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Derivation of Rating Curve for Suspended Sediment Flow of River Indus at Besham

Shafeeq-Ur-Rehman [1] Muhammad Mudassar Abbasi [2]

Abstract: *This study aims at reclaiming the huge amount of wastewater, produced from pulp and paper industry by physico-chemical treatment method following a combination of primary settling, coagulation-flocculation aided clarification (alum, lime and magnesium sulphate as coagulant) and activated carbon adsorption, in order to reduce the quantity of wastewater generation, from this water intensive industry. The chemical secondary treatment indicate the reduction in turbidity (89%), COD (84%), Total Suspended Solids (90%) and colour (89%) was obtained at the mass loading of 3400 mg l-1 of MgSO4, when 4 hours primary treated effluent was further treated by coagulation flocculation process. The combination of primary settling and lime coagulation (optimum dosage of 1400 mg l-1) resulted in effluent turbidity removal of 94%, COD reduction of 86%, TSS (Total Suspended Solids) removal of 93% and colour removal of 91.6% at initial pH of 11. The results showed that plain settling with 4 hours of retention time was effective for reducing the pollution load form pulp and board mill wastewater and this treatment step could reduce the pollution parameters up to 30%. This water could be recycled back into production process. Pilot scale study and further investigation is required before implementation of proposed treatment technology.*

Key Words: Rating Curve, Suspended Sediment Flow, River Indus, Besham, Coagulation-flocculation

Introduction

The purpose of this report is to present conceptual models of suspended load sediment transport. The suspended load transport model attempts to account for variations in sediment supply with respect to flood intensity.

Mean discharges at sampling date have been fitted to the suspended sampling load of the day using least squares regression on log transformed data. In addition, the data set for the rating was subdivided according to season and four separate rating relationships were developed for data set. Besham Qilla is the last gauging station of the series established in upland of Indus River. The study at this site is therefore important to understand the behavior of upper Indus basin.

Objectives of Study

The main objectives of this report are summarized as follow:

a) To investigate the flow rate variation of the Indus River Besham Qilla.
b) To determine the sediment load of the relevant discharge data.
c) Statistical analysis of sediment load and flow rate at data collection point.
d) Conceptual modeling of suspended load and sediment transport.

Limitations

Assumptions of uniformity in channel dimensions, flow and sediment characteristics are general features of many sediment transport equations, yet these assumptions do not often match the natural variability

[1] Superintending Engineer Mega Projects, Mardan, Khyber Pakhtunkhwa, Pakistan.
[2] Assistant Professor, Department of Management Sciences, COMSATS University Islamabad, Abbottabad Campus, Khyber Pakhtunkhwa, Pakistan. Email: mmudassarabbasi@cuiatd.edu.pk

▪ Corresponding Author: Shafeeq-Ur-Rehman (engrshafiq2005@gmail.com)
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of sediment availability, channel characteristics and flow conditions associated with streams. This variability is summarized as fallow:

(1) variable source areas of sediment
(2) Transient flow
(3) Particle size gradations
(4) Non-uniform channel geometry and flow
(5) Dynamic / adjusting channels.

Literature Review

Introduction

Rivers are very effective transport agents which, through associated erosion and depositional activity are responsible for changes in the morphology of fluvial systems. There are several possible space and time scales for considering such activity, each valid for its own specific purpose.

Gravel-bed River

Gravel-bed Rivers are generally found near the head of a river system, while sand-bed rivers occur at the lower, flatter reaches. Thus gravel-bed rivers are generally in upland regions and are therefore nearer the primary sources of sediment. Sediment supply events tend to be periodic and non-uniform in their spatial distribution, with the result that the in-channel sediment transport is both unsteady and non-uniform, even for steady water discharges (Bathurst, 1985)

Channel Pattern Changes

Channel Patterns generally classified in the most basic form as straight, meandering or braided. The pattern type is thought to depend on discharge, slope and sediment load. (Bradley & McCutcheon, 1985)

Characteristics of Gravel-bed Rivers

Regarding sediment supply, very often the bed material encountered when sampling gravel, cobble and boulder-bed rivers may appear to consist of abnormally large sizes exposed on the bed of stream. (D.B Simons & Simons 1985)

Variations in Bed Scour and Fill

The rapid change in the bed elevation can be most commonly in braided sand-bed rivers where the major currents can quickly shift laterally filling existing channels and forming new ones. (D.B Simons & R.K Simons 1985).

Variations in Channel Slopes

Generally the gradient of stream is directly correlated with the median diameter of the bed material forming the stream, the steeper the river the coarser the material on the bed of channel (D.B Simons & R.K Simons 1985).

Variations in Sediment Transport

In the simplest form, it can be concluded that the sediment transport in sand-bed channels varies as a function of the velocity to approximately the fifth power. For gravel-bed rivers, there are fewer equations and fewer tests to base them upon, and it is difficult to obtain field data in these highly dynamic, rapidly flowing rivers. There it is suggested that the sediment transport is proportional to the velocity to about third power. In any event regardless of the form of river, our ability to calculate the rates of sediment transport accurately are limited (Simons & Simons, 1985).

Mountain Torrent Erosion

Mountain torrent erosion takes several forms depending on channel slope, flow depth and sediment properties. Massive erosion such as slope failure and debris flow during heavy rain accounts for a considerable part of the erosion in torrents steeper than some critical value. In mountain torrents for which slope are under the critical value, only the erosion of individual particles occurs.

Conceptual Models of Sediment Transport in Streams

Introduction

The downstream movement of inorganic particles involves an investigation of processes occurring over a wide range of spatial and temporal scales. Some particles may begin movement in headwater catchments, be routed through the entire channel system and be deposited on an ocean floor during a single storm event. Others may similarly enter the channel system during a storm event and, because of different hydraulic conditions, particles size or some other factors, may more only short distance or not at all. Subsequent movement of these particles may consist of incremental downstream transport over relatively short distances, intermingle with long residence times during which little if any change in position might occur. Hence, the complex array of processes and variables influencing sediment transport makes generalization difficult (Lawson ad O'Neil 1975).

Deterministic and Probabilistic Relations or Models

The relationship among variables may or may not be governed by an exact physical law. For convenience, let us consider a set of n-pairs of observations (Xi, Yi). If the relation between the variables is exactly linear, then the mathematical equation describing the linear relation is generally written as

Yi = a + bXi

Where a is the value of 'Y' when 'X' equals zero and is called the Y-intercept, and 'b' indicates the change in 'Y' for a one-unit change in 'X' and is called the slope of the line. Substituting a value for 'X' in the equation, we can completely determine a unique value for 'Y'. The linear relation is such a case is said to be a deterministic model.

Scatter Diagram

A first step in finding whether or not a relationship between two variables exists, is to plot each pair of independent dependent observations {(Xi , Yi), where i=1,2,3,........,n} as a point on graph paper, using the X-axis for regression variable and Y-axis for the dependent variable. Such a diagram is called a sector diagram or a sector plot. If a relationship between the variables exists, then the point in the sector will show a tendency to cluster around a straight line or some curve. Such a line or curve around which the points cluster, is called the regression line or regression curve which can be used to estimate the expected value of the random variable 'Y' from the values of the non-random variable 'X'.

Co-efficient of Determination

The co-efficient of determination which measures the proportion of variability in the values of the dependent variable (Y) explained by its linear relation with the independent variable (X), is defined by the ratio of the explained variation to the total variation. We use the symbol r^2 for the estimate obtained from sample (Prof. Sher M. Chaudhry1968 et. al.).
Thus the sample co-efficient of determination is given by
$r^2 = [a\Sigma Y + b\Sigma XY - (\Sigma Y)^2/n] / [\Sigma Y^2 - (\Sigma Y)^2/n]$

Curve Fitting by Least Squares

Approximating Curve and the Principle of Least Squares

For this purpose, some of many common types of approximating curves and their equations are given as:

A straight line or linear curve	$Y = a + bX$
A parabolic of second degree or quadratic curve	$Y = a + bX + cX^2$
A parabolic of third degree or cubical curve	$Y = a + bX + cX^2 + dX^2$
An exponential curve	$Y = ab^x$ or ae^{bx}
A geometric power curve	$Y = aX^b$
A hyperbola	$1/Y = a + bX$

In all these equations, Y is the dependent variable and X, the independent variable. In some situations however, the variables X and Y can be reversed.

Fitting a Straight Line

To do so, we need to solve the two equations

$\sum Y = na + b\sum X$

$\sum XY = aVX + bVX^2$

Solving these two normal equations simultaneously, we get

$b = [n\sum XY - \sum X\sum Y] / [n\sum X2 – (\sum X)2]$..........(1)

and $a = Y' – bX'$ .... (2)

$Y' = (\sum Y) / n$ and

$X' = (\sum X) / n$.

Geometric power curve is most co-relating discharges with sediment flow. In order to get a straight line from geometric equation, following procedure is adopted:

$Y = aX^b$

Taking log of both sides

$\log Y = \log a + b \log X$

Or $Y = A + bX$

Solving it with the help of (1) & (2), we get the values of 'a' and 'b'.

Now a = Anti log A

In our case, general equation is form $Q_s = aQ_b$

Where

Q_s = Sediment load in short (tons per day).

Q_b = mean daily discharge at Besham Qilla.

Description of the Project Area

Study Area

For the purpose of the present study the drainage area may be divided into three sub areas;

(1) Area outside the political boundaries of Pakistan. Water contributed to Besham is derived primarily from snow and glacier melt and from rainfall.

(2) Area within the political boundaries of Pakistan and outside of the monsoon area. Water contributed to Besham is derived primarily from snow and glacier melt and from very meager rain fall.

(3) Area within the political boundaries of Pakistan and in area subject to monsoon rains (in general below latitude 35°). Very small area is covered under this category.

Himalayas

The Himalayas are a series of several more or less parallel or converging ranges, intersected by large valleys and extensive pleatues, rather than a single continuous chain or range of mountains.

Indus River

It receives the waters of Shyok River at an elevation of about 8,000 feet just south west of Skardu, and the Shigar near Skardu. After flowing northwesterly some distance further, it turns southerly and is joined by the Gilgit, south-east of Gilgit. Passing beneath the Hattu pir it swings westerly and flows past Gor, Chilas and Sazin. Turning south some 15 miles west of Sazin, the Indus continues southerly and emerges at Besham.

Glaciers

The greater Himalaya area, with peaks reaching above 20,000 feet, receives large quantities of snow which feed a great number of glaciers, some of which are among the largest in the world outside of the Polar Regions. The majority of the present Himalayan glaciers are small, about 2 to 3 miles in length, but some range from 24 up to 38 and 40 miles long. The largest glaciers are found in the Karakoram. Range on the Indus drainage.

Suspended Sediment Data

Suspended sediment samples taken near Besham indicate that from mid-October to mid-April the sediment concentration is low, hardly exceeding 200 ppm. During the period mid-April to mid-October the sediment concentration is reported to increase to an average figure of about 8,000 ppm. The sediment as analyzed from samples taken at the Besham station has been determined to consist of about 60% sand, 33% silt and 7% clay.

Sources of Sediment

Glaciers transport various amounts of debris derived from abrasion of rocks over which they travel and other sources. Certainly some debris is released each year by melting; the amount varying with the characteristics and degree of melting of the numerous glaciers.
Table 3.1 is a general tabulation of the various sources of sediment and manner in which sediment from various sources is available for transported by the Indus River. Some alluvial deposits or sources of sediment are a combination of several types or origins.

Temporary River Damming

The steep side slopes of the Indus and some tributaries combined with schistose rocks of adverse orientation and subject to seismic action is conductive to large landslides or rock falls that can lead to the formation of temporary dams. The complex arrangement of alpine type glaciers can also cause temporary interruption of drainage by dams formed of moraine and/or ice blocks. It is reported that an ice dam forms each year on the Shimshah River, a tributary to the Hunza River, blocks of ice and possibly moraine, form a dam that impounds snow and glacier melt water. It is reported that the Shimshah ice dam breaks each year between June 15 and July 15.

Stream Gauging Station at Besham

Besham station is at river Indus about 130 km upstream of Tarbela Dam. This site covers about 96% of the catchment for Tarbela dam. In addition to the climatological instruments such as manometer, evaporation pan, thermometer, rain gauges (recording and non-recording) there is an automatic gauge recorder, sediment sampler P-50 (for high flows), sediment sampler P-63 (for low flows), bed material sampler BM-8-62 and a current meter.The gauge observations are recorded hourly. The discharge measurement is carried out twice a week (Thursday and Monday), while suspended sediment sampling is done daily during flood season.

Data Collection and Evaluation

Sediment Sampling Procedure

The river width is divided into several sections and observations are taken at regular intervals (normally at 60ft). The sampler is first lowered to the river bed and then raised by 1ft to 1.5ft. At this point nozzle of the sampler is opened and sampler is raised gradually to the surface. From each section one sample is collected in all 7 to 9 samples are collected daily during high flows.

During site visit the sediment sampling was demonstrated. The information of observed data is as follow:

Gauge height	19.2 to 19.3ft
Sampler	P-63
Nozzle	1/8
(Brass).	

Table 1

Sediment Sampling Procedure

Sample No	Distance from Left	Gauge Height	Clock Timing	Sample Depth	Total Depth	Time (sec)
1	160	19.30	15:00	8.4	9.4	21
2	250	19.25	15:10	16.4	15.5	18
3	340	19.20	15:20	22.0	23.5	16
4	430	19.20	15:30	20.7	21.7	16
5	520	19.20	15:40	18.5	19.5	19

The sampler was lowered to the bottom, then raised by 1ft kept there for one minute nozzle opened and then raised gradually to get depth integrated sample. After each sample was collected, the trolley was moved to right bank where sample bottle was removed and empty bottle fixed in the sampler.

Bed material sampling is not done regularly. Bed sampling can be performed during low flows. During high flows bed samples may be taken at points close to the bank because in the middle of the river the sampler is carried away by the flow and it is not possible to take bed sample.

Remarks on Sampling Procedure

At Besham station sediment sampling procedure seems to be an unsettled matter. In this context, different procedures have been contemplated uptil now as given below:

1. According to the note brief summary of sediment sampling, Tarbela dam project, the samples at Besham are collected once or twice a week during low flow season and twice or thrice a week during high flow season. The cable is marked at quarter, centre and three quarter of the river width where suspended sediment sampler P-63 is lowered and samples are collected at 3 to 4 depths.
2. During the first periodic inspection (1987), it was observed that sediment samples were obtained at three locations at 1/3, ½ and 2/3 river width. At these locations point samples were obtained at 0.2, 0.5 and 0.8 of flow depth. Thus in all 9 point samples were taken.
3. Dr. Sabol in his note of June 17, 1987 contemplated that at three locations in the river, depth integrated samples should be obtained in the following manner:
    a) Divide water depth in three equal parts. Start from the bottom of the river and obtain separate samples for three parts. Then start from the top and obtain separate samples for the three parts. Thus at one locations six samples will be collected and in all eighteen samples will be obtained.
    b) At present six to nine depth integrated (D.I) sediment samples are obtained at Besham station in the manner as described above.
    c) For selection of the most appropriate sampling procedure at Besham station, it is suggested that all procedures be tried and results compared. The procedure yielding the best results is adopted in future.

Data Evaluation

In general, the records indicate a relatively long period of observations at the sediment gauging station. The suspended sediment discharge data is not available on daily basis, but instantaneous sediment discharge records are available. The sediment concentration (ppm) is multiplied with mean daily discharge (cusecs) and a factor $[(62.4/10^6) * (24 * 60 * 60) = 0.002696]$ for obtaining daily sediment load (MST). Same concentration is used till next reading available.

Because of the difficulties associated with quantifying the total amount of suspended sediment available to a stream and any changes in available over time, it is not surprising that most suspended sediment transport models are based upon empirical relationships between sediment concentration and water discharge. The most useful model of this type is the sediment –rating curve:

$C = aQ_b$

Where C = suspended sediment concentration, m/v; Q = stream discharge, v/t; a and b = coefficients determined by linear regression between 'log C', m = mass of sediment; v = volume of water; t = time. The suspended sediment load or transport C can be simply obtained by multiplying the sediment concentration by stream discharge.

Thus

$C' = aQ^{b-1}$

Where C' has units of m/t. by integration over time, the total yield for individual storms, runoff events or other periods can be evaluated.

Alternately, an equation of the following form may be used;

$Q_s = aQ^b$

Where Qs = suspended sediment load, m/t and Q = stream discharge.

In general, the results of the study reveal that average annual suspended loads derived from rating curves matches well with the computed values.

Basic Equation

Data of the mean daily discharge at suspended sediment sampling days and sediment concentration was obtained from Wapda. Flow pattern of the river Indus at Tarbela and Besham is quiet similar, therefore regression analysis between flow at Tarbela and Besham was performed for the year 2009 and correlation was extended to 1985 to find out flow at Besham Qilla during study period. Mean daily discharge at Tarbela on suspended sediment sampling days is given in Annex. I. Mean daily discharge at Tarbela Q_T and Besham Q_B for the year 2009 is given in Annex. II and their graphical relation have shown in Annex.III. Governing equation for flow at Besham is:

$Q_B = 4 \times 10^{-7}(Q_T)^2 + 0.916(Q_T) - 1.106$

For the above equation, coefficient of determination (r^2) is 0.998. Data derived from above equation and used for further analysis is given in Table 5.1.

From the data, rating relationship of the form:

Sediment load $Q_S = a\,Q^b$ was established.

Where Q = mean daily discharge of the sampling date have been fitted to the data set using least squares regression on log transformed data.

Trifurcating the Data

In order to find the relationship in the desired form $Qs = a\,Q^b$, Log of both sides have been taken. Equations (1) & (2) described in section 4.6 have been used for calculating values of coefficients a and b as follows:

$b = [n\sum LogQ\,LogQs - \sum LogQ\sum LogQs] / [n\sum (LogQ)^2 - (\sum LogQ)^2]$........ (1)

And $A = LogQs' - b\,Log\,Q'$...(2)

$LogQs' = (\sum LogQs) / n$

And $LogQ' = (\sum LogQ)/n$

Also $a = Anti\,Log\,A$

Summary of Results

The results have been calculated by the method of least squares. The method has been explained in detail in chapter 2. Summary of the results have been given as follow:

Table 2

Summary of results

Relationship	A	b	r^2	N
Whole data	8 x 103	2.47	0.93	2194
Rising stage (Apr-June)	5 x 10-7	2.32	0.87	551
Peak (July-Sep)	9 x 10-7	2.27	0.72	792
Falling Stage (Oct- March)	3 x 10-6	2.12	0.61	851

From above table, it is clear that sediment load is high during rising stage, when compared with peak flood period. Moreover, it is lowest during falling stage.

A general curve for whole data and three segmented curves have been fitted on scatter diagrams plotted on Log-Log scale and are shown in Fig. 5.1 to 5.4.

Alternate Technique

From perusal of the Figure 5.5, relation of suspended sediment load Qs in MST with flow of water in Q million cusecs is as water:

Qs = 6.67*Q – 6.97

Mean discharge of sediment can be calculated by multiplying the mean annual runoff of the river.

The load duration data for the year 2009 plotted in Fig. 5.7 indicate that during 30% of period, sediment load was negligible. On the other hand, 64% of the total suspended load was transported in 30 percent of the study period.

Conclusions and Recommendations

Conclusion

Assumptions of uniformity in channel dimensions, flow and sediment characteristics are inherent features of sediment transport equations, yet these assumptions do not often match the natural variability of sediment availability, channel characteristics and flow conditions associated with streams. This variability is summarized as follows:

(1) Variable source areas of sediment affecting sediment availability and inputs to channel systems (e.g. land-use particles, fire occurrence and severity, storm magnitude, land form, geology and soils, etc.).

(2) **Transient flow:** During storm and/or snow melt events, which represent periods when most sediment transport occurs within the channel system, conceptual models of sediment transport in streams flows are continually changing

(3) **Particle size gradation:** The range of particle sizes comprising the channel beds and banks and their spatial distribution with in the stream system can have profound effects on transport processes. Of particular importance is the role of the armour layer.

(4) **Non-uniform channel geometry and flow:** Meanders, large and small roughness elements (e.g. woody debris and boulders), pools/rippled, etc; are examples of channel characteristics, which indicate that flow are seldom uniform.

(5) **Dynamic/adjusting channel:** Variability in sediment availability and flows interacts to affect hydraulic geometry (width, depth, bed form, plan form etc.) of self-formed (alluvial) channels. Thus, even 'stable' channels may be dynamic around a long-term regime condition.

In view of these variable conditions, it is easy to understand why a wide variety of factors have been associated with sediment transport in streams. Because factors may be affecting suspended load and bed load differently, these two major categories of sediment sizes need to be considered independently.

The search for a general solution will continue to improve our understanding of the mechanisms and parameter interactions involved in the movement of the sediment. From the perspective of the particular problem, however, there are two concerns with the general approach. Firstly, an equation is considered to be forming well if most or even half of the predicted transport rates are within a factor of two of the corresponding observed rates. Secondly, trends within a particular data set often do not match the overall trend of the combined database. These factors combine to yield a low level of confidence and potentially large extrapolation errors in any particular case.

Recommendations

Due to final constrains the Hydrologic Services practice of more frequent observations in flood season than in flow periods, so as a general practice, concentration hydrograph and sediment rating curve methods are used for the estimation of annual sediment load.

For the most reliable sediment yield estimates frequent and continuous data records are required and cannot safely be derived by interpolation. Observations have to be made more frequently, especially in peak flow periods.

For further improvements in discharge observation and sediment sampling at Besham station, it is suggested to provide a motorized cableway trolley system, a direct reading current meter, and a sonic sounder to observe bed profile. Also two additional gauges, one upstream and the other downstream of the existing site should be installed to calibrate the reach for measuring discharge by slope-area method.

A study of sediment transport in individual sub-catchments of Indus River and their combine impact at Besham Qilla may be conducted for advancement in understanding 'River Engineering' to make this report more meaningful.

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Appendix

Table 1

Sources of Sediment

General type of Location	Simplified Origin	Type of Material	Method of Contribution of Sediment to Indus
Valley fill and fans Indus and tributaries. Some may be lacustrine.	Stream aggradation due to base level change or by damming. Material derived mainly from glacial outwash, stream erosion of rock or older alluvial deposits	Clay size through sand to large gravel and some boulders may be satisfied.	Primarily by present degradation of Indus and some tributaries. Some sheet erosion.
Old moraines at various elevations. Old streams terrace deposits at various elevations.	Older remnants of glacial activity, stream erosion and deposition	Clay size up to large blocks	Sheet erosion by snow melt or runoff. Some tributary stream erosion.
Relatively recent moraines.	Recession of glacial front.	Sand to boulders	Stream erosion
Talus on steep slopes	Mechanical disintegration of bed rock.	General coarse, but may contain fines	Gravity, snow melt or rainfall runoff. Snow avalanche. Lubrication by freezing and thawing.
Mentally in relatively flat areas	Mechanical disintegration of bed rock.	Generally sand size, especially in granite rock areas.	Sheet erosion by snow-melt or rain fall runoff wind.
Soil mantle in moon soon belt	Normal weathering processes of bed rock in areas subject to rainfall	Clay to sand	Stream erosion. Sheet erosion, where not protected by vegetation (availability may be aggravated by culture i.e. logging)
Glacial melt release	Abrasion of bedrock by ice. Advance of glacier over older alluvial deposits.	Clay size (rock floor) to sand rock floor predominates	Glacial melt
Aeolian (demes).	Reworking of alluvial deposits of sources by wind.	Silt to sand	Generally by wind
Soft rock areas	Various	Generally fine grained	Erosion by various methods assisted by weathering

Table 2

Indus River Flow (In 100 CFS) vs Sediment Concentration at Besham Qilla

Date	Flow	PPM	Date	Flow	PPM	Date	Flow	PPM
Jul25,2004	2067	2355	May9,2005	601	1505	Nov30,2005	174	83
31	2473	1380	15	1370	1340	Dec1,2005	174	83
Aug1,2004	2777	1380	16	1319	1195	9	127	63
5	3841	1410	23	1126	1050	15	137	54
15	2585	1390	28	1055	979	20	183	69
20	1673	1803	31	1075	974	26	118	81

Date	Flow	PPM	Date	Flow	PPM	Date	Flow	PPM
25	1885	2090	Jun1,2005	955	974	30	127	81
31	1422	1835	6	777	812	Jan1,2006	146	77
Sep1,2004	1463	1835	13	757	2328	8	118	72
10	1045	1835	20	1651	3085	15	118	78
15	866	2350	27	1443	2513	22	99	97
21	1319	1810	Jul1,2005	2035	2513	Feb5,2006	90	79
25	1391	965	5	1578	3130	12	99	44
30	846	132	7	1422	3470	19	127	94
Oct1,2004	757	132	11	1831	3585	26	155	82
5	505	132	16	2133	4165	Mar5,2006	99	61
10	400	132	20	1579	4830	12	118	44
15	343	134	25	2462	4600	19	109	44
20	296	141	31	2936	4600	26	109	79
27	286	145	Aug1,2005	3507	4600	Apr9,2006	164	82
Nov1,2004	259	131	3	3377	5310	16	174	140
5	277	102	4	3663	4820	23	183	137
20	230	35	7	2003	4330	30	220	172
30	211	127	8	1992	4750	May7,2006	400	783
Dec1,2004	211	127	10	2003	5170	14	767	171
10	174	163	11	1949	3915	22	925	1160
15	174	111	18	1694	2195	29	826	1990
21	183	121	29	1370	1730	Jun5,2006	1258	2080
31	137	42	31	1707	1030	8	1055	2170
Jan1,2005	155	42	Sep1,2005	1778	1885	13	1247	6630
5	137	37	5	1578	2685	15	1599	14600
15	176	38	7	1578	26830	18	1707	2450
20	127	38	9	1474	1798	21	1197	1480
30	146	38	12	955	1023	25	1237	1620
Feb1,2005	174	48	15	797	599	28	116	1540
15	127	66	18	915	117	Jul2,2006	1620	3707
20	109	66	21	1085	105	7	2253	3840
25	164	50	25	718	94	9	5575	4720
29	220	54	27	582	78	12	1608	5439
Mar1,2005	220	54	30	476	61	16	2585	3793
8	155	74	Oct1,2005	476	61	19	1897	3973
15	127	68	5	409	63	23	2165	3990
21	174	76	12	333	62	30	1981	3477
30	183	113	18	267	68	Aug6,2006	1712	3690
Apr1,2005	192	113	25	239	73	9	1821	2490
5	192	143	31	239	73	13	1746	2977
11	192	131	Nov1,2005	239	16	16	2057	2870
20	277	218	7	249	79	20	1662	2783
25	314	966	15	211	76	23	2057	2437
30	343	966	22	220	79	27	1319	3047
May1,2005	314	966	27	192	94	30	1288	2273

Table 3

Indus River Flow (In 100 CFS) vs Sediment Concentration at Besham Qilla

Date	Flow	PPM	Date	Flow	PPM	Date	Flow	PPM
Sep6,2006	1146	1310	Jul-02	2264	3087	Mar25,2008	186	38
10	806	674	26	1725	2383	Apr1,2008	339	47
17	572	318	Aug5,2007	1725	3073	11	258	188
20	467	291	7	1970	2827	19	420	197
24	390	94	12	13132	4900	30	455	189
27	371	120	14	3590	5067	May1,2008	503	323
Oct8,2006	333	152	19	1789	2276	13	808	1310
15	249	66	21	1725	2407	19	979	1044
22	249	246	26	2231	3087	26	1159	1170
29	202	90	28	2308	3230	Jun2,2008	1317	1906
Nov5,2006	258	121	Sep2,2007	2111	2763	4	1927	2163
12	174	51	4	1715	1853	16	1999	1410
19	202	51	9	816	420	18	2213	1600
26	164	33	11	826	408	23	2581	1403
Dec3,2006	155	23	16	660	433	25	2348	2170
10	109	27	18	738	406	Jul7,2008	2904	2300
16	99	28	23	582	334	9	2839	2300
24	155	31	25	582	380	14	2184	2103
Jan7,2007	99	61	Oct2,2007	396	259	21	2625	2806
14	90	22	8	366	155	23	3073	3313
26	90	44	14	362	172	Aug4,2008	2855	3503
28	90	49	18	289	136	6	2498	2720
Feb4,2007	109	15	21	255	99	11	2051	2233
11	118	30	26	266	81	13	1683	2073
18	90	43	28	244	64	20	1912	8543
25	146	33	31	241	63	29	1190	978
Mar4,2007	99	46	Nov2,2007	226	63	Sep1,2008	1390	1200
11	174	49	4	211	32	8	1216	1008
18	137	61	5	211	54	15	931	821
25	220	292	11	205	45	24	944	6654
Apr4,2007	174	346	15	193	47	Oct6,2008	393	95
8	211	159	19	190	148	13	347	108
15	230	110	25	178	248	27	265	65
18	239	101	Dec1,2008	168	32	Nov,3,2008	267	65
22	296	686	5	163	33	10	257	71
May5,2007	230	26	11	147	40	17	251	37
13	263	836	16	137	46	24	221	35
20	1005	154	20	176	59	Dec1,2008	146	39
27	1075	848	25	162	71	8	160	115
Jun3,2007	1443	366	30	137	44	15	219	100
6	1906	291	Jan1,2008	124	16	22	179	129
10	2089	2403	11	122	9	Jan5,2009	141	138
13	1970	1790	21	112	30	12	132	123
17	2025	2027	31	101	45	19	141	139
24	1895	1507	Feb1,2008	106	35	26	144	79
27	1757	1480	6	93	38	Feb6,2009	147	160
Jul1,2007	2046	1283	15	171	109	9	177	114
4	2264	3073	22	144	54	16	137	115
8	2433	2827	Mar2,2008	306	59	Mar1,2009	190	105
19	2024	4900	10	167	46	8	145	64
21	2363	5067	16	174	61	15	177	77

Table 4

Indus River Flow (in 100 CFS) vs Sediment Concentration at Besham Qilla

Date	Flow	PPM	Date	Flow	PPM	Date	Flow	PPM
Mar 22,09	191	118	Jan17,10	137	50	Jul21,10	2886	1800
29	177	73	24	134	20	21	2886	1890
APR5,09	218	111	Feb7,10	207	54	21	2886	1920
12	309	106	14	344	41	Aug1,10	2857	1970
19	244	137	21	193	53	1	2857	2090
26	302	108	28	191	47	1	2857	2140
MAY10,09	431	252	Mar7,10	221	99	8	2776	1780
17	914	1197	15	264	138	8	2776	2110
24	1315	2450	22	434	158	8	2776	2160
JUNE2,09	941	2800	24	332	60	10	2326	1770
14	1393	1860	Apr4,10	250	202	10	2326	2040
17	1987	1430	11	310	283	10	2326	1950
21	2367	3506	18	331	132	15	1852	2570
23	2483	2126	25	481	49	15	1852	2240
28	1344	1356	May4,10	767	404	15	1852	1900
30	1177	939	9	1009	473	17	2271	1910
Jul 05,09	1896	2186	16	806	282	17	2271	1890
7	2154	1386	23	580	373	17	2271	2530
12	2005	1906	June8,10	1253	1838	24	1709	2140
14	1810	2073	8	1253	1560	24	1709	2100
19	1616	1910	8	1253	2150	24	1709	2290
21	1432	1356	13	1288	1090	Sep7,10	1559	1830
26	1048	913	13	1288	1480	7	1559	2460
28	1528	1706	13	1288	1770	7	1559	2170
Aug2,09	1910	2820	15	1171	2549	12	1580	1560
4	1658	2016	15	1171	1750	12	1580	1620
9	1803	2130	15	1171	1990	12	1580	1090
11	1878	1980	20	1942	1460	14	1120	321
16	1672	3766	20	1942	2320	21	912	346
18	1987	2123	20	1942	1040	26	690	303
23	1542	1426	22	2125	896			
25	1337	1140	22	2125	1620			
Sep6,09	674	1510	22	2125	909			
9	702	1024	27	3471	1540			
13	1018	1423	27	3471	1170			
15	1132	1303	27	3471	1050			
20	895	1250	Jul4,10	3454	1450			
Oct5,09	449	106	4	3454	819			
11	520	57	4	3454	746			
18	279	40	6	2286	1460			
25	276	77	6	2286	1890			
Nov1,09	256	82	6	2286	1650			
8	222	60	11	2465	1470			
16	220	68	11	2465	1460			
22	216	67	11	3547	1390			
Dec6,09	176	123	13	3547	1360			
13	154	64	13	3547	2280			
20	156	110	13	3547	2020			
29	146	103	19	3411	1740			
Jan4,10	164	56	19	3411	1820			
10	164	68	19	3411	2310			