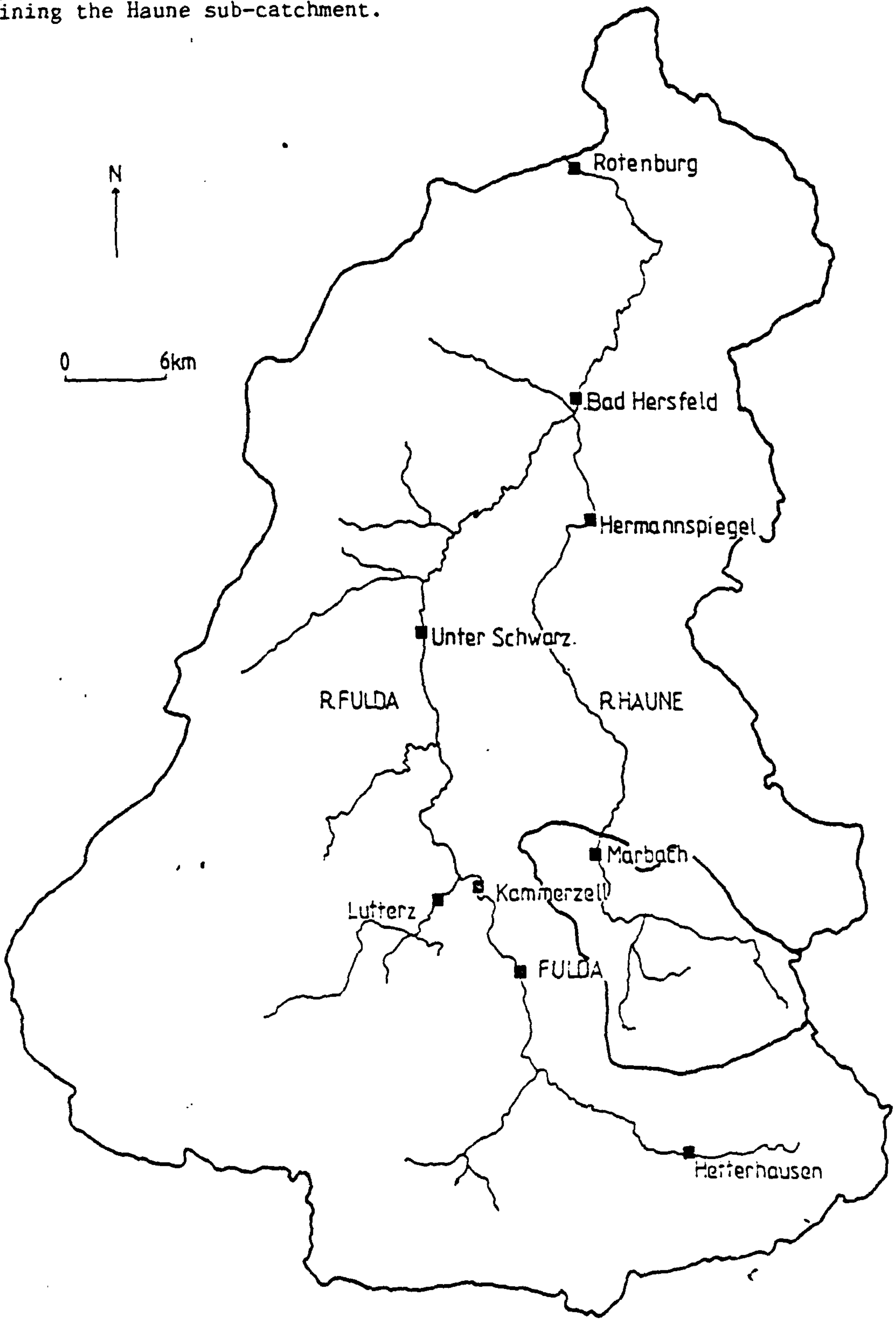

Fig. 2.9: Fulda catchment

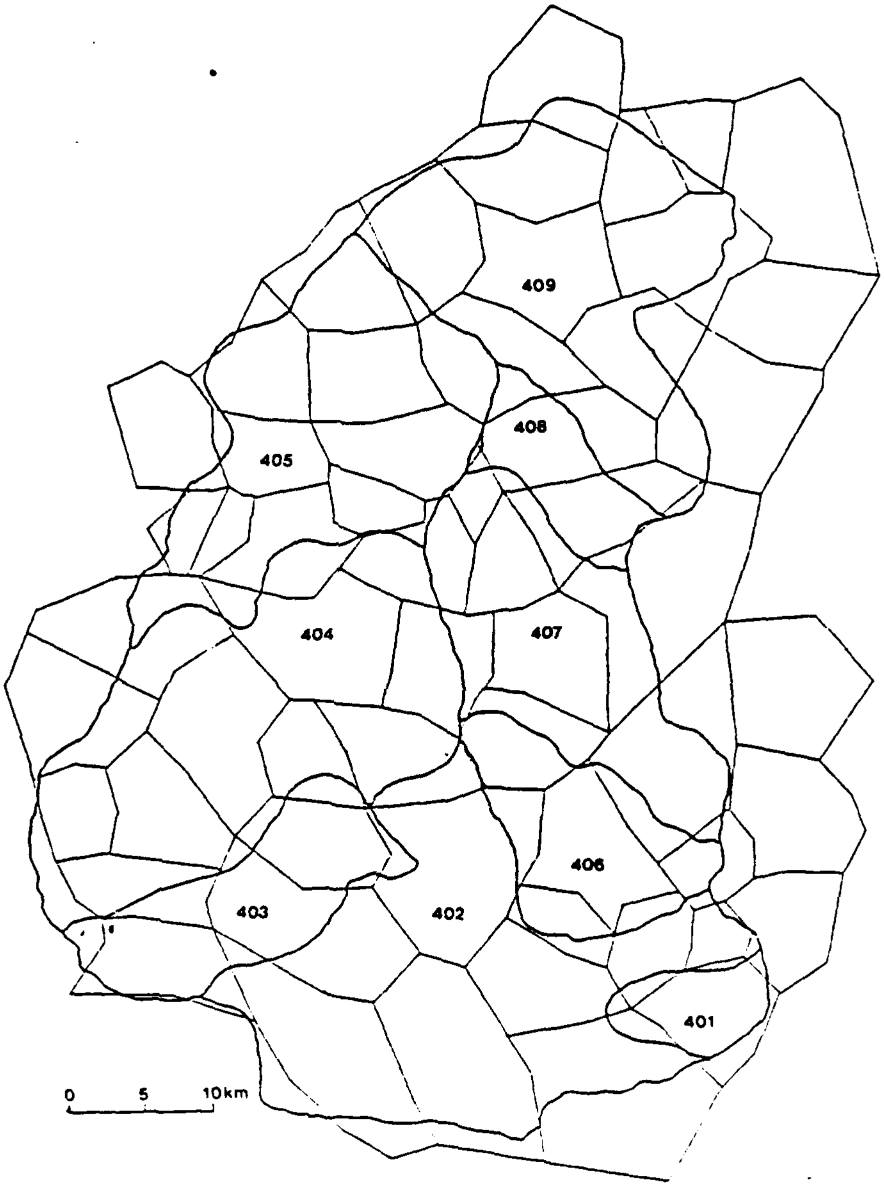

Fig. 2.10: Fulda catchment illustrating weighted Theisson Polygons for the stations for which daily precipitation data is available

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