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Mean Instantaneous Unit Hydrographs of Random Channel Networks

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Abstract

The IUH (instantaneous unit hydrograph) of a channel network is still used as a component in rainfall runoff modeling. There are two approaches to determine the IUH in relation to geomorphological basin characteristics. One of these approaches is Rodriguez-Iturbe and Valdes, approach known also as Exponentially Distributed GIUH (geomorphologic instantaneous unit hydrograph); the alternate approach is that of Gupta and Waymire, known also as Linear Routing GIUH in the literature. A model developed in a previous study which relates the geomorphological IUH of one of these approaches to the diffusive approximation of the momentum equation is used for obtaining the IUH s the networks will produce. Also the concept of junction configuration is made use of. A simulation study has been carried out for 6-source channel networks with a certain junction configuration. Here the aim is to see the distribution of the IUH s which these networks produce. The relationships between mean IUH properties and non-dimensionalized mean interior link length of the network are obtained for a Froude number of 0.2 and for all possible junction configurations of 3, 4, 5, 6-source channel networks. The average relationships between IUH properties and dimensionless mean interior link length are obtained for 3-8 source channel networks.

Key Words: mean instantaneous unit hydrograph, river network, topology, dimensionless response.

Rastgele Akarsu Ağlarının Ortalama Anlık Birim Hidrografları

Özet

Bir akarsu ağının ABH (anlık birim hidrograf)ı halen yağış akış modellemesinde bir bileşen olarak kullanılmaktadır. ABHı jeomorfolojik havza karakteristiklerine bağlı olarak belirlemek üzere iki yöntem bulunmaktadır. Bu yöntemlerin birisi aynı zamanda literatürde Üstel Dağılmış JABH (jeomorfolojik anlık birim hidrograf) olarak ta bilinen Rodriguez-Iturbe ve Valdes yöntemidir; diğer yöntem ise Doğrusal Öteleme JABH olarak ta bilinen Gupta ve Waymire yöntemidir. Önceki bir çalışmada geliştirilen ve bu yöntemlerden birisinin jeomorfolojik ABHını momentum denkleminin difüzif yaklaşımı ile birleştiren bir model akarsu ağlarının üreteceği ortalama ABHları elde etmek için kullanılmıştır. Ayrıca düğüm noktası konfigürasyonu kavramından da yararlanılmıştır. 6-kaynaklı ve belli bir düğüm noktası konfigürasyonunu haiz akarsu ağları için bir simülasyon yapılmıştır. Buradaki amaç bu ağların ürettikleri ABHların dağılımlarını görmektir. Froude sayısının 0.2 olması halinde 3, 4, 5, 6-kaynaklı mümkün olabilecek bütün düğüm noktası konfigürasyonları için ağın ortalama ABH özellikleri ile boyutsuz ortalama iç link uzunluğu arasındaki ilişkiler elde edilmiştir. 3-8-kaynaklı akarsu ağları için ABH özellikleri ile ortalama iç link uzunlukları arasındaki ilişkilerin averajları elde edilmiştir.

Anahtar Sözcükler: Ortalama anlık birim hidrograf, akarsu ağı, topoloji, boyutsuz davranış.

Introduction

The IUH (instantaneous unit hydrograph) of a river basin is a classical tool which is commonly used as a component in rainfall-runoff modeling during the planning, design and operation phases of hydraulic structures. It has been attempted to relate the IUH to the characteristics of the channel network. There are two approaches to determine the IUH in relation to geomorphological basin characteristics. The first approach is Rodriguez-Iturbe and Valdes, (1979) approach. The second is an alternate approach proposed by Gupta and Waymire (1983). These two approaches are also named Exponentially Distributed GIUH (geomorphologic instantaneous unit hydrograph) (ED-GIUH) and Linear Routing GIUH (LR-GIUH) respectively. Rodriguez-Iturbe and Valdes, approach is called exponentially distributed GIUH because they have assumed that the probability density function (pdf) of time of travel in watershed streams is exponential. Gupta and Waymire's approach is named linear routing GIUH since a time distribution based upon the linearized equations of motion has been used (Allam et al., 1990). More information on both of the approaches will be given in the following paragraph.

In an earlier study, a more realistic representation for the IUH of Gupta and Waymire's approach by the introduction of diffusion routing was experimented with (Oguz, 1994). By making use of a concept, junction configuration, suggested by Oguz and Önöz (1999) all possible mean IUH s of 3, 4, 5, 6-source channel networks can be obtained. In this study these IUH s have been obtained for a single Froude number (F=0.2) and for a single dimensionless length value ($L^* = 0.3$).L^* is mean interior link length of the channel network non-dimensionalized with the slope and water depth of the channel network (eq.11). If the Froude number is defined as $F = V/(gy)^{0.5}$, and if $V = 1$ m/sec, $y = 2.5$ m (as common values in subcritical flows) F is found as 0.2.

Another aim of the study is to determine the relationships between mean IUH properties and the characteristic length for 3, 4, 5, 6-source networks for a Froude number of 0.2. A final objective is to average the IUH properties for a network with a given number of sources in the range 3-8.

Basic Concepts

Some basic concepts related to random channel networks are presented below to facilitate understanding of the material that follows.

A channel network has points farthest upstream known as *sources* and a point farthest downstream known as the *outlet*. The number of sources a channel network has is known also as its *magnitude*. The point at which two channels combine to form one is called a *junction*. An *exteriorlink* is a segment of a channel network between a source and the first junction downstream; an *interiorlink* is a segment of a channel network between two successive junctions or between the outlet and the first junction upstream.

Strahler ordering scheme for channel networks is defined as follows: (1) channels that originate at a source are defined to be first order streams; (2) when two streams of the same order w join, a stream of order $\Omega+1$ is created; (3) when two streams of different order join, the channel segment immediately downstream has the higher of the orders of the two combining streams (Smart, 1972). In Fig. 1, a schematic channel network of order 3 numbered ordered according to Strahler's scheme is shown.

A channel *state* of order i is defined as the collection (ensemble) of all the Strahler channels of that order. Denoting a channel state by c_i and the order of the network by Ω, i can take a value between 1 and $\Omega (1 < i < \Omega)$. It is known that for a basin of order Ω there are $2^{\Omega-1}$ possible *paths*. For $\Omega = 3$ the path space $S = \{s_1, s_2, s_3, s_4\}$ consists of the following paths:

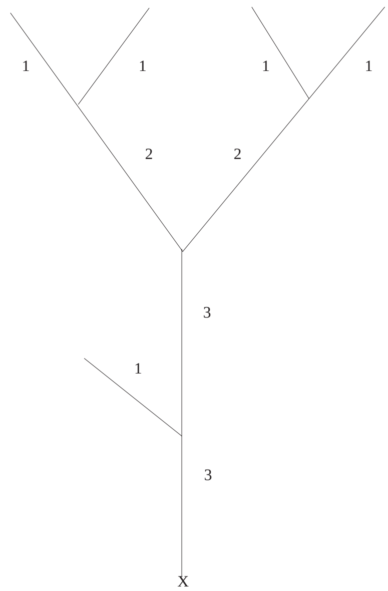

Figure 1. A schematic channel network ordered according to Strahler scheme.

path s_1 $c_1 \rightarrow c_2 \rightarrow c_3 \rightarrow$ outlet
path s_2 $c_1 \rightarrow c_3 \rightarrow$ outlet
path s_3 $c_2 \rightarrow c_3 \rightarrow$ outlet
path s_4 $c_3 \rightarrow$ outlet (Gupta and Waymire, 1983).

The important concept of *topology* was first introduced into geomorphology by Shreve in 1966 (Smart, 1972). The number of sources, links, junctions of a channel network and the branching system of the network are topological characteristics of a network. In the topology of a channel network system the lengths of the links are not of interest. In Fig. 2, two channel networks with five sources are seen, of which the topologies are different. Channel networks with equal number of sources have also equal numbers of links, junctions and first-order Strahler streams and thus are topologically comparable (Smart, 1972).

The $width function$ is the width, in a sense, of the network drawn against a distance x from the outlet as shown in Fig. 2. The width of the channel network is symbolized by the number of links ($N(x)$) that exist at a certain distance x from the outlet. This concept is similar to what is called as the time-area diagram. Thus, once the channel network is known, it is quite easy to determine its width function.

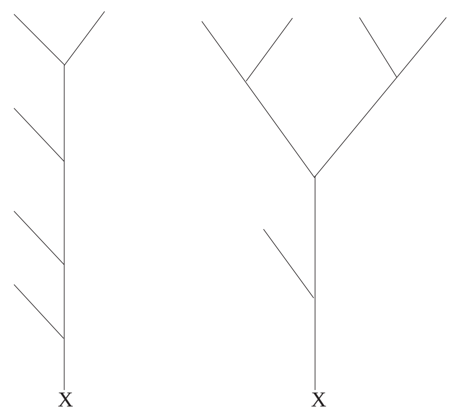

Figure 2. Two 5-source channel networks which are topologically different.

In a natural basin, rainfall particles released instantaneously and uniformly over the basin will follow different paths before arriving at the outlet. For a channel network, the probability that the particle chooses a certain path from among all possible paths (the path function probability) can be determined using the Strahler scheme. Each path has its own random holding time (travel time to the basin outlet). The IUH of a basin is the pdf of the holding time of rainfall particles; it is obtained by multiplying the probability that a particle follows a certain path with the pdf of the holding time for this path and then summing these products over all possible paths. This leads to the general mathematical representation of the geomorphological IUH of a basin (Gupta et al., 1980). In the literature, there are two approaches to determine the IUH in relation to geomorphological basin characteristics.

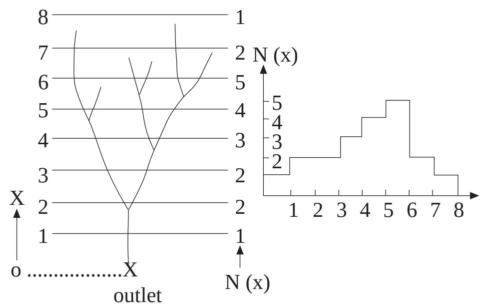

Figure 3. Explanation of the width function of a channel network.

The first approach is the one proposed by Rodriguez-Iturbe and Valdes (1979), called the $R-V$ approach and also known as Exponentially Distributed GIUH (ED-GIUH), because they assumed the pdf of time of travel in watershed streams to be exponential. The mathematical structure of the R-V approach was simplified and generalized by Gupta et al. (1980) leading it to being named the generalized $R-V$ approach. In this approach, a given channel network is ordered according to the Strahler ordering scheme. It is assumed that rainfall particles are introduced into the basin instantaneously and uniformly. The aim is to find the pdf of the random time a particle spends in the basin until it reaches the outlet (the holding time). Firstly, the possible paths these particles may follow are determined. Then, using the geomorphological information, the path probabilities are calculated. Secondly, the pdf s of the holding time of links of order i (for all orders) are determined (this is the time a link of order i holds the particle before it moves onto a link of order $i+1$). Thirdly, making use of these link holding time pdf s and using the convolution concept, the path holding time pdf s can be obtained. Finally by multiplying the path holding time pdf s by the corresponding path probabilities and summing for all possible paths, the pdf of the holding time of the basin can be found, which is identical to the IUH.

Gupta and Waymire (1983) proposed an alternate approach. They studied the pdf of arrival times of rainfall particles injected instantaneously and uniformly at all the nodes of the network. Rainfall input is then routed to the basin outlet; routing is usually linear. This alternate method is also named Linear Routing GIUH (LR-GIUH). The simplest case is pure translation with constant velocity V. Starting at the outlet, let x_j define the number of links at level j, then the response is

$$P(T_B = j) = x_j/(2M-1) \tag{1}$$

Here T denotes the holding time for the basin and M is the number of sources or the magnitude. In this case, the IUH will be similar to the width function $N(x)$, number of links at distance x from the outlet: $U(t) \sim N(Vt)$ where V is the velocity of the rainfall particles. Network order does not play a role in this approach (Gupta and Waymire, 1983). Although Gupta and Waymire (1983) stated that the IUH will be similar to the width function $N(x)$ when pure translation with constant velocity is considered, they also mentioned that the IUH derived by this approach did not agree with that of Rodriguez-Iturbe and Valdes (1979). The structure of the second approach is much simpler than that of the first approach.

Review and Development of Previous Work

a) Diffusion Routing Applied to the Derivation of the IUH of a Channel Network

There are several methods used for flow routing. Diffusion wave routing is one type of the distributed (hydraulic) models used for this aim. In this model, the diffusion approach used for various physical phenomena is:

$$\frac{\delta y}{\delta t} = \beta_2 \frac{\delta^2 y}{\delta x^2} \tag{2}$$

where β_2 is the diffusion coefficient. Neglecting the inertia terms in the momentum equation and applying a linearized perturbation, the following equation is obtained (Cunge, 1975):

$$\beta_1 \frac{\delta(Vy)}{\delta x} + \frac{\delta(Vy)}{\delta t} = \beta_2 \frac{\delta^2(Vy)}{\delta x^2} \tag{3}$$

In the diffusion wave model, this equation is used instead of the momentum equation. The coefficient β_2 expresses the damping of the flood wave, thus, this model considers damping during routing.
Troutman and Karlinger (1985) give the impulse response function of the model given by eq. 3 for one-dimensional routing of flows in wide and rectangular channels and in which the frictional effects are assumed to follow the Chezy law as:

$$h(x,t;\beta) = x(4\pi\beta_2 t^3)^{-1/2} exp[-(4\beta_2 t)^{-1}(\beta_1 t - x)^2] \tag{4}$$

$$\beta_1 = 1.5V \text{ (wave propagation velocity, kinematic wave velocity)} \tag{5a}$$

$$\beta_1 = V_m + \sqrt{g y_m} \text{ (dynamic wave velocity)} \tag{5b}$$

$$\beta_1 = V_p + \sqrt{g y_p} \text{ (dynamic wave velocity)} \tag{5c}$$

$$\text{and } \beta_2 = (2SB)^{-1} q(1-F^2) \text{ (diffusion coefficient)} \tag{6}$$

in eqs. 3, 5 and 6, V is velocity, B is width, q is unit discharge, S is the slope, y is the depth of the channel network. F is used for the Froude number. V_m and V_p stand for mean and peak velocities and y_m and y_p stand for flow depth at mean and peak discharges respectively (Sorman, 1995). In eq. 6, β_2 becomes singular for $F = 1$. The impulse response function $h(x,t;\beta)$ must be valid for certain values of diffusion coefficient β_2 and wave velocity β_1 each of which depends on F and V. In this study eq. 5a is used for β_1.

Eq. 4 shows the response of a channel subject to an instantaneous upstream input which is at a distance of x (impulse response function). Eq. 4 can be interpreted as the pdf corresponding to the travel time of a drop travelling a distance of x. This equation is not a dimensionless equation, the response $h(x,t;\beta)$ is in units of $[1/T]$. The non-dimensionalized form of eq. 4 is obtained as follows (Oguz, 1994):

$$h^*(x^*,t^*) = x^* \left[2\pi(1-F^2)t^{*3}\right]^{-1/2} exp\left[-\frac{(1.5t^* - x^*)^2}{2(1-F^2)t^*}\right] \tag{7}$$

if

$$h^* = \frac{h}{SV/y} \text{ is dimensionless response} \quad (8a)$$

$$t^* = \frac{t}{y/SV} \text{ is dimensionless time} \quad (8b)$$

$$x^* = \frac{x}{y/S} \text{ is dimensionless distance} \quad (8c)$$

Introduction of diffusion routing into the width function can be done by the following formulation (Oguz, 1994):

$$U^*(t) = \frac{\sum_x h^*(x^*, t^*).N(x)}{\sum_x N(x)} \quad (9)$$

where U^* is the dimensionless IUH ordinate.

b) Junction Configuration

In this study an attempt is made to find the relation between the topology of the network and the properties of the hydrograph at the outlet. It is known from the literature that the number of topologically distinct channel networks (TDCN) would be 2, 5, 14 and 42 for networks with 3, 4, 5 and 6 sources respectively (Smart, 1972). That is to say, for example, a network with 5 sources may have 14 different network configurations and not more. We also know that the property of the network which will affect the hydrograph at the outlet is its width function. By a very simple and close analysis of the different network variations of 3, 4, 5, 6-source networks, it is seen that the number of different width functions remains much smaller than the TDCN number, which is of interest for a network with a certain number of sources (Table).

Table 1. Characteristics of all possible junction configurations of 3, 4, 5, 6 source channel networks

N Source Number	No. of possible Configurations	Possible junction Configurations	No. of TDCN*	Probability of Junction configuration
3	1	[1]	2	1.0
4	2	[1,1]	4	0.8
		[2]	1	0.2
5		[1,1,1]	8	0.571
	3	[1,2]	2	0.143
		[2,1]	4	0.286
6		[1,1,1,1]	16	0.381
		[1,1,2]	4	0.095
	5	[1,2,1]	8	0.190
		[2,1,1]	8	0.191
		[2,2]	6	0.143

*TDCN: Topologically discrete channel network

A network with 3 sources has only one width function (2 TCDN), a network with 4 sources has only 2 different width functions (5 TCDN), a network with 5 sources has only 3 different width functions (14 TDCN) and a network with 6 sources has only 5 different width functions (42 TDCN). This shows that some different channel network configurations produce the same width function. At this point the concept junction configuration must be used. This is the characteristic of the network affecting the width function. All the networks having the same junction configuration have identical width functions. The junction configuration will be shown in square brackets, by numbers of junctions having a_i junctions between them and the outlet as $[a_1, a_2, ..., a_i, ..., a_n]$ where $n = \lambda - 1$ (λ:termination level of the network).

Looking at Fig. 4, 3 different TDCN s are observed for a network with 6 sources. The junction configuration of Fig. 4(a) and Fig.4(b) are the same $[2, 1, 1]$ whereas the junction configuration of Fig. 4(c) is different, $[2, 2]$. As an example the $[2, 1, 1]$ notation tells us the number of junctions having only 1 junction between themselves and the outlet is 2; the number of junctions having 2 junctions between themselves and the outlet is 1; the number of junctions having 3 junctions between themselves and the outlet is 1 (Oguz and Önöz, 1999).

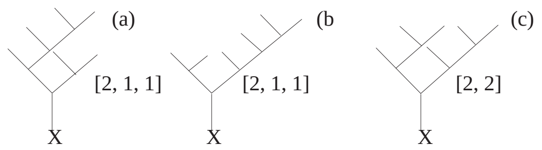

Figure 4. Definition of "junction configuration" for source no. 6 for two possible junction configurations.

As seen in Table 1, one junction configuration has almost always more than one TDCN corresponding to it. A formula can be written for finding the number of TDCN s having the same junction configuration.

If any junction configuration is shown as $[a_1, a_2, ..., a_i, ..., a_n]$ and if the number of TDCN s having the same junction configuration is M, then

$$M = \prod_{i=1}^{n-1} \begin{pmatrix} 2a_1 \\ a_{i+1} \end{pmatrix} \tag{10}$$

can be written in a slightly different way after proposition 3 of Gupta and Waymire (1983). This formula is valid for cases where $N \geq 3$ (N is the number of sources). a_i must satisfy the following conditions:

$$1.\sigma a_i = N - 2$$

$$2.a_{i+1} \leq 2a_i$$

$$3.a_{1max} = 2$$

A Simulation Study and the Dimensionless Mean IUH S of 3, 4, 5, 6-Source Channel Networks

Let L stand for the mean interior link length of the network. If a dimensionless characteristic length

$$L^* = \frac{L}{y/S} \tag{11}$$

is defined, it is known that the IUH depends on the Froude number (F) and the characteristic length (L^*) (Oguz, 1994). For this study, a Froude number of 0.2 is selected. The mean exterior link length is assumed to be 1.5 times the mean interior link length (Smart, 1972). An L^* value of 0.3 is chosen; it corresponds to a network of which the mean interior link length is 1000 m and the mean exterior link length is 1500 m if the slope S and the depth of water y are taken as 0.0003 and 1 m respectively. In a study on Saudi Arabian wadis by Sorman (1995) the slopes of three wadis (basins) were determined to be 0.0076, 0.0330 and 0.0092. Such information was not available for Turkish river networks. The slope value selected for this study seems too low, compared with the above cited slope values, to define the dimensionless characteristic length L^*. L^* may in reality get higher values than were tested in this paper.

A simulation study has been performed for 6-source channel networks with a junction configuration of [2,1,1]. The generation mechanism of a channel network has two phases. The first one is generation of the topology and the second phase is the assignment of link lengths. In this study the junction configuration is chosen as [2,1,1], which is to say that the topology of the networks is the same and it is known. So the second phase of the generation mechanism follows. Both the interior and exterior links of channel networks can be assumed gamma distributed, with the mean of the exterior links being assumed to be 1.5 times the mean of the interior links (Smart, 1972). In this study, the mean interior link length and the mean exterior link length are taken as 1 km and 1.5 km respectively. Thus, gamma distributed random numbers with mean 1 are assigned to interior link lengths and those with mean 1.5 are assigned to exterior link lengths. Six random channel networks are simulated by this mechanism.

The IUH s of these channel networks are obtained by first finding the width functions of the networks, then applying eq. 9. Calculations at different x^* distances from the outlet must be made. In this case the following definition is made,

$$\Delta x^* = \frac{\Delta x}{y/S} \tag{12}$$

these x^* distances are selected at equal Δx^* distances from the previous one. Δx^* is taken as one third of the mean interior link length. The IUH s obtained are shown in Fig. 5. Here the aim is to see the distribution of the IUH s.

It is observed that the dimensionless peaks take values between 0.91 and 1.55, whereas the dimensionless times to peak vary between 0.05 and 0.40. An attempt is made to find the mean IUH s of 3, 4, 5, 6 source networks for all possible junction configurations.

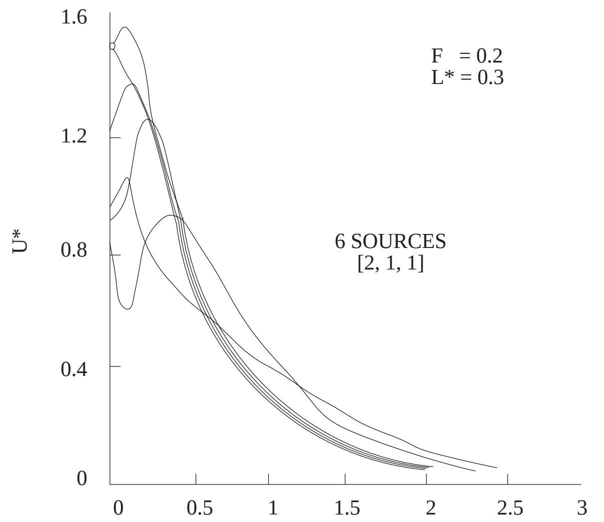

Figure 5. A simulation study for a 6-source channel network with a junction configuration of [2,1,1]

Networks with mean interior and exterior link lengths are considered. In other words, the interior and exterior links of the networks are assigned values of 1 and 1.5 respectively. The width functions are calculated taking Δx^* as one third of the mean interior link length and the IUH s are obtained as previously described. Since the interior and exterior links are assigned mean lengths, the IUH s produced must be considered as mean IUH s for certain junction configurations. These dimensionless mean IUH s are shown in Fig. 6. It is observed in this figure that the peak of the mean IUH of a 6-source network with a junction configuration of [2,1,1] remains in the range of the IUH peaks of the simulation study with a value of 1.3 and similarly the time to peak of the same IUH takes a value between the time to peak values of the simulation study with a value of 0.2.

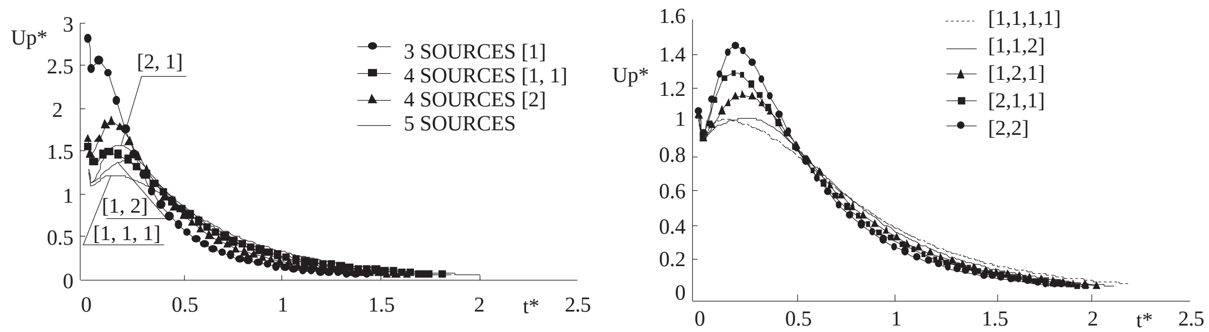

Figure 6. The mean IUH s of 3,4,5,6 source channel networks for all possible junction configuration.

The Relationship Between Mean IUH Properties and Characteristic Length

All the work in this paragraph is done for one Froude number, F=0.2. The same work as in the previous paragraph has been performed for six different L^*, dimensionless characteristic length values, L^*=0.1-0.6 (increased by 0.1) for all possible junction configurations of 3, 4, 5, 6-source channel networks. The most important characteristics of the mean IUH s produced, the dimensionless mean peaks (Up^*) and the dimensionless mean times to peak (tp^*) have been evaluated.

The relationships between the logarithmic values of dimensionless mean IUH peak and dimensionless characteristic length are given in Fig. 7. It is observed that these relationships are almost linear for small source numbers and become curvilinear as the source number increases. Generally, the mean IUH peak decreases as the source number increases for a given dimensionless characteristic length value. For a certain junction configuration, the mean IUH peak decreases as the dimensionless characteristic length increases.

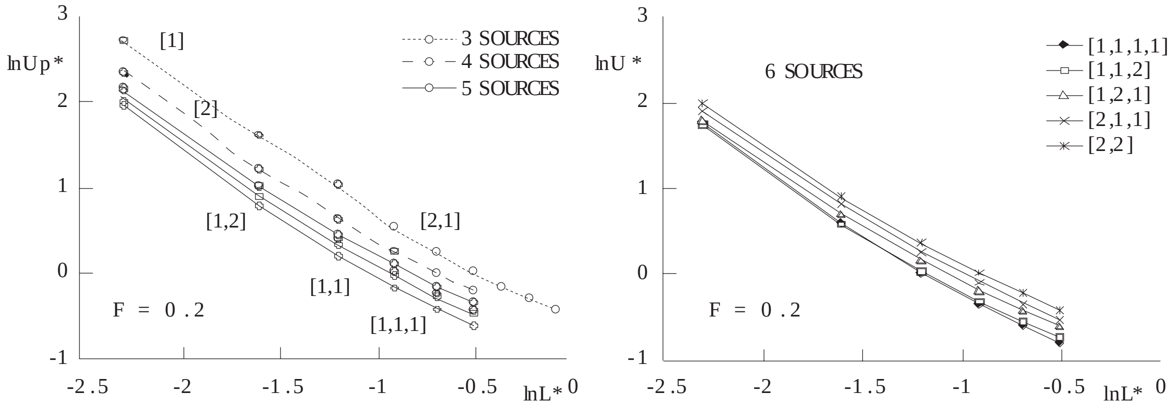

Figure 7. The relationship between logarithm of dimensionless mean IUH peak and logarithm of dimensionless characteristic length for all possible junction configurations of 3, 4, 5, 6 source networks.

The relationships between the logarithmic values of dimensionless mean time to peak and dimensionless characteristic length are given in Fig. 8. In this figure, the relationships do not appear for some smaller L^* values. This means that the peak of the IUH is met at time zero. As a general trend, the mean time to peak increases as the source number increases for a given dimensionless characteristic length value. For a given junction configuration the dimensionless mean time to peak increases with increasing dimensionless characteristic length.

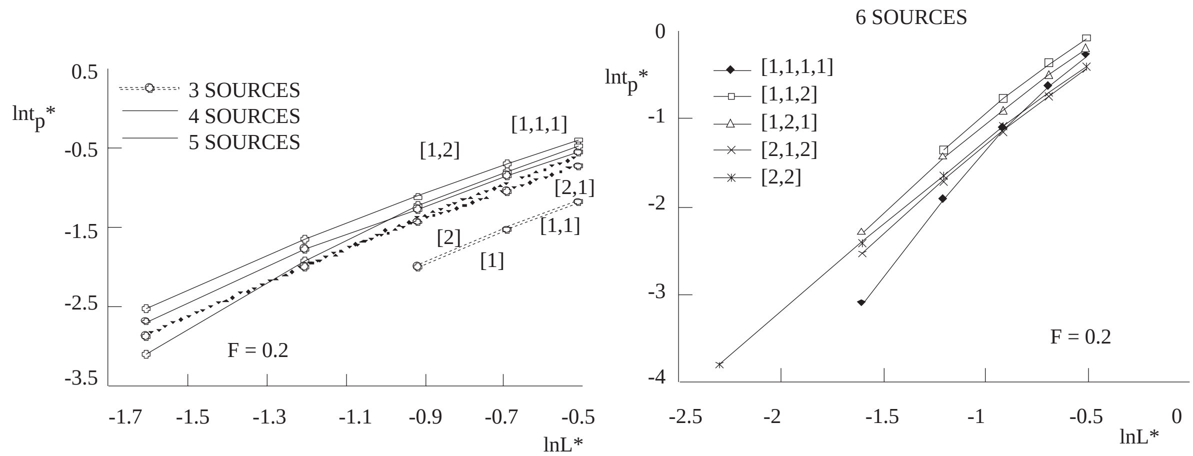

Figure 8. The relationships between logarithm of dimensionless mean time to peak and logarithm of dimensionless characteristic length for all possible junction configurations of 3, 4, 5, 6 source networks.

IUH Properties Averaged for a Network With a Certain Number of Sources

Since the probability of a certain junction configuration for a network having up to six sources is known (Table), it is possible to average the relations shown in Figs. 7 and 8. In other words, these relations can be averaged for a network with a certain number of sources, independent of the junction configuration. Consequently, the relations seen in these figures will be summarized by one average curve for each value of the number of sources. By using similar logic and with the help of eq. 10, the source number is extended to eight.

In Fig. 9, the average relationships between logarithm of dimensionless IUH peak and logarithm of dimensionless characteristic length are given. These relationships are almost linear and the IUH peaks decrease as the source number increases for a given characteristic length. It is observed that as the source number increases these relations come closer to one another. This implies that, for sufficiently large source numbers, there might be only one relation, which needs further investigation. For a given source number the IUH peaks decrease with increasing characteristic length.

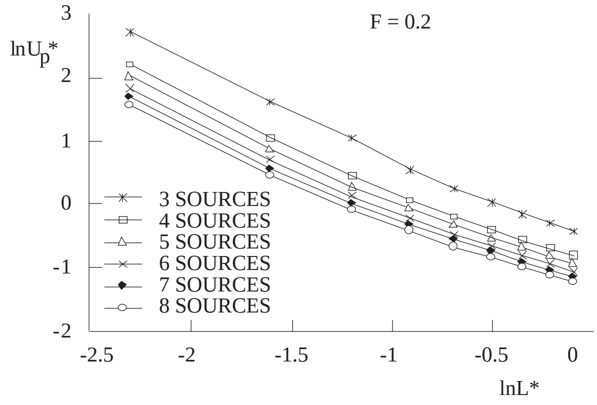

Figure 9. The average relationships between logarithm of dimensionless IUH peak and logarithm of dimensionless characteristic length for 3-8 source networks.

In Fig. 10, the average relationships between logarithm of dimensionless time to peak and logarithm of dimensionless characteristic length are given. The times to peak increase as the source number increases for a given characteristic length. Similar to Fig. 9, the relations get closer to each other as the source number increases. For a given source number, the times to peak increase with increasing characteristic length.

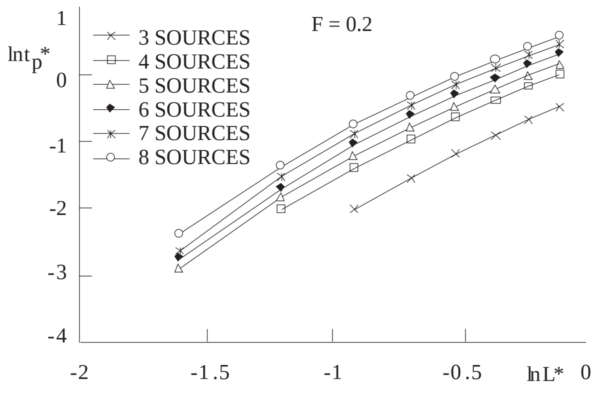

Figure 10. The average relationships between logarithm of dimensionless time to peak and logarithm of dimensionless characteristic length for 3-8 source networks.

In Figs. 9 and 10, the relationships depend only on F and the source number of the network. The relationships shown in Fig. 9 and Fig. 10 for U_p^* and t_p^* may differ for different trial of F which is different from 0.2. The logarithmic relationships between U_p^* vs L^* and t_p^* vs L^* for $F = 0.2$, 0.4, 0.6, 0.8 values are given in Oguz, 1994 for a range of 0.001-0.1 for L^*. Further research using a wider range of L^* values and greater F than the one tested in this paper is recommended.

Conclusions

1. The dimensionless mean IUH s of 3, 4, 5, 6 source networks are obtained for all possible junction configurations for a Froude number (F) of 0.2 and a dimensionless characteristic length (L^*) value of 0.3 (Fig. 6).

2. The relationships between logarithm of dimensionless mean IUH peak (U_p^*) and logarithm of dimensionless characteristic length (L^*) for all possible junction configurations of 3, 4, 5, 6 source networks for a Froude number of 0.2 are obtained (Fig. 7).

3. The relationships between logarithm of dimensionless mean time to peak (t_p^*) and logarithm of dimensionless characteristic length (L^*) for all possible junction configurations of 3, 4, 5, 6 source networks for a Froude number of 0.2 are obtained (Fig. 8).

4. The average relationships between logarithm of dimensionless IUH peak (U_p^*) and logarithm of dimensionless characteristic length (L^*) for 3-8 source networks for a Froude number of 0.2 are given (Fig. 9).

5. The average relationships between logarithm of dimensionless time to peak (t_p^*) and logarithm of dimensionless characteristic length (L^*) for 3-8 source networks for a Froude number of 0.2 are obtained (Fig. 10).

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List of Symbols

ai	junction configuration
B	width of channel network
c	channel state
F	Froude number
g	gravitational acceleration
h	response of network
h^*	dimensionless response of network
L	mean interior link length of network
L^*	dimensionless characteristic length
M	magnitude of network
$N(x)$	width function
P	path space
q	unit discharge
Q	discharge
S	slope of channel network
t	time
t^*	dimensionless time
t_p	time to peak of IUH
t_p^*	dimensionless time to peak of IUH
T	holding time for the basin
U	IUH ordinate
U^*	dimensionless IUH ordinate
U_p^*	dimensionless peak of IUH
V	velocity
V_m	mean velocity
V_p	peak velocity
x	distance from outlet
x^*	dimensionless distance
Δx	distance interval
Δx^*	dimensionless distance interval
y	depth
y_m	flow depth at mean discharge
y_p	flow depth at peak discharge
β_1	advective velocity (celerity)
β_2	diffusion coefficient
λ	termination level of network
Ω	order of stream
ω	order of network

References

Allam, M.N., Sorman, A.U., Ishaq, A.M., and Khan, A.M., Geomorphologic Rainfall-Runoff Models for Infiltrating Watersheds, King Abdulaziz City for Science and Technology (KACST), Report No 7-85, Riyadh, 1990.

Cunge, J.A., Unsteady Flow in Open Channels, (eds, Mahmood, K. and Yevjevich, V.),Water Resources Publications, Fort Collins, Colorado, 1975.

Gupta, V.K., Waymire, E., and Wang C.T.,. "A Representation of an Instantaneous Unit Hydrograph from Geomorphology, Water Resources Research, Vol.16, No.5, 855-862, 1980.

Gupta, V.K., and Waymire E., On the Formulation of an Analytical Approach to Hydrologic Response and Similarity at the Basin Scale, Journal of Hydrology, Vol.65, No.1/3,.95-123, 1983.

Oğuz, B., An Approach to the Derivation of the Instantaneous Unit Hydrograph of a Topologically Random Channel Network, Procs. of NATO ASI Defence from Floods and Floodplain Management, (eds. Gardiner, J., Starosolszky, Ö., and Yevjevich, V.), 235-240,1994.

Oguz, B., and Önöz, B., Distributions of Instantaneous Unit Hydrograph Peak Characteristics for Small Networks, Turkish Journal of Engineering and Environmental Sciences, 1999 (accepted for publication).

Rodriguez-Iturbe, I., and Valdes, J.B., The Geomorphologic Structure of Hydrologic Response, Water Resources Research, Vol.15, No.6,1409-1420,1979.

Smart, J.S., Channel Networks, Advances in Hydroscience, Vol. 8. (ed, Ven Te Chow), Academic Press, 1972.

Troutman, B.M., and Karlinger, M.R., Unit Hydrograph Approximations Assuming Linear Flow Through Topologically Random Channel Networks, Water Resources Research, Vol.21, No.5, 743-754, 1985.

Sorman, A.U., Estimation of Peak Discharges Using GIUH Model in Saudi Arabia, Journal of Water Resources Planning and Management of ASCE, Vol. 121, No. 4, 287-293, 1995.