Non-Structural Solutions to Floodplain Management -- Past, Present and Future

Conference Proceedings

Floodplain Management Association

and the Arizona Floodplain Management Association

February 28 - March 2, 2000

Catamaran Hotel

San Diego, California

March 1 – Wednesday (Cont.)

10:30 – 12:00 PM	***Special Interactive Session*** **An Interactive Dialogue Between Local Officials and State and Federal Agency Representatives** ***Moderator: Andrew S. Lee, California Department of Water Resources, Chief, Floodplain Management Branch*** **Clark Frentzen**, *U.S. Army Corps of Engineers, Panelist* **Jack Eldridge**, *FEMA Region 9, Panelist* **Mary Butterwick**, *EPA, San Francisco, Panelist* **Ken Bryant**, *Program Coordinator, Flood Mitigation Assistance, California Office of Emergency Services, Hazard Identification & Analysis Unit, Panelist*	**Toucan & Macaw 2nd Floor**
12:00 – 2:00 PM	***Conference Luncheon*** **Guest Speaker: Frank Belock, City Engineer, City of San Diego** ***"Case Studies of Floodplain Encroachment in the City of San Diego"***	**Kon Tiki Ballroom, 2nd Floor**
2:00 - 3:15 PM	***Paper Session IIA – Floodplain Management*** ***Moderator: Marty Teal, WEST Consultants*** Paper: → **"Floodplain Management in the Las Vegas Valley,"** Gale Wm. Fraser, III, Kevin Eubanks, Clark County Regional Flood Control District put slides on Home page. Tim Sutko = Hydrologist @ County. Collaboration **"Floodplain Management & Watershed Challenges for the New Millennium,"** Doug Plasencia, Kimley-Horn & Associates **"Federal Reimbursement for Local Flood Control Projects,"** Wayne Smith, San Joaquin Area Flood Control Agency	**Toucan Macaw 2nd Floor**
2:00 – 3:15 PM	***Paper Session IIB – Computers & Technology*** ***Moderator: Joe Hill, WFS Inc.*** **"Post-Hazard Verification – Hurricane Floyd, New Jersey and New York,"** Paul Weberg, FEMA Region II, and David Jula, Dewberry & Davis, Flood Map Coordination **"Estimating Changes in Sediment Transport Trends Due to Catchment Changes,"** Ted Hromadka II and Timothy J. Durbin, California State University Fullerton **"Automated Hydrologic and Hydraulic Analysis Using Geographic Information Systems,"** David Preusch, Massoud Rezakhani, Michael Baker Jr., Inc.	**Multi-Purpose Room**

ESTIMATING CHANGE IN SEDIMENT TRANSPORT TRENDS DUE TO CATCHMENT CHANGES

T.V. Hromadka II[1] and T.J. Durbin[2]

Abstract

Anticipation and mitigation of changes in sediment transport trends, such as due to urbanization of a catchment and resulting changes in runoff flow trends, is an important factor in nonstructural solutions in floodplain management because changes in sediment transport can result in changes in the flood carrying capacity of a watercourse. Almost all sediment transport relationships found in the literature equate sediment load, in a flow of storm runoff, to flow rate, by use of the well-known power law mathematical model involving two parameters; namely, a coefficient and an exponent. Some equations relate sediment load to flow velocity by use of the power law equation. Other equations relate sediment load to flow rate, or a flow rate in excess of a threshold flow rate. For most conditions, where changes in erosion or deposition is primarily due to changes in flowrate (such as due to urbanization and/or diversion effects), the changes in sediment transport trends can be readily related to the changes in catchment runoff trends (or flow rate trends) by examining the cumulative changes in the ratio of each storm's sediment transport load for a time history of storm events.

Using this approach, the sediment transport parameter needs, for a soil species, are reduced to a single parameter, the exponent, greatly simplifying the uncertainty in sediment transport estimates. By equating the computed cumulative change in sediment transport to the observed effects in the watercourse (i.e., observed or computed total erosion or deposition), the proportion of the observed effects caused by the particular changes in the catchment can be estimated.

---

[1] Professor , Departments of Mathematics, Environmental Studies, and Geology, California State University, Fullerton, California.

[2] Adjunct Professor, Department of Geology, California State University, Fullerton, California.

INTRODUCTION

Almost all sediment transport relationships found in the literature equate sediment load, in a flow of storm runoff, to flow rate, by use of the well-known power law mathematical model involving two parameters; namely, a coefficient and an exponent. The literature contains numerous references that list sets of load estimation equations, all of which are formulated in terms of a power law relationship (see references). Some equations relate sediment load to flow velocity or flow rate by use of the power law equation. Other equations relate sediment load to flow velocity or flow rate in excess of threshold values. For most conditions, where changes in erosion or deposition is primarily due to changes in flowrate (such as due to urbanization and/or diversion effects), the changes in sediment transport trends can be readily related to the changes in catchment runoff trends (or flow rate trends) by examining the cumulative changes in the ratio of each storm's sediment transport load for a time history of storm events.

Using this approach, the sediment transport parameter needs, for a soil species, are reduced to a single parameter, the exponent, greatly simplifying the uncertainty in sediment transport estimates. By equating the computed cumulative change in sediment transport to the observed effects in the watercourse (i.e., observed or computed total erosion or deposition), the proportion of the observed effects caused by a set or sequence of changes in the catchment can be estimated.

Sediment Transport Relationships

Sediment transport, at a fixed point along a watercourse, can be modeled by a power law equation that relates sediment load (e.g., mass of sediment per unit flow rate) to flow rate or flow velocity, of the form

$$L = \begin{cases} \alpha_1 Q^{\beta 1} & \text{(1a)} \\ \alpha_2 V^{\beta 2} & \text{(1b)} \\ \alpha_3 (Q-Q_t)^{\beta 3} & \text{(1c)} \\ \alpha_4 (V-V_t)^{\beta 4} & \text{(1d)} \end{cases}$$

where L is the sediment load; the α_i and β_i parameters are held fixed for a particular soil species; Q is flow rate; V is the flow velocity; and Q_t and V_t are a threshold flow rate and flow velocity, respectively, such that load is zero unless the threshold value is exceeded. Numerous researchers and authors (see reference list) have developed equations to predict values for the above α_i and β_i, resulting in dozens of parameter predictor equations, but the use of the well-known power law, as in Eq. (1), is common to all of these load equations. In general, β values lie in the range of between 1 and 5, with values frequently falling between 2 and 3.

In general, for a fixed point along the watercourse and for a particular range of flow rates, a logarithmic stage-discharge relationship can be developed that can be used to transform Eqs. (1b) and (1d) into the form of Eqs. (1a) and (1c), respectively. Therefore, only Eqs. (1a) and (1c) will be carried forward in this paper. The use of Eqs. (1a) and (1c) is widespread among practitioners and has found use in numerous standard computer programs and governmental agency policy guidelines (e.g., Los Angeles County Hydrology and Sedimentation Manual, p. 3.10, 1991).

Catchment Runoff Trend Changes

The effects of catchment urbanization include increased impervious areas, changes in stream flow velocities, and diversions, among other factors. These alterations generally change flow rates for a given storm, and also change the sediment delivery to the watercourse such as in a reduction in wash load due to the development of land sediment wash load sources.

At a particular point along a watercourse, the parameters used in Eqs. (1a) or (1c) generally remain the same for both the pre- and post-development conditions, for a subject species of soil particles unless there exist significant differences in channel soil properties with depth. Consequently, the sediment load for both conditions remains predicted by Eqs. (1a) or (1c) under the mild conditions that, for example, erosion (at the subject point) is not limited by sediment supply at that point (in which case a factor may be multiplied to the power law to represent a reduced sediment load) and that sediment supply, such as from wash load, does not alter the load equation parameters (for example, if wash load is reduced, the subject point may be subject to even more erosion than as represented by only considering an increase in flow rates in the equations).

Change in Sediment Transport Load for a Single Event

From the above discussions, a single storm event, can be modeled as a set of unit period flows, over time, such as estimated by a runoff hydrograph procedure, denoted as q_i, $i=1,2,\ldots,n$, where n is the number of unit periods. Then, for q_i^2 and q_i^1 being the unit period i flow rate for conditions 2 and 1, respectively, of the catchment

$$\frac{L_i^2}{L_i^1} = \frac{\alpha_1 (q_i^2)^{\beta 1}}{\alpha_1 (q_i^1)^{\beta 1}} = \left(\frac{q_i^2}{q_i^1}\right)^{\beta_1} \tag{2}$$

where L_i^2 and L_i^1 are the load estimates from Eq. (1a). A similar equation results from using Eq. (1c) in Eq. (2).

For the total storm event, k, composed of n_k intervals of unit flow rates,

$$\left(\frac{L^2}{L^1}\right)_k = \sum_{i=1}^{n_k} \left(\frac{q_i^2}{q_i^1}\right)_k^{\beta_1} \Delta t \tag{3}$$

where L^2 and L^1 are the total loads for the subject single storm event; Δt is the unit period duration; and the considerations of sediment supply are as discussed previously.

Change in Sediment Transport Load for a Storm History

For m storm events in a storm history, the total ratio of sediment load, for the load estimator of Eq. (1a), is given by

$$\frac{L_t^2}{L_t^1} = \sum_{k=1}^{m} \left(\frac{L^2}{L^1}\right)_k = \sum_{k=1}^{m} \sum_{i=1}^{n_k} \left(\frac{q_i^2}{q_i^1}\right)_k^{\beta_1} \tag{4}$$

where L_t^1 is the total sediment load involved over the storm history, for condition 1, and Eq. (3) applies for each storm event, k. Note that in Eq. (4), a $\beta_1 = 1$ results in the ratio L_t^2/L_t^1 being the ratio of total storm runoff, over the storm history, between the two catchment conditions. It is also noted that a catchment history of changing conditions can be considered in Eq. (4) by simply using the appropriate runoff values. A similar equation, to Eq. (4), results in the use of Eq. (1c).

Estimating the Proportion of the Change in Sediment Transport caused by a Particular Change in Catchment Conditions

Equation (4) can be used to estimate the proportion of, for example, observed erosion at a particular location, caused by a change in the catchment (that primarily only causes a change in runoff trends, i.e., the change in runoff trends is the primary factor that explains the change in sediment transport trends).

For example, if the erosion observed at a particular site is depth D_o, occurring over T_o years, and for the total storm history of T_o years Eq. (4) results in

$$\frac{L_t^2}{L_t^1} = r \tag{5}$$

where, for example, condition 1 represents natural unurbanized conditions and condition 2 is the evolving urbanization occurring over the T_o years, then an estimate of the proportion, P, of observed erosion D_o, caused by the changing catchment conditions is

$$P \cong \begin{cases} 0\ ; & r \leq 1 \text{ (i.e., little change in erosion trends is estimated)} \\ (r - 1)\ ; & r > 1 \end{cases}$$

For example, if r = 3 in Eq. (5), then P = 2.0, or an increase in erosion rate of 200%, over condition 1, is estimated, and hence about 2/3 of the observed erosion is estimated to have been caused by changing catchment conditions, by use of the above equations and assumptions. Naturally, other factors enter into the above analysis, such as a change in threshold flow rate or flow velocity values, and changes in sediment supply. For example, if wash load is decreased by urbanization, then sediment supply is reduced, and Eq. (6) underestimates the impact of urbanization in increased erosion.

CONCLUSIONS

Anticipation and mitigation of changes in sediment transport trends, such as due to urbanization of a catchment and resulting changes in runoff flow trends, is an important problem in the analysis of the environmental effects of urbanization. Almost all sediment transport relationships found in the literature equate sediment load, in a flow of storm runoff, to flow rate, by use of the well-known power law mathematical model involving two parameters; namely, a coefficient and an exponent. Some equations relate sediment load to flow velocity by use of the power law equation. For most conditions, where changes in erosion or deposition is primarily due to changes in flowrate (such as due to urbanization and/or diversion effects), the changes in sediment transport trends can be readily related to the changes in catchment runoff trends (or flow rate trends) by examining the cumulative changes in the ratio of each storm's sediment transport load for a time history of storm events.

Using this approach the sediment transport parameter needs, for a soil species, are reduced to a single parameter, the exponent, greatly simplifying the uncertainty in sediment transport estimates. By equating the computed cumulative change in sediment transport to the observed effects in the watercourse (i.e., observed or computed total erosion or deposition), the proportion of the observed effects caused by the changes in the catchment can be estimated. In this paper, an easy to use equation is developed that can be applied in estimating the effects of urbanization in cases of observed increases in erosion, or in predicting future increases in erosion, for mild assumptions regarding sediment supply and channel soil homogeneity.

REFERENCES

1. Simons, Daryl B., and Sentiirk, Fuat, 1992, Sediment Transport Technology, Water and Sediment Dynamics, Water Resources Publications, p. 544 to 550.
2. Henderson, F.M., 1966, Open Channel Flow, MacMillan Publishing Co., Inc., New York and Collier MacMillan Publishers, London, p. 435 to 448.
3. Morris, Gregory L. and Fan, Jiahua, 1998, Reservoir Sedimentation Handbook, Design and Management of Dams, Reservoirs, and Watersheds for Sustainable Use, McGraw-Hill, p. 9.34 to 9.39, 11.14.
4. Leopold, Luna B., Wolman, M. Gordon, and Miller, John P. Fluvial Processes in Geomorphology, Dover Publications, p. 181 to 184.
5. Maidment, David R., Handbook of Hydrology, Part 4, Hydrologic Technology, Chapter 21, Computer Models for Surface Water by J.J. DeVries and T.V. Hromadka II, McGraw-Hill, Inc., p. 12.31 to 12.36.
6. Linsley, Ray K. and Franzini, Joseph B., 1972, Water-Resources Engineering, Second Edition, McGraw-Hill Book Company, p. 171 to 173.
7. Sedimentation Engineering, Vanoni, Vito A., Editor, reprinted 1977, American Society of Civil Engineers, p. 472 to 480.
8. Hromadka, T.V. II, McCuen, R.H., DeVries, J.J., and Durbin, T.J. Computer Methods in Environmental and Water Resources Engineering, Lighthouse Publications.
9. Los Angeles County Hydrology and Sedimentation Manual, 1991, p. 3.10.

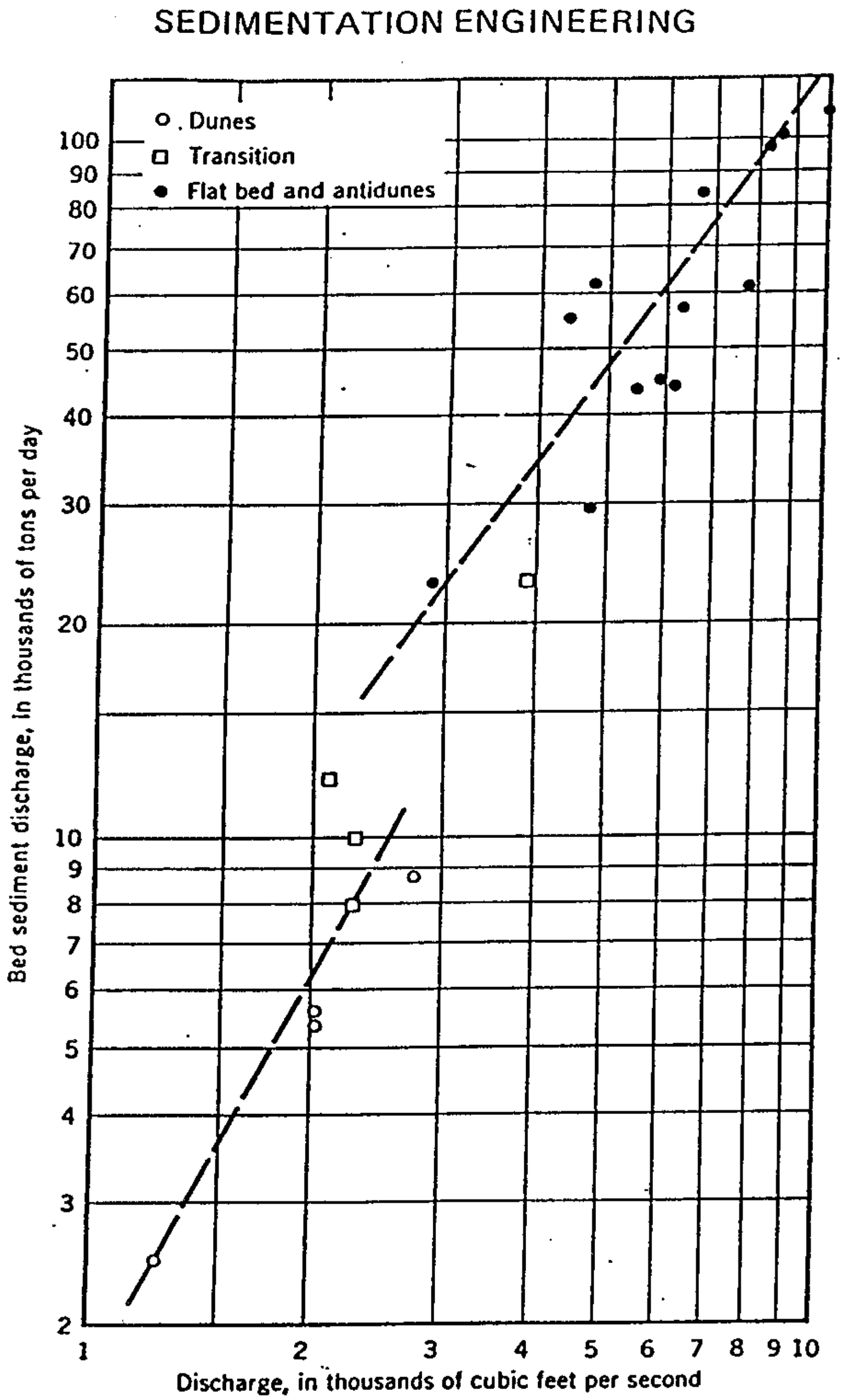

Figure 1. Bed sediment discharge vs. water discharge at Section F of Rio Grande, near Bernalillo, New Mexico (Nordin 1964).

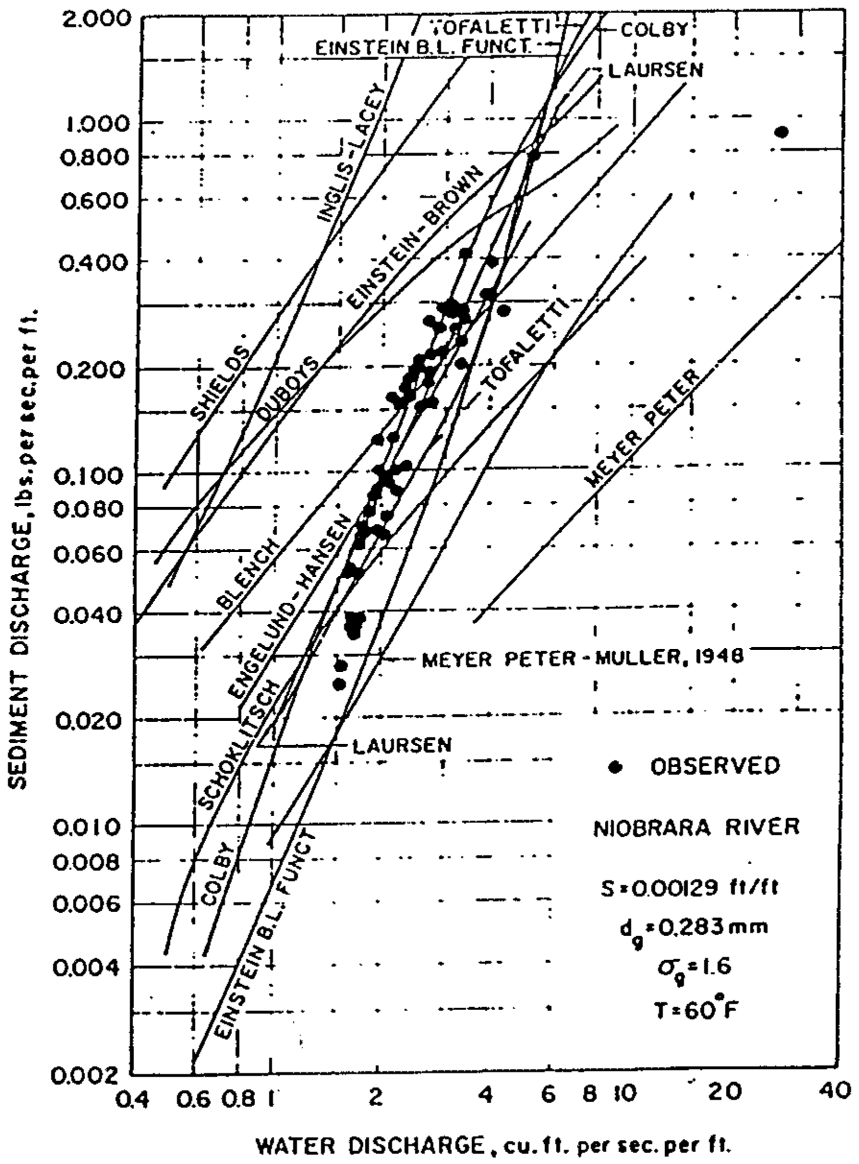

Figure 2. Sediment discharge as a function of water discharge for Niobrara River near Cody, Nebraska obtained from observations and calculations by several formulas (Vanoni 1977).

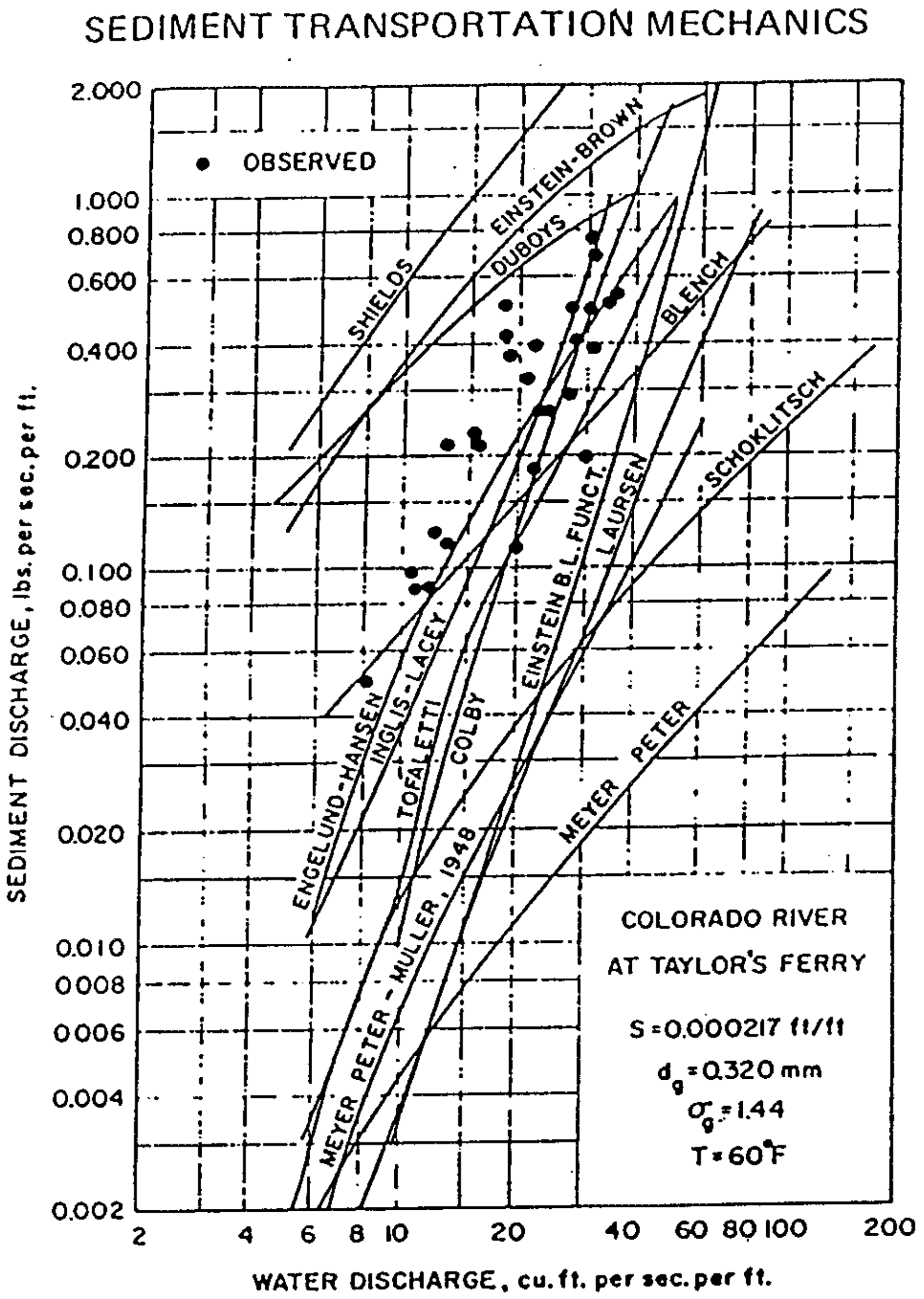

Figure 3. Sediment discharge as function of water discharge for Colorado River at Taylor's Ferry obtained from observations and calculations by several formulas (Vanoni 1977).

SEDIMENT TRANSPORTATION MECHANICS

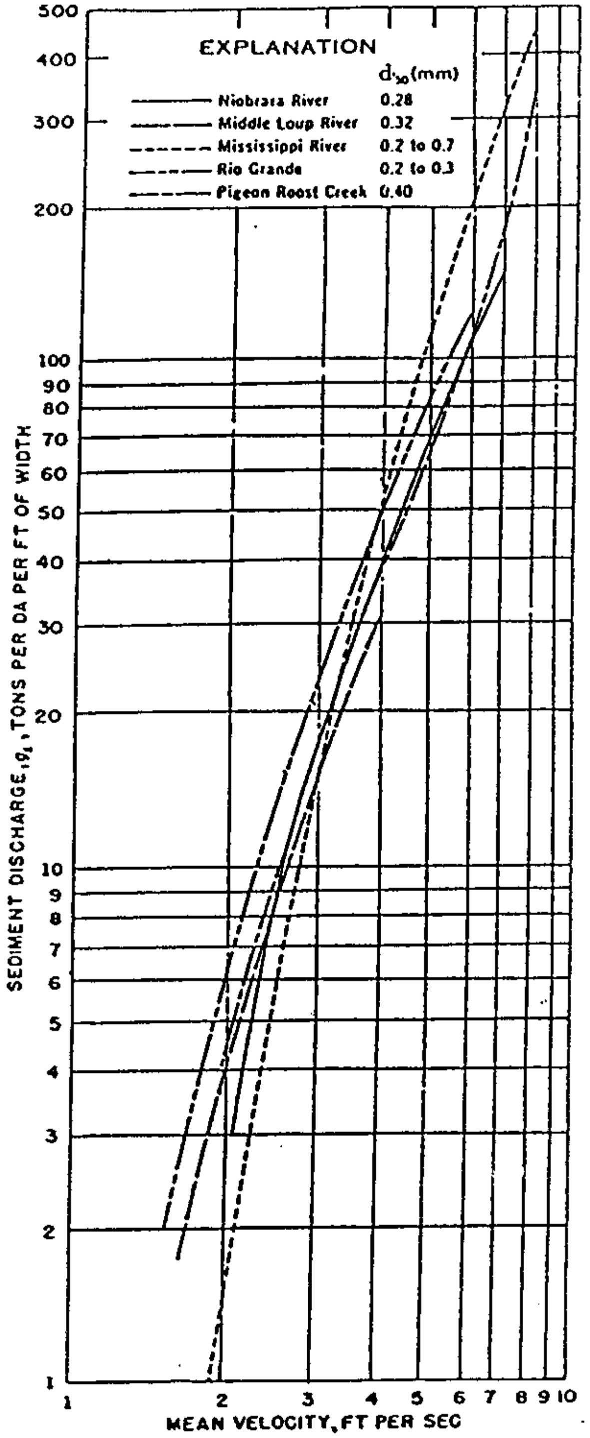

Figure 4. Relationship between observed discharge of sands and mean velocity for five sand-bed streams at average temperatures of about degrees F (Colby 1964b).

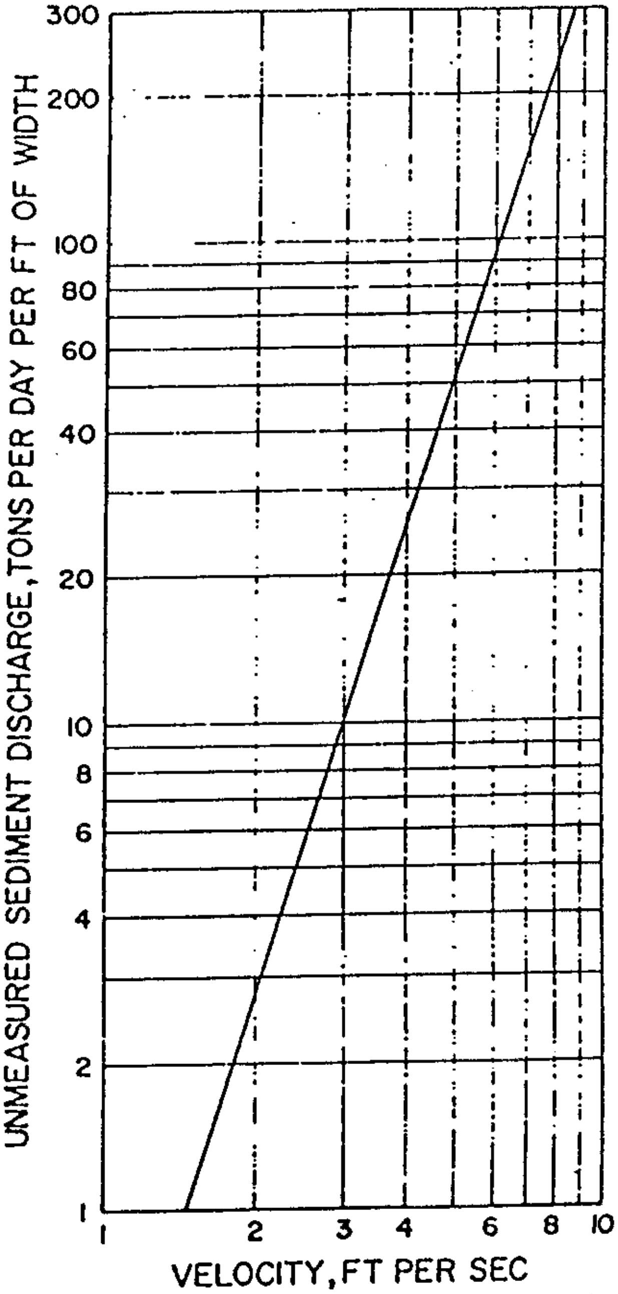

Figure 5. Unmeasured sediment discharge and mean velocity (Colby 1957).

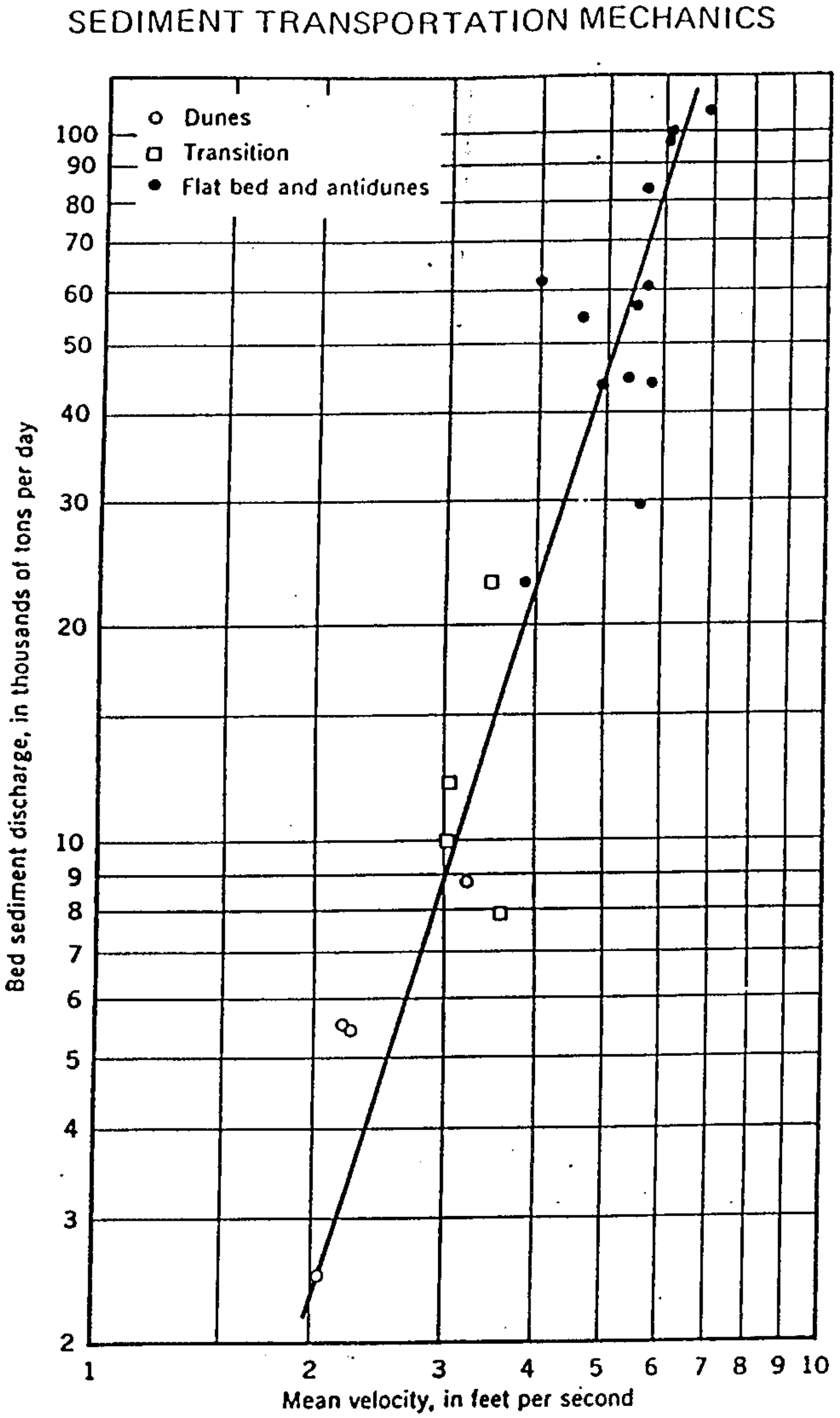

Figure 6. Bed sediment discharge and mean velocity for Section F of Rio Grande, near Bernalillo, New Mexico (Vanoni 1957).

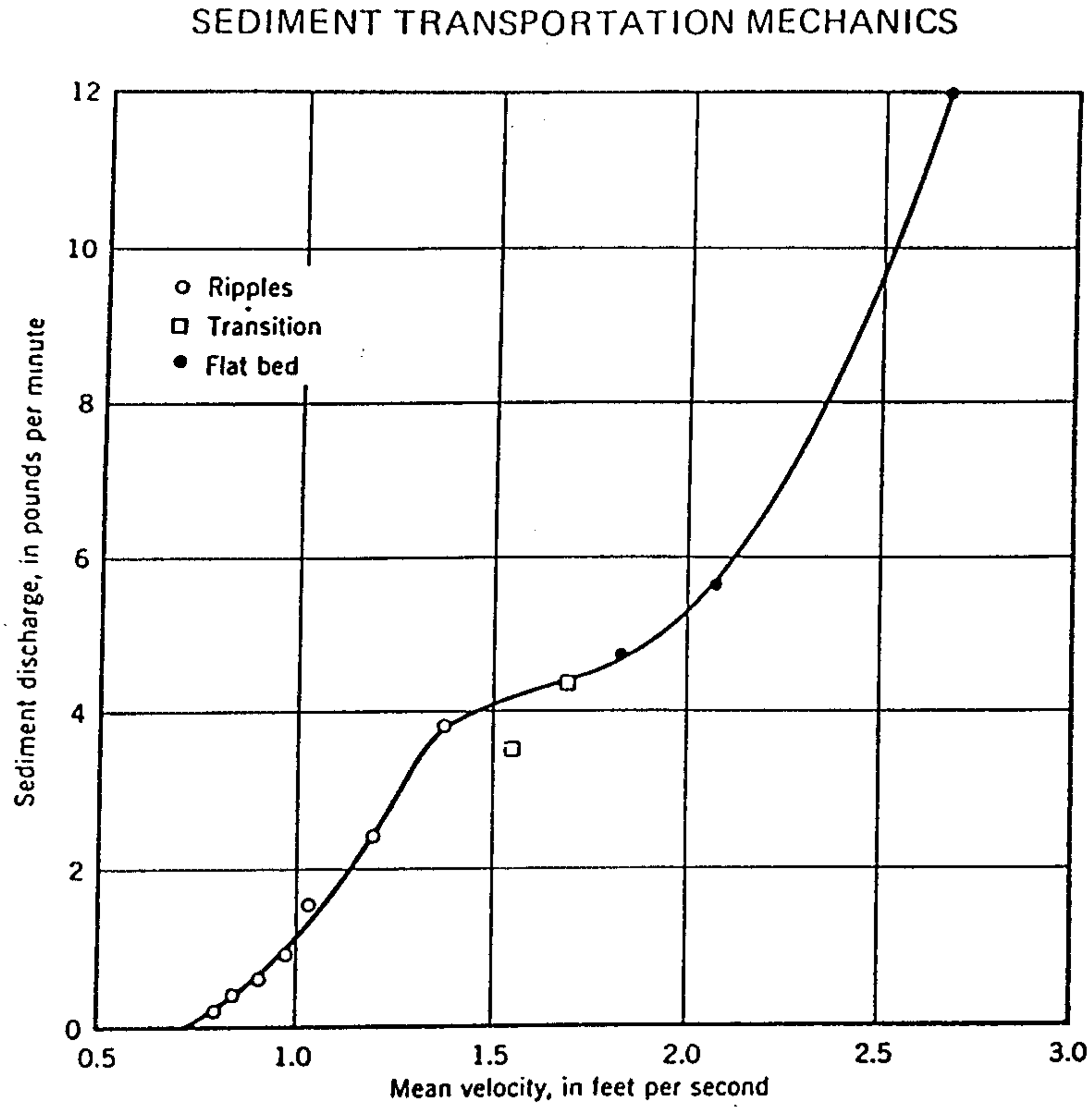

Figure 7. Sediment discharge as function of mean velocity for flow 0.241 feet deep in bed of fine sand (Vanoni 1977).

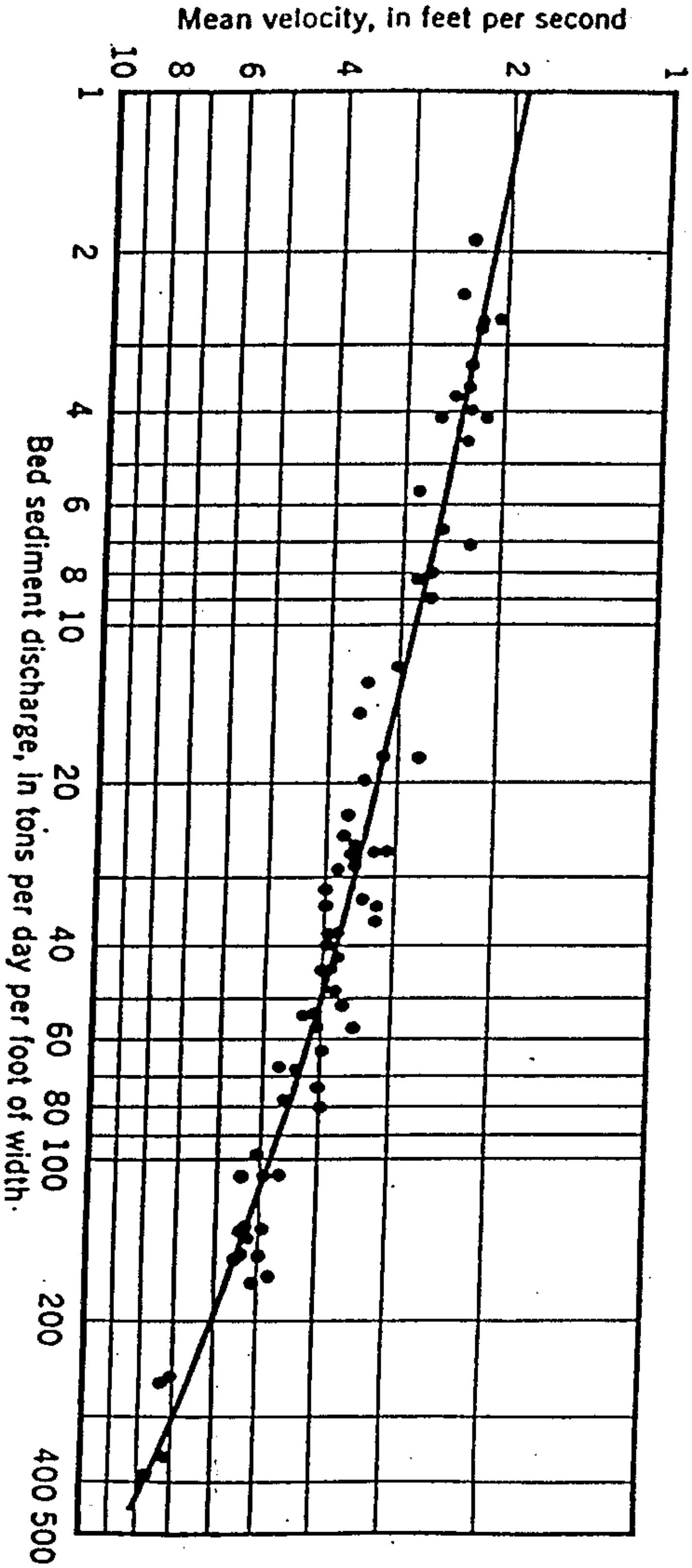

Figure 8. Bed sediment discharge and mean velocity for Mississippi River at St. Louis, Missouri (Colby 1964).