Pertanika J. Sci. & Technol. 7(1): 57-67 (1999)

ISSN: 0128-7680

Regime Hydraulic Concepts and Equations: The Case of Klang River, Malaysia

Aziz F. Eloubaidy, T. A. Mohammed, Abdul Halim Ghazali and A. B. Jusoh[1]

Faculty of Engineering, Universiti Putra Malaysia, Serdang, Malaysia

[1]Faculty of Applied Science, Universiti Putra Malaysia, Terengganu, Malaysia.

Received 15 September 1998

ABSTRAK

Kertas kerja ini mengutarakan hasil penilaian dan ujian terhadap persamaan rejim sungai sedia ada yang melibatkan berbagai faktor di dalam mereka bentuk sungai lanar. Analisis bagi data makmal dan lapangan yang berkaitan, yang di perolehi daripada empat stesen penyukatan di sepanjang laluan Sungai Kelang, dilakukan untuk menghasilkan konsep dan persamaan baru bagi ciri-ciri sungai tersebut. Persamaan-persamaan yang meliputi cerun, kadaran dan aliran dihasilkan melalui teknik analisis dimensi yang mengaitkan parameter-parameter geometri dan aliran.

ABSTRACT

Updating and testing of available river regime relationships governing the various factors involved in alluvial river design are presented. Analysis of relevant laboratory and field data, gathered from four gauging stations along the water course of Klang River in Malaysia, were undertaken in order to formulate new regime concepts and equations characterizing the river. The functional formulations, to include the slope, rating and flow equations were achieved by employing dimensional analysis techniques relating the geometry and flow parameters.

Keywords: alluvial rivers, flow regime equations

INTRODUCTION

The hydraulic characteristics of natural alluvial streams or rivers are unpredictable and specific regime theory studies and analysis are needed in order to determine their regime concepts. The changes in river pattern such as flow depth, discharge, slope, and width of water surface add to the difficulty in determining these concepts. All these factors are dependent on each other and detailed study for each is needed in order to obtain sufficient and reliable relationships governing the various factors involved.

Results of studies assessing the hydraulic behaviour of fluvial rivers are important and are usually needed for the proper designs and implementations of hydraulic structures along the water course of such rivers. The hydraulic structures include flood control, diversion and storage structures together with other works related to training or meandering of the river. Since 1895, many researchers have written extensively on the regime theory of fluvial rivers based upon field data and observations mostly collected from European and American rivers and canals. But, a relatively recent study undertaken on the River Nile in Egypt (Khalil, 1975) and that of a more recent studies on the Tigris and Euphrates Rivers within the Mesopotamia Plain (Eloubaidy and Mohammed, 1995) have revealed different concepts and formulations as compared to earlier publications. So, in this research work it is suggested to perform a parallel study on the Klang River to formulate relationships involving the various factors governing the flow and geometry of the river. In this context, a semi empirical procedure, through dimensional analysis techniques, has been developed and is presented herein.

SOME PREVIOUS REGIME STUDIES ON ALLUVIAL RIVERS

The evolution of the canal regime concept was initiated by Kennedy (1895) during his studies of problems associated with the irrigation canals in India. Introducing the type of bed material as a contributing factor in the regime process of alluvial canals, Kennedy has proposed the following empirical formulation between the velocity, V, and depth of flow, D,

$$V = 0.84\ m\ D^{0.64} \tag{1}$$

in which m is a coefficient, defined as critical velocity ratio, and its value depends on soil type of bed material.

An important step towards the establishment of the regime theory was made by Lindley (1919), who has concluded that a change in the geometry of the section, to include depth of flowing water and/or gradient of bed, will occur when silty water is to be conveyed, until a state of balance is attained at which the channel is said to be in regime. The regime dimensions depend on discharge, quantity and nature of bed and sides, size of silt and roughness of the silted section. From data containing 786 observations, Lindley has formulated the following relationships:

$$V = 0.95\ D^{0.57} \tag{2}$$

$$V = 0.59\ B^{0.355} \tag{3}$$

in which B is the canal width. By eliminating V from the above two equations, the following equation can be deduced:

$$B = 3.80\ D^{1.61} \tag{4}$$

Perhaps the most well known regime equations are those developed by Lacey (1946). Based upon data collected by Kennedy and Lindley, the Mandras Land data and others from the Ismaelia Canal in Egypt, Lacey has published lists of regime equations and concepts. The results of his analysis are the following empirical relationships (in English units) :

$$V = 0.801\ Q^{0.166}\ f^{-0.33} \tag{5}$$

$$R = 0.4725\ Q^{0.33}\ f^{-0.33} \quad (6)$$
$$P = 2.67\ Q^{0.5} \quad (7)$$
and
$$S = 0.00055\ Q^{-0.16}\ f^{1.66} \quad (8)$$

in which Q is the discharge ; R denotes the hydraulic radius ; P represents the wetted perimeter ; S is the energy gradient ; and f is the silt factor = $1.587\ \sqrt{d}$, where d is diameter of the predominant sediment transported.

Blench (1957, 1961) has reported that a canal regime must depend not only on the characteristics of the sediment transport, but also on the bed material. The mean depth, D, surface width, T, and canal slope, S, were expressed as :

$$D = (F_s/F_b^{\,2})^{1/2}\ \sqrt{Q} \quad (9)$$
$$T = (F_b/F_s)^{1/2}\ \sqrt{Q} \quad (10)$$
and
$$S = (F_b^{\,5/6}\ F_S^{\,0.5}\ \upsilon^{0.25})\ /\ (3.63\ Q^{1/6}\ g) \quad (11)$$

where F_b and F_s are Blench factors for bed and side, respectively, F_b = 1.9 =d and F_s values vary from 0.1 to 0.3, depending on the cohesiveness of the bank material; υ is the kinematic viscosity of water; and g represents the gravitational acceleration.

Henderson (1966) has examined the data prepared by Simons and Albertson (1960) for a wide range of conditions of American canals and streams from which the following equations (in English units) were developed:

$$B = 0.9K_1\ Q^{0.25} \quad (12)$$
$$D = 1.21\ K_2\ Q^{0.36} \quad \text{for } R < 7\text{ft} \quad (13)$$
$$D = 2.0 + 0.93\ K_2\ Q^{0.36} \quad \text{for } R > 7\text{ft} \quad (14)$$
and
$$V^2/gDS = K_3\ (VB/\upsilon)^{0.37} \quad (15)$$

The values for the coefficients K_1, K_2 and K_3 are given in relations to soil types forming the bed and banks.

In line with Laycey's formulations (Eqs. 5, 6 and 7), many river regime studies [Pettis (1937), Nixon (1959), Nash (1959), and Leopold and Maddock(1953)] have correlated the width, depth, and velocity with discharge to provide the following empirical regime expressions:

$$B = C_1\ Q^a \quad (16)$$
$$D = C_2\ Q^b \quad (17)$$
$$V = C_3\ Q^c \quad (18)$$

where the numerical values of the exponents (a, b, c) and the constants (C_1, C_2, C_3) are all dependent on the stream and the location of gauging station where the data are obtained. Also, and according to the above formulations, continuity principle requires that:

$$a + b + c = 1 \quad (19)$$
and
$$(C_1)\ (C_2)\ (C_3) = 1 \quad (20)$$

Khalil (1975) , in summarizing the regime relationships developed for the River Nile, departed from the conventional channel regime concept and concluded that the variables involved are interrelated such that for a given discharge, Q, and sediment load, Q_s, the depth, width and slope are mutually adjusted. The same general conclusion but with different values of coefficients correlating the variables involved, were made by a recent regime study undertaken by Eloubaidy and Mohammed (1995) on the Tigris and Euphrates Rivers within the Mesopotamia Plain.

The range of application of the regime theory has been steadily increasing from canal to sand bed streams and rivers and, more recently; Julien (1988) and Heg and Heritage (1988), to rough and gravel bed rivers but these latter applications have highlighted a lack of field data. It is worth noting that the regime theory has started as an empirical subject and it is to remain firmly based on observations.

DATA ACQUISITION

The relevant field data concerning the river regime were collected at four stations along the water course of the Klang River in Malaysia. The designated numbers of the four stations are 3116430, 3116432, 3116433, and 3116134. The stations are distributed along the river water course with distances ranging from 12 km to 16 km apart. The station 3116134 is the nearest to the mouth of the river, at a distance of 65 km. The collected field data were concurrent for all stations for one calendar year. The measured field data required for the analysis at each station include: a) the mean daily discharge, b) the bed slope of river, c) cross sectional area of flow, d) gradation of bed materials, e) stage vs. discharge, and f) sediment concentration. It should be noted that the ten-day mean discharges for the calendar year 1974 and their corresponding depths have formed the basic data for the present analysis.

Slope Determination

Assuming a uniform flow condition and based upon basic principles of hydraulics, the slope of the river bed and that of the longitudinal water surface profile, and the energy gradient are equal to each other. So, field land levelling works were undertaken to measure the natural water surface slope at each of the four selected gauging stations. For the relation of slope, S, and distance, L, downstream from a location where the slope is S_o, the field data for the Klang River furnished an exponential equation characterizing many other rivers which is of the following formulation:

$$S = S_o \, e^{-\beta L} \tag{21}$$

For the Klang River, $\beta = 0.11$.

Gradation of Bed Materials

Several representative soil samples of bed materials were taken from the field at each gauging station. Sieve analyses were made to determine the mean size diameter of bed materials at each location. It was found that the mean size is decreasing with distance downstream along the water course of the river. This expected finding is attributed to the sorting action of the flow where the finer particles are carried forward while the coarser particles are deposited to constitute the bed load materials at a given location. The field data are grouped about a straight line, on a semi-log graph, that conforms to the relation:

$$d = d_o e^{-\alpha L} \tag{22}$$

where d is the mean size of bed particles at a distance L downstream from a location where the grain size is d_o. For Klang River, analysis of data revealed that the value of the constant α is 0.25.

RIVER REGIME FUNCTIONAL FORMULATIONS

It is known that a natural river has four degree-of-freedom, while a canal has three degree-of-freedom; the additional fourth degree-of-freedom being the river meandering. A canal is usually straight or only mildly curved such that the development of the canal is under control. Canal discharge can be kept fairly constant but the river discharge is subjected to fluctuations which may be considerable. It could be stated, according to Nixon (1959), that the discharge that dominates the river geometry occurs for less than three days in the year. The topography of the river course will determine its slope while the canal slope is fairly under control.

Dimensional Analysis

A dimensional analysis of the problem will provide an evaluation in dimensionless terms which will be completely general. A study of the conditions of river regime reveals the problem to be a consideration of the following variables:

Geometric properties: R, B, S, and d

Flow properties: V, Q, Q_s, τ_o, and g

Fluid properties: υ, ρ, and ρ_s

in which τ_o is the bed shear stress; ρ denotes the water mass density; ρ_s represents the particle mass density; and g is the gravitational acceleration. Other symbols are as defined before.

In the analysis of the problem, the following parameters could be eliminated: τ_o (since, for uniform flow, it is mainly a function of R and S), V(since it is related to Q, B, and R, for a wide channel), and B(since from the practical point of view, it is impossible to control R, B and S simultaneously). Also, for a certain river, ρ, ρ_s, υ and g may be regarded as constants, so that the problem may be stated as:

$$\phi_1(R, S, Q, Q_s, d, g) = 0 \tag{23}$$

Using dimensional analysis techniques, the problem reduces to:

$$\phi_2(Q^{2/5}/g^{1/5} R , Q_s/Q , R/d , S) =0 \tag{24}$$

The solution illustrated in the above equation may be evaluated in terms of the available laboratory and field data by assigning various values to some factors and observing the resultant effects on the remaining parameters.

Slope Equation

In the light of the functional relationship given in Eq. 24 and at any gauging station, Q_s/Q and R/d are regarded as constant, the following regression equation is obtained:

$$Q^{2/5}/g^{1/5}\ R = wS^{z} \qquad (25)$$

where w and z are numerical constants. Based on the measured field data, the values of these constants obtained from this investigation and those obtained for the Nile River, Khalil (1975), and the Tigris and Euphrates, Eloubaidy and Mohammed (1995), are summarized in Table 1. The results illustrate that there is no unique bed slope for a river in regime and the value of w is a function of silt concentration.

TABLE 1

Typical average values for the constants w and z

River	Location and Average Silt Concentratio	w	z
Tigris	North of Bahdad (200 ppm)	1.2	1/6
	South of Baghdad (1200 ppm)	2.0	
Euphrates	North of Falluga (400 ppm)	1.1	1/5
	South of Falluga (1750 ppm)	1.8	
Klang	For all stations (concentration not available)	1.28	1/4
Nile	North of Khartoum (2000 ppm)	7.25	1/8
	South of Khartoum (200 ppm)	5.45	

The Rating Equation

Referring to Eq. 24 , a relationship is to be established between $Q^{2/5}$ and R for the various gauging stations. Based upon the premise that at any station both S and Q_s/Q are constant, and neglecting R/d effects, a plot of $Q^{2/5}/g^{1/5}$ versus R is made for each station. The straight line relationship, as shown in *Fig. 1*, indicates that:

$$Q^{2/5}/\ g^{1/5} = k\ R \qquad (26)$$

The calculated values for the coefficient k for the Klang River ranged between 0.32 and 2.92 for the four stations. It could be stated, therefore, that the variables R, S, Q and silt concentration in an alluvial river are interrelated and for a given discharge and silt concentration, the depth and slope are mutually adjusted to attain the regime condition.

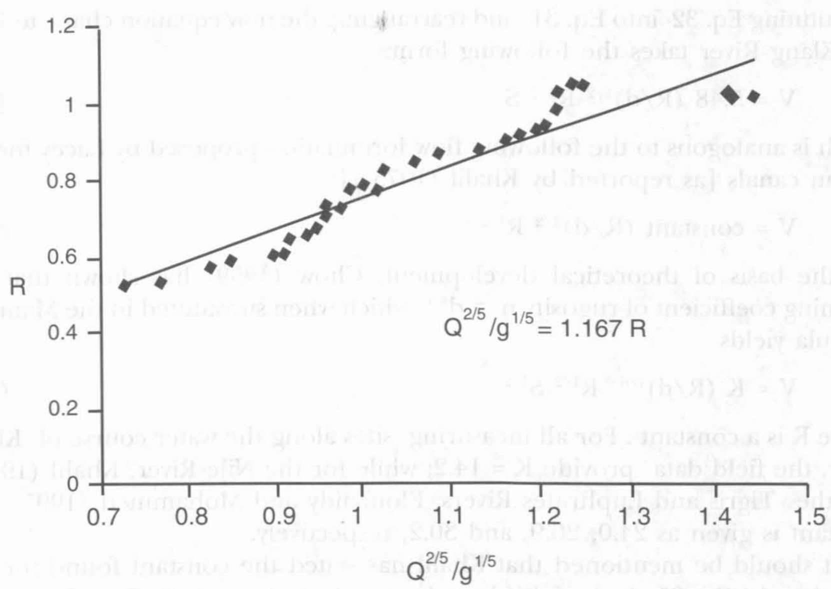

Fig 1. Relationship between hydraulic radius and discharge (station 3116433)

Flow Regime Equations

It was observed by Buckly (1923) and Khalil (1975) for the Nile River and then by Eloubaidy and Mohammed (1995) for the Rivers Tigris and Euphrates that the mean velocities in these alluvial rivers differ in magnitudes from those calculated with $(RS)^{1/2}$. For all sites on these rivers, the measured field data furnished the following relation:

$$V = (\text{constant})\ RS^{0.25} \qquad (27)$$

where $V = 1.45\ RS^{0.25}$ (for the Nile River) (28)

$V = 1.90\ RS^{0.25}$ (for the Tigris River) (29)

and $V = 2.50\ RS^{0.25}$ (for the Euphrates River) (30)

To test such formulation and to ascertain a numerical constant applicable to the Klang River, the field data gathered from the four stations yielded the following expression:

$$V = 3.61\ RS^{0.25} \qquad (31)$$

Now, a recourse is made to compare Eqs. 21 and 22 from which it is evident that the grain size, d, is a function of longitudinal slope, S. From a plot of log d versus log S, for the four measuring sites along the Klang River, the following relation is deduced

$$d = 2.31\ S^{1.5} \tag{32}$$

Substituting Eq. 32 into Eq. 31 and rearranging, the flow equation characterizing the Klang River takes the following form:

$$V = 5.48\ (R/d)^{1/2}\ R^{1/2}\ S \tag{33}$$

which is analogous to the following flow formulation proposed by Lacey for the Indian canals [as reported by Khalil (1975)]:

$$V = \text{constant}\ (R/d)^{1/2}\ R^{1/2}\ S \tag{34}$$

On the basis of theoretical development, Chow (1959) has shown that the Manning coefficient of rugosity $n \cong d^{1/6}$, which when substituted in the Manning formula yields

$$V = K\ (R/d)^{1/6}\ \ R^{1/2}\ S^{1/2} \tag{35}$$

where K is a constant . For all measuring sites along the water course of Klang River, the field data provide K = 14.2; while for the Nile River, Khalil (1975), and the Tigris and Euphrates Rivers, Eloubaidy and Mohammed (1995), the constant is given as 24.0, 26.9, and 30.2, respectively.

It should be mentioned that Khalil has stated the constant found for the Nile river in Eq. 35 is most likely to be a universal constant. But, due to the fact that his analysis is based upon a single site measurement of grain size and river slope, one should expect that the constant is neither representative of the River Nile nor it is a universal constant. The findings of this regime study substantiate the conclusion that there is no universal constant in the flow equation. The expected variation could be attributed to differences in geometry, morphology and flow pattern.

As to the relatively large disagreement in values of the constant K for the Klang River and those of the other three rivers mentioned above, the following explanations could be provided:

- The relatively short reaches between measuring stations taken on the Klang River as compared to those on the other rivers.
- The two tributaries to the Klang River between gauging stations considered in this study could have an effect on the natural water surface slope (backwater curves) at stations starting from the points of confluence in the upstream direction. In addition, these tributaries could have changed the natural sizing of the bed load of the Klang River by bringing in a variety of new materials.

Other Regime Formulations

The empirical general regime formulations (Eq. 16, 17, and 18) indicate that during the regime process the depth, width and the mean velocity at a river cross section do vary with variation in mean discharge. Based upon field observations taken at the four stations along the Klang River, the average numerical values obtained for the exponents a, b, and c are 0.5, 0.3, and 0.2 respectively, and those for the constants C_1, C_2, and C_3 are 8.3, 0.4, and 0.3, respectively. It is worth noting that:

$$a + b + c = 0.5 + 0.3 + 0.2 = 1.$$

and $$(C_1)(C_2)(C_3) = (8.3)(0.4)(0.3) = 0.996 \approx 1$$

As a result, one may conclude that Eq. 19 and 20 are satisfied and thus the Klang River is in regime condition.

CONCLUSION

Within the scope and limitations of the field and experimental data, the following conclusions could be made:

- While there is no unique rating equation describing the regime of the river in all its reaches, the Klang River may be divided into several longitudinal parts described by the same formulation with different values for the coefficients.
- The flow regime equation obtained for the Klang River is consistent with that of Lacey's findings on the Indian canals.
- The Manning formula is given in terms of the mean grain size of bed materials.
- Empirical formulations relating discharge and regime parameters show that the Klang River is in regime condition.

REFERENCES

BLENCH, T. 1957. *Regime Behaviour of Canals and Rivers.* London: Butterworth Scientific Publications.

BLENCH, T. 1961. *Hydraulics of Canals and Rivers of Mobile Boundary.* London: Butterworth Scientific Publications.

BUCKLEY, A. B. 1923. The Influence of Silt on Velocity of Water Flowing in Open Channels. *Minutes of Proceedings of Institution of Civil Engineers, England* **216(2)**: 183-211.

CHOW, V. T. 1959. *Open Channel Hydraulics.* McGraw-Hill Company.

ELOUBAIDY, A. F. and T.A. MOHAMMED. 1995. River Regime with Special Reference to the Tigris and Euphrates Rivers within the Mesopotamia Plain. Technical Report, Ministry of Irrigation. Baghdad, Iraq: Limited circulation.

HEG, R. D. and G. L. HERITAGE. 1988. Dimensional and Dimensionless Regime Equation for Gravel-Bed Rivers. In *Proceedings of International Conference on River Regime.* Wallingford, U.K.

HENDERSON, F. M. 1966. *Open Channel Flow.* New York: Macmillan Publishing Company.

JULIEN, P. Y. 1988. Downstream Hydraulic Geometry of Noncohesive Alluvial Channels. In *Proceedings of International conference on River Regime,* p. 9-16. Wallingford, U. K.

KENNEDY, R. G. 1895. The Prevention of Silting in Irrigation Canals in India. *Proceedings of the Institution of Civil Engineeres,* Vol. CXIX, London, U.K.

KHALIL, M. B. 1975. River Regime with Special Reference to River Nile. *Journal of the Hydraulic Division* ASCE **101** **(1)**: 135-153.

LACEY, G. 1946. A General Theory of Flow in Alluvium. *Journal of the Institution of Civil Engineers* **27(1)**: 16-47.

LEOPOLD, L. B. and T. MADDOCK. 1953. The Hydraulic Geometry of Stream Canal, and Some Physiographic Implications. *Professional Paper, U.S. Geol. Survey, Paper No. 252.*

LINDLEY, E. S. 1919. Regime Canal. *Proceedings,* Vol. 7. Punjab Engineering Congress.

NASH, E. A. 1959. A Study of the Bank-full Discharge of Rivers in England and Wales. *Proceedings of the Institution of Civil Engineers* **14**: 403-406.

NIXON, M. 1959. A Study of the Bank-full Discharge of Rivers in England and Wales. *Proceedings of the Institution of Civil Engineers* **12**: 157-174.

PETTIS, C. R.1937. Stable channels in erodable materials. *Transactions ASCE,***102**: 149-152.

SIMONS, D. B., and M. L. Albertson. 1960. Uniform water conveyance in alluvial materials. *Journal of the Hydraulic Division. ASCE,* **86** **(5)**: 33-73.

APPENDIX—NOTATION

a,b,c	=	numerical constants
B	=	canal width
C_1, C_2, C_3	=	numerical constants
D	=	depth of flow
d	=	mean size of bed particles
F_s	=	Blench's side factor
F_b	=	Blench's bed factor
f	=	silt factor
g	=	gravitational acceleration
L	=	length or distance
P	=	wetted perimeter
Q	=	discharge
Q_s	=	discharge of sediment
R	=	hydraulic radius
S	=	longitudinal river slope
T	=	surface width of water
V	=	mean velocity
υ	=	kinematic viscosity
α	=	exponent

β	=	exponent
ρ	=	water mass density
ρ_s	=	particle mass density
τ_o	=	bed shear stress
ϕ	=	function