River Response to a Local, Excess Inflow of Water, Analyzed by Computer Modelling

An Honors Thesis (ID 499)

by

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INTRODUCTION

Nowadays, a typical situation with mining operations is the pumping of a considerable amount of water out of a mine and into a nearby stream. An understanding of a stream's response to this onslaught of excess water is essential for predicting future changes in the stream both upstream and downstream of the point at which the water is dumped. Engineers are an example of a group of people that might be interested in such changes if bridge supportings or piers exist along the stream. Also, people who live near the stream may be concerned with flooding. Whether or not these changes in the stream after the inflow of water are enough to be noticeable and undesirable, and the role of sediment size being transported by the stream in affecting these changes, are the two topics to be explored in this thesis.

To explore these topics, a modified fortran computer program, written by my thesis advisor as part of his Ph.D thesis (Snow, 1983), was used. With certain stream characteristics as input, this program was used to model stream response. The results from a program run are in table format, showing some of the stream characteristics at designated points along the segment of stream modeled.

The basic method of study was threefold. First, I developed a fairly realistic "stream". Second, using the computer program, I modeled a 10 km segment of the stream in its natural state. Third, I modeled the stream segment in its state after response to an excess inflow of water halfway down it. I chose 2 cu m/sec for the excess inflow since this is not an unreasonable amount to be dumped for mines. With each computer run, time of response is not known.

To test the effect of sediment size, these computer runs were done five separate times, varying only sediment size each time. Sediment size was the only control variable because the study had to be limited and so not everything could be varied. Size was chosen over discharge since variation in response due to size variance isn't as easy to predict.

EXPERIMENTAL DATA

Although the stream modeled in this experiment was a hypothetical one, stream characteristics were chosen for it based on data from actual natural streams, and also based on the typical length of 200 km that I chose for it. The major characteristics needed to be found (that is, required by the computer program used) were: water discharge at the upstream end of the river to be modeled, sediment discharge at the upstream end, change in water discharge downstream, change in sediment discharge downstream, sediment sizes being transported by the stream, channel width, and settling velocity of the sediments.

By examining the discharge characteristics of selected streams in the Missouri River basin in "Perennial-Streamflow Characteristics Related to Channel Geometry and Sediment in Missouri River Basin" (Osterkamp and Hedman, 1982), I came up with a typical value of 10 cu m/sec for discharge at the upstream end of the river segment to be modeled.

To determine a value for sediment discharge, I used the formula, A is approximately equal to $x^{1.7}$ (Snow, 1983), where A is the drainage area and x is the total stream length in kilometers. The variable "A" is then calculated to be 8,161 km^2 for the modeled stream. Using a denudation rate of 3 cm/1,000yr for lowland climatic conditions with cold winters (Bloom, 1978), sediment discharge is calculated to be 0.00007 m^3/sec. This calculation is based on the assumption that all of this 3 cm/1,000 yr. denudation becomes part of sediment load.

In calculating downstream changes in both water and sediment discharges, a linear increase in them will be assumed, since this appears to be a reasonable and simple assumption (Snow, 1983). Water discharge downstream can then be calculated to be 0.05 m^3/sec/km (10/200), while the change in sediment discharge becomes 0.00000035 m^3/sec/km (0.00007/200).

Five different sediment sizes, ranging from mud to gravel, were used: 0.002 mm (high silt-clay or very muddy), 0.0156 mm (medium silt-clay or muddy), 0.053 mm (low silt-clay or slightly muddy), 0.35 mm (sand bed), and 3.36 mm (gravel bed). Sediment size was not made to vary downstream since over a 10 km length, it would change an insignificant amount. Using these sediment sizes, both channel width (Osterkamp and Hedman, 1982) and settling velocity (Leeder, 1982) could then be determined, using figures 1 and 2, respectively.

Also necessary for setting up the conditions for the modeled stream were a sediment transport equation and a value for hydraulic roughness of the river channel (or Manning's N). The sediment transport equation used is one developed by Yang and is based on unit stream power. It is a "total" sediment load equation - not just suspended or bed load. For hydraulic roughness, a value of 0.03 was used, since this is a typical value for winding natural streams (Ritter, 1978).

RESULTS

Figure 3 and tables 1 and 2 summarize the results of the computer runs. From figure 3, it is obvious that the stream experienced noticeable, erosional changes due to the excess inflow of water, with a maximum change of 0.7 meters. Major change with sediment type is also obvious from this figure. For the three smaller sediment sizes, there is a pronounced drop in height downstream of the point at which the water

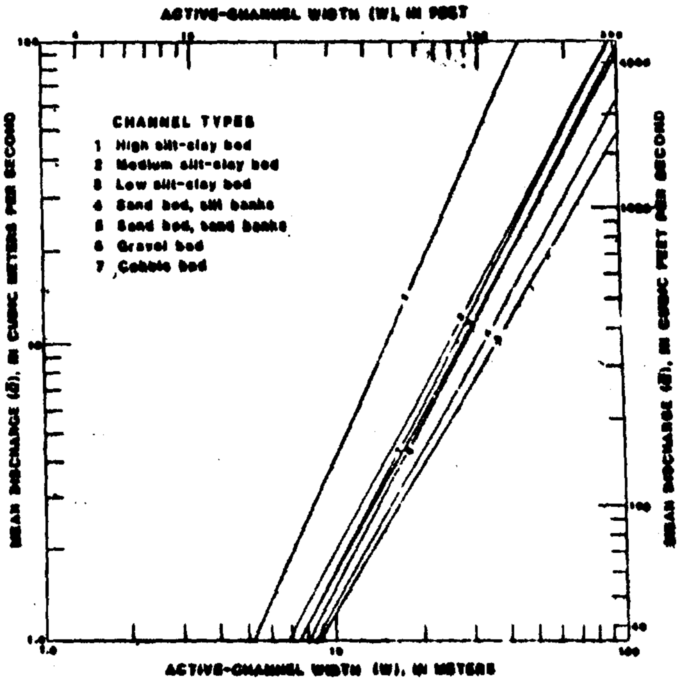

Figure 1. - Structural relations between active channel width and mean discharge for stream channels of specified sediment characteristics. (From Osterkamp and Hedman, 1982)

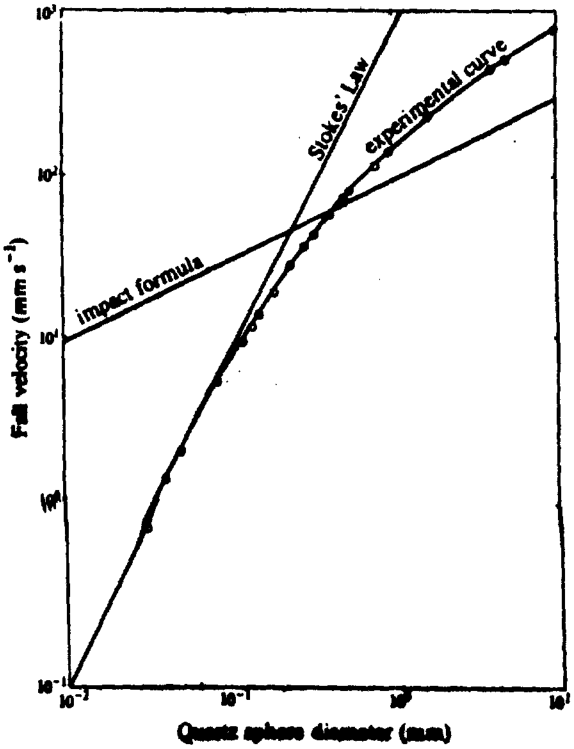

Figure 2. - Graph to show fall velocity as a function of grain diameter for quartz spheres in water at 20^{o}C.(Leeder, 1982)

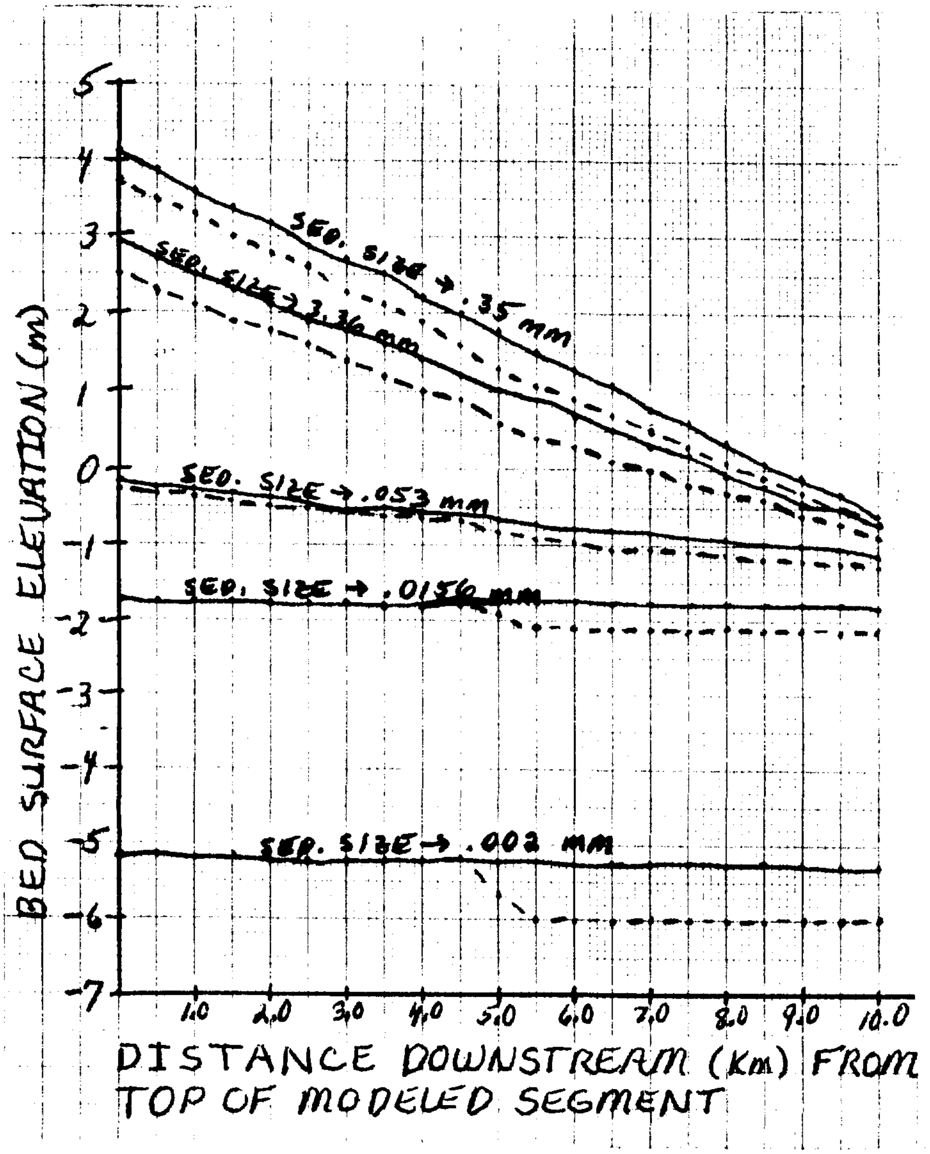

Figure 3. - Longitudianal profiles resulting from computer modelling of stream at equilibrium. Profiles for before (solid line) the excess inflow of water and after (dashed line) the inflow, are depicted for each sediment size.

Table 1. Amount of erosion of bed surface due to extra inflow of water.

RUN	SEDIMENT DIAMETER (mm)	BED SURFACE EROSION (m) AT VARIOUS LOCATIONS DOWNSTREAM 0km	2.5km	5km	7.5km	10km
1	.002	.001	.001	.39	.77	.76
2	.0156	.01	.01	.15	.29	.28
3	.053	.05	.05	.14	.20	.17
4	.35	.38	.38	.42	.29	.10
5	3.36	.36	.36	.42	.007	.13

Table 2. Percentage change in velocity, slope, and depth downstream of the point of excess inflow of water.

		VELOCITY, SLOPE, AND DEPTH DIFFERENCES (%) AT VARIOUS LOCATIONS DOWNSTREAM								
RUN	SEDIMENT DIAMETER (mm)	VELOCITY 5km	VELOCITY 7.5km	VELOCITY 10km	SLOPE 5km	SLOPE 7.5km	SLOPE 10km	DEPTH 5km	DEPTH 7.5km	DEPTH 10km
1	.002	2.2	3.93	3.92	-6.3	-12.5	-12.5	7.47	11.6	14.5
2	.0156	1.9	3.62	3.58	-5.98	-11	-11	7.71	15.1	15.0
3	.053	1.6	2.97	2.94	-7.0	-12.8	-12.7	8.1	15.8	15.6
4	.35	.92	1.75	1.74	-8.93	-16.2	-16.1	8.8	17.2	17
5	3.36	.12	.23	.23	-11.3	-20.3	-20.1	9.6	19.0	18.8

comes in. On the other hand, for the two larger sediment sizes, change in bed surface elevation is not as pronounced, but exists throughout the stretch of the stream. In other words, as sediment size increases, the depth of change of bed height increases upstream and decreases downstream (see table 1).

An examination of table 2 will aid in determining whether or not these, and other changes in the stream that aren't obvious in figure 3 and table 1, are undesirable ones. In table 2, differences in velocity, slope, and depth are listed starting at the 5 km point downstream (the point at which the excess water is pumped in), because upstream of this point, velocity, slope, and depth are unchanged from their initial values, before the inflow. From this table, it can be seen that there is an abrupt increase in velocity and depth, and abrupt decrease in slope, between 5 km and 7.5 km downstream; in other words, the changes are not gradational along the stream.

Also obvious from table 2, and perhaps of more importance, the river generally gets a lot deeper but not much faster, in order to account for the excess discharge. However, noticeable variations in the relative changes in velocity and in depth exist between the small and the large sediment sizes. There is a greater percent change in velocity in the small sediment sizes than in the large sediment sizes. But there is a smaller percent change in depth in the small sediment sizes - in fact, in the larger sizes, almost all percent change goes into depth as opposed to velocity.

The undesirability of all these observed results will obviously depend on whether one is concerned with the upstream or with the downstream portion of the river relative to the point of excess inflow, as well as with small or large sediment size. For example, when dealing with small sediment sizes, comparable to those of the first three runs, the major decreases in bed stream height downstream of the point of added inflow will be of great importance in making any decisions regarding bridge supportings, piers, or other structures in place along the stream.

CONCLUSIONS

In conclusion, typical, medium-size streams with a discharge around 10 m^3/sec at their upstream end, noticeably respond to the pumping of a considerable amount of water into them, such as might be released from a nearby mining operation. Also, their response is in part controlled by their sediment size. The undesirability of a response of a stream with a particular sediment size, basically depends on whether the focus of attention is upstream or downstream of the point at which the large inflow of water is being dumped. With streams of relatively small sediment sizes, the downstream end experiences the significant changes, while the upstream end remains virtually unchanged. With larger sediment sizes, there is a significant increase in depth downstream, as well as a marked decrease in bed surface elevation all along the stream.

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