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AD-A218 662

REPORT DOCUMENTATION PAGE

FEB 27 1990

1a.	1b. RESTRICTIVE MARKINGS
2a.	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) ARO 26220.7-GS
6a. NAME OF PERFORMING ORGANIZATION Univ. of Mississippi; 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION U. S. Army Research Office
6c. ADDRESS (City, State, and ZIP Code) University, MS 38677	7b. ADDRESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211
8a. NAME OF FUNDING/SPONSORING ORGANIZATION U. S. Army Research Office; 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DAAL03-89-K-0070
8c. ADDRESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Fundamental Studies on Hydrology, Hydraulics and Geometry of River Networks

12. PERSONAL AUTHOR(S)
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13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 2/1/89 TO 11/30/89	January 1990	4

16. SUPPLEMENTARY NOTATION The view, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
River Networks, Hydrology, Hydraulics

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Research was directed toward a mathematical understanding of the empirical main channel length-area relationship for river networks based on the two postulates of the random model. The most significant analytical finding was that, up to a scale factor, the average

(continued on reverse side)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT	21. ABSTRACT SECURITY CLASSIFICATION
☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code) / 22c. OFFICE SYMBOL

main channel length L varies as the square root of the network magnitude m, i.e.,

$$L = \mu\, 2\sqrt{u}\,\sqrt{m} \qquad (1)$$

where μ, as the scale factor, denotes the mean link length. It has been rigorously proved for constant link lengths [Waymire, Water Resour. Res., 25(5), 1989] and for exponentially distributed link lengths [Gupta et al., J. Appl. Prob., 1990]. The results in Gupta et al. [1990] suggested that eq. (1) should be true under broad mathematical conditions on link length probability distributions, e.g., when their variance is finite, regardless of the parametric form of these distributions. This suggestion has since been verified rigorously. The results will appear in a forthcoming article by Durrett, Kesten, and Waymire, [J. Theoretical Prob., 1990]. In this sense, eq. (1) exhibits universality.

FINAL REPORT

ARO PROPOSAL NUMBER: 26220-GS

TITLE OF PROPOSAL: Fundamental Studies on Hydrology, Hydraulics and Geometry of River Networks

CONTRACT NUMBER: DAAL03--89-K-0070

NAME OF IN ST'TUTIONS: University of Mississippi and Oregon State University

AUTHORS OF REPORT: V. K. Gupta and Ed Waymire

1. OBJECTIVES:

The proposed research had two broad objectives. These objectives, as stated in the proposal, were:

(1) [NETWORK HYDRAULIC-GEOMETRY AND RUNOFF PRODUCTION] To seek analytical generalizations of the current theory of channel networks which include hydraulic-geometric variables, e.g., channel widths, depths, gradients, velocities, streamflows, etc. This will require theoretical studies of channel networks in three-dimensional space, taking into account both elevation and horizontal spatial dimensions.

(II) [MESOSCALE CLIMATE] To undertake analytical and empirical studies of intermittency and 'statistical self-similarity' in space-time rainfall intensity at natural basin scales.

2. MAIN FINDINGS AND RESULTS

Among the most important themes which are central to this entire research effort is an understanding of the scaling invariance property in spatial variability of channel network geometry, river runoff and rainfall. This theme provided the focus for our research during this period.

OBJECTIVE I

Our research on this objective was directed toward a mathematical understanding of the empirical main channel length-area relationship for river networks based on the two postulates of the random model. The most significant analytical finding was that, up to a scale factor, the average main channel length L varies as the square root of the network magnitude m, i.e.,

$$\overline{L} = \mu\, 2\sqrt{\mu}\, \sqrt{m} \tag{1}$$

where μ, as the scale factor, denotes the mean link length. It has been rigorously proved for constant link lengths [Waymire, Water Resour. Res., 25(5), 1989] and for exponentially distributed link lengths [Gupta et al., J. Appl. Prob., 1990]. The results in Gupta et al. [1990] suggested that eq. (1) should be true under broad mathematical conditions on link length probability distributions, e.g., when their variance is finite, regardless of the parametric form of these distributions. This suggestion has since been verified rigorously. The results will appear in a forthcoming article by Durrett, Kesten, and Waymire, [J. Theoretical Prob., 1990]. In this sense, eq. (1) exhibits universality.

The empirical findings of Hack, Muller, etc., however, show that the exponent of network magnitude is about .57, rather than 1/2 as predicted above by the random model. An explanation of this discrepancy is being explored by us in different directions. As a follow-up to the results contained in Durrett et al. [1990] one direction is to explore if a scaling invariance property (simple or multiscaling) in link lengths can explain the observed departure from 1/2 in the empirical main channel length-magnitude relationship. For instance, simple scaling behavior has been recently discovered by us in link heights [Gupta and Waymire, Water Resour. Res., 25(3), 1989]. It's generalizations to multiscaling are being investigated in spatial rainfall, river flows, and river networks, as explained below.

Wang and Waymire [1989] proved a central limit theorem for the Horton bifurcation ratio. This can assist in estimating departures from the average value of the bifurcation ratio in empirical observations.

OBJECTIVE II

River basins span a broad range of spatial scales ranging from about 10^{-1} to about 10^6 km^2. So from the view point of predictions from ungaged basins it is necessary to understand and model the spatial variability in rainfall and river flows over this range of scale. In our earlier work [Cadavid, MS Thesis, Univ. of Mississippi, 1988] it was first observed that instantaneous peak flows do not obey statistical self-similarity or simple scaling. Likewise, arguments have been made against self-similarity of spatial rainfall in the recent literature. Since then, we have been looking into the ways to generalize simple scaling to the so-called multi-scaling and test it on some data. The first step towards this generalization is taken in the forthcoming article by Gupta and Waymire [J. Geophys. Res.,1990].

Suppose that peak flows obey multi-scaling in space. Moreover, suppose that link slopes in a river network obey statistical self-similarity [Gupta and Waymire, Water Resources Research, 25(3), 1989] with a scaling exponent θ. The problem is to predict θ in terms of the scaling exponents appearing in flows and test these predictions against the value computed directly from channel network data. The first steps towards solving this problem are taken by Kapoor [M.S. Thesis, Univ. of Mississippi, 1989]. He formulated a notion of uniform power distribution over a network in dynamic equilibrium (motivated by the ideas of Gilbert) and applied this concept to predict the exponent θ using flow data from Brandywine Creek in Pennsylvania. The predicted value compares favorably with the values of θ computed by Gupta and Waymire [1989] for four river basins. This line of investigation also provides the first major step towards linking network geometry with flows. This will play an important role in solving the problem of prediction from ungaged basins.

3. LIST OF PUBLICATIONS

3.1 In Refereed Journals

Gupta, V. K., and E. Waymire, Multiscaling properties of spatial rainfall and river flow distributions, JGR, 1990 (in press).

Gupta, V. K., O. Mesa, and E. Waymire, Tree Dependent Extreme Values, J. Appl. Prob., 1990 (in press).

Ossiander, M., and E. Waymire, Certain Positive Definite ernels, Proc. Amer. Math. Soc., 107(2):487-492, 1989.

Waymire, E., On the main channel length-magnitude formula for random networks: A solution to Moon's conjecture, Water Resour. Res. 25(5):1049-1050, 1989.

3.2 Theses & Dissertations for advanced degrees

Kapoor, V., Spatial Uniformity of Power and Prediction of the Altitudinal Geometry of River Networks, M.S. Thesis, Department of Civil Engineering, The University of Mississippi, 1989.

4. LIST OF SCIENTIFIC PERSONNEL SUPPORTED BY THIS PROJECT

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