USGS

WATER RESOURCES RESEARCH GRANT PROPOSAL

Title: Impact of stream-subsurface exchange on fine sediment dynamics in streams

Focus Categories: SED, G&G, WCL

Keywords: sediment transport, fine suspended sediments, soil erosion, streams, geomorphology, contaminant transport

Duration: 3/00-2/01 (2nd year of two)

Federal Funds Requested: $19, 940 (of total budget $39,482 over two years)

Matching Funds Pledged: $46,210 (of total budget $90,336 over two years)

Principal Investigator: Dr. Aaron I. Packman, Drexel University

Congressional District: 2nd District

Statement of critical regional or state water problem

High concentrations of fine sediments adversely impact stream ecosystems by decreasing light penetration through the water column and filling pore spaces in the stream bed. Suburban development leads to increased soil erosion and higher sediment loadings in nearby streams. The geomorphologic characteristics of eastern Pennsylvania coupled with extensive development of rural areas make fine sediment dynamics a key issue for the preservation of streams in this region. Further, the mobility of fine sediments controls the fate and transport of some aqueous contaminants. Most importantly, mine wastes are generally associated with fine sediments—mine tailings are themselves a pollutant, and other contaminants released during mining (metals, arsenic, acidity) interact strongly with sediments. The prevalence of mining and mining-associated water contamination in Pennsylvania also indicates the regional need for an improved understanding of the dynamics of fine sediments in streams.

In spite of these needs, relatively little is known about how fine sediments progress through a watershed. Based on classical sediment transport theory, very fine sediments such as clays are expected to simply progress downstream because they will not settle appreciably in the stream flow. However, new research has indicated that exchange between the stream and subsurface causes fine sediments to be trapped in the stream bed. Though the basic elements of this process are understood, the practical implications for the distribution and impact of high sediment loads have not been explored. Thus this proposal seeks to examine and describe the complex interactions between high sediment loadings, downstream transport of suspended sediment, stream-subsurface exchange, and siltation of stream beds.

Statement of results or benefits:

Fine sediment dynamics in streams will be explored through the use of both laboratory and field experiments. A recirculating flume will be used to investigate fine sediment transport in a controlled, easily-observable environment. The sediment loading, stream flow rate, and bed composition will be varied in these experiments. The concentration of sediment in the stream and the changes induced in the stream bed will be observed over time in order to assess both fine sediment dynamics and the impact of fine sediments on the benthic environment. Smaller column experiments will also be used to examine particle capture by the bed sediment. A model developed previously by the PI will be applied to predict the impact of stream-subsurface exchange on downstream suspended sediment transport in the flume. This model will be modified to account for the feedback between accumulation of fine sediments in the bed, reduction in the hydraulic conductivity of bed sediments, and the decrease of stream-subsurface exchange.

Once the basic effect of high sediment loadings is understood, one or more field sites will be established to observe this process in the natural environment. The dynamics of a single reach will be considered—that is, the effect of incoming high sediment loads on a localized section of stream bed will be observed and related to the downstream change in suspended sediment concentration over the reach. The fine sediment transport model will then be used to analyze these data. The successful development and application of this model will provide a tool for the analysis of the impact of high sediment loadings on streams. Such a model could be used to develop guidelines for acceptable sediment loadings for different types of streams, indicate the possible benefit of different release strategies or erosion control measures, and evaluate the potential for recovery of streams that have become loaded with fine sediments. The fine sediment transport model would also be useful to predict the fate and transport of contaminants that associate with these sediments.

RESEARCH PLAN

Nature, Scope, and Objectives

This proposal represents a renewal request for the 2nd year's funding of a project initiated last year. The purpose of the research program is to develop fundamental physical understanding of the basic processes controlling the transport and distribution of fine suspended sediments in streams, especially under high sediment loadings. The primary process being studied is the exchange of fine suspended sediments between a flowing stream and the underlying stream bed. Understanding the exchange of suspended sediments is especially important because these fine sediments can greatly change the physical characteristics of the stream bed and adversely impact benthic communities.

In the initial proposal, four key questions were raised:

1. What is the rate of uptake of suspended sediment by the stream bed?

2. How does the accumulation of fine sediment affect the hydraulic conductivity, porosity, and other physical characteristics of the bed?

3. How do these changes in the stream bed affect stream-subsurface exchange? That is, what feedback is there between the fine sediment accumulation in the bed and the rate of uptake?

4. What is the net effect on the suspended sediment transport in the stream?

In the first year of the project, we utilized stream-side flumes to examine the deposition of suspended sediments in a gravel bed. Stream water, suspended sediments, and bed sediments were taken directly from the adjacent stream so that the flumes essentially reproduced the conditions in the stream but had controlled flow rates. This work clearly demonstrated that stream-subsurface exchange delivers suspended sediments to the stream bed, that this fine material accumulates in the stream bed under normal flow conditions, and that this accumulation plugs the bed surface and greatly reduces stream-subsurface exchange fluxes.

The second year of the project will be devoted to further analysis of our data from the stream-side flumes, execution of both more-controlled experiments in laboratory flumes and additional field experiments, and the development of models for the long-term accumulation of suspended sediments in stream beds. We observed suspended sediment deposition in the stream-side flumes for over three months, with weekly measurements of solute-exchange and particle-deposition. While we have solid conclusions from the first month's worth of data, the longer-term behavior still has to be analyzed and modeled. Additional experiments must also be conducted in laboratory flumes, which allow much better control over the stream conditions, composition and concentration of sediments, etc. These experiments will allow us to examine both the deposition and release of suspended sediments, whereas the stream-side flumes only allow observation of deposition. We would also like to conduct a second set of experiments in the field in order to better understand the rapid changes that occur in a clean stream bed at the onset of siltation. Finally, we will model the interplay between stream-subsurface exchange and stream bed siltation. The PI's existing model for colloid deposition in stream beds will be modified to include the feedback effect between fine sediment accumulation in the bed, plugging of bed sediments, and the corresponding reduction in stream-subsurface exchange. The new model will allow much better prediction of the long-term effects of fine sediment accumulation in stream beds.

Methods, Procedures, and Facilities

Our experiments in the stream-side flumes will be discussed first, and then the proposed laboratory experiments will be outlined.

Stream-Side Flume Experiments

Stream-side flumes represent an intermediate between laboratory flumes and full stream conditions. The flumes used for this work were set up at the Stroud Water Research Center (Avondale, PA) primarily to investigate biological processes. Thus, they are intended to reproduce the local conditions at the stream bed while providing modest control over flow conditions. Most importantly, all materials in these flumes are taken from a nearby stream—White Clay Creek, which runs through the Stroud Center and is routinely used as a field site by Center scientists. This work was conducted in collaboration with Denis Newbold, an ecologist at the Stroud Center.

Key features of the flumes are shown in Figure 1. Bed sediments were gravels taken from the creek . Two flumes were utilized in this study, with different sizes of stream gravels. In their initial state, these gravels had been somewhat plugged by the natural suspended sediments. To assess exchange with the beds, a salt solution was injected as a pulse at the upstream end of the flumes and then the resulting output was measured. To assess particle deposition, suspended sediments which had been concentrated from the creek water were also injected as a pulse and their output measured over time at the flume outlets. Exchange and particle deposition were measured with the pre-existing bed condition, and then the flumes were cleaned to remove the accumulated silts from the gravel beds. Solute and particle releases were then repeated in order to assess the difference in exchange and deposition between the clean and clogged beds. We observed a considerable increase in exchange after cleaning, which can be seen in the longer tail on the solute release curve in the second experiment, shown in Figure 2.

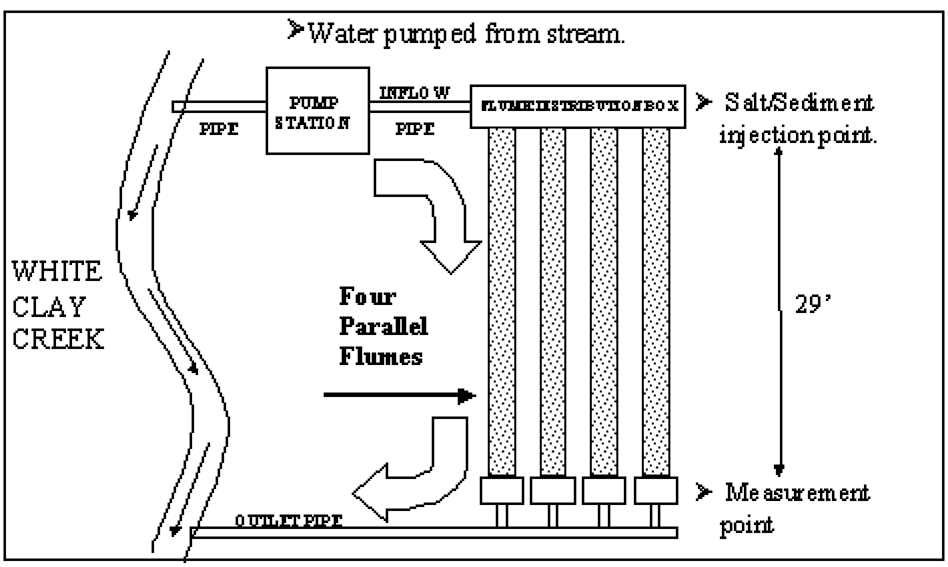

Figure 1: Schematic Drawing of Stream-Side Flumes

Following cleaning, stream water was pumped through the flumes continuously for almost 3½ months, starting in late August and ending at the beginning of December. Stream suspended sediments were pumped into the flumes along with the stream water, so that suspended sediments were continuously delivered to the flumes at the same concentration as in the nearby stream. We observed that the stream bed readily silted up over time, such that the bed was obviously plugged by the end of the season. Solute exchange and particle deposition rates were measured approximately weekly with the method described above.

To date, we have only analyzed the solute exchange data from one of the flumes. Solute exchanges were modeled with a transient-storage type model of the form

$$A\frac{\partial C}{\partial t} = -\frac{\partial (UAC)}{\partial x} + \frac{\partial}{\partial x}\left[AD\frac{\partial C}{\partial x}\right] - A\alpha C + A_s\alpha\frac{A_s}{A}C_s$$

$$A_s\frac{\partial C_s}{\partial t} = A\alpha C - A_s\alpha\frac{A_s}{A}C_s$$

where A = channel area, C = in-stream concentration, t = time, U = mean stream velocity, x = downstream coordinate, D = dispersion coefficient, a = exchange coefficient, A_s = storage zone area, and C_s = storage zone concentration. The model is implemented in a computer code, which is run to produce output curves which can be fit to the experimental results. This procedure allowed us to determine exchange parameters a and A_s for evaluation of the effects of bed siltation. Exchange decreased rapidly over the first few weeks of the experiment, as shown in Figure 2. After the first month, exchange varied somewhat; the implications of this are unclear, but we believe that other factors such as leaf-fall are responsible for the later variations.

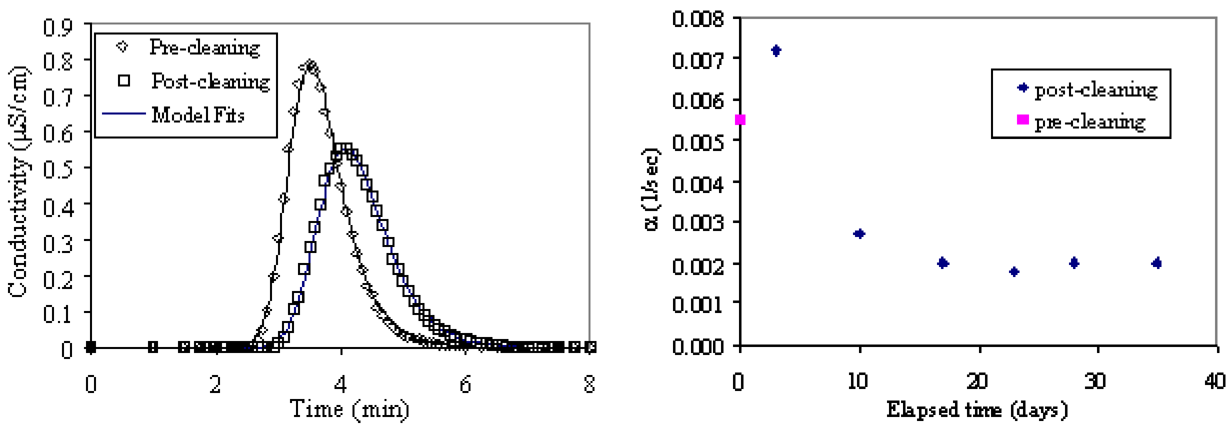

Figure 2, Left Panel: Curves of solute concentration vs. time measured at downstream end of flume following pulse inputs at the upstream end, before and after cleaning of the gravel bed. Additional tailing of the pulse shows that removal of silts from the bed increased stream-subsurface exchange. Right Panel: exchange rates measured at various states of bed siltation. Following cleaning of the bed, exchange decreased considerably due to ongoing siltation.

We have a considerable amount of data from these experiments which still needs to be analyzed. We must run the exchange model for the remaining salt data from our 3½ month time series to assess longer-term effects. We must also run the exchange model on the salt data from the other flume. This will allow us to evaluate the effect of bed sediment size on the siltation/exchange process. We also have a considerable amount of data on particle deposition, in the form of injected sediment concentration and mass, and effluent concentration vs. time following the injection. As mentioned previously, we conducted these experiments weekly in both flumes. These data need to be converted into average deposition rates in order to compare long-term trends in particle deposition. We also cored both beds at the end of the set of experiments in order to measure the extent of fine sediment accumulation in the bed. These samples have been preserved, and analysis of them will allow us to evaluate how the size distribution, porosity, etc. of the bed sediment changed due to siltation. Thus, we will have two ways to assess the net effect of siltation: first, we have measured the decrease in stream-subsurface exchange due to the plugging of the pores in the gravel with fine sediments, and secondly we will be able to measure how the size distribution of the bed sediment changed over the 3½ months of our study.

Based on this first set of experiments, we believe it will be worthwhile to conduct a similar run next summer. The stream-subsurface exchange rate decreased much more rapidly than we expected, essentially dropping to a steady state after a few weeks. Thus we would like to clean the beds again and then execute an intense set of experiments, with solute and particle injections at least once per day. We theorize that the rapid decrease in exchange could be due to the development of benthic biofilms. Biofilms capture stream sediments, which are a food source because they contain a considerable amount of carbon. Thus particle capture by fresh biofilms, subsequent biofilm growth, and the resulting closing of pores could be an important biological process contributing to the overall siltation/clogging of stream beds. To assess this, we propose to run two flumes in parallel with the same initial conditions and flow rates. One flume would be used to measure solute exchange and particle deposition, and the other would be used to measure silt accumulation and biofilm growth. These measurements cannot be made in the same flume because the bed must be disturbed to collect samples for analysis of grain size distributions and biofilm growth. Size distributions are easily measured by sieving, and we will primarily be interested in the fraction of fines. Biofilm growth will be measured by scraping biofilms from rocks and analyzing the samples for carbon and chlorophyll. Comparison of bed conditions in the two flumes at the end of the experiment run will allow us to verify that the two flumes operated similarly.

The only natural process that we cannot observe in the stream-side flumes is the long-term dynamics related to flushing by storm flows. While stream water is continually pumped into the flumes, the pumping rate is always constant. Thus, we capture the increase in suspended sediment concentration due to storm flows, but the flumes never experience the associated increase in velocity. We will probe these effects by conducting experiments in White Clay Creek. This is a convenient site because the Stroud Center already routinely monitors stream conditions such as flow rate, suspended sediment concentration, etc. We will assess the net effect of storms on siltation simply by obtaining size distributions of bed sediment samples before and after storms. In addition, we will conduct a series of solute injections to observe the corresponding changes in stream-subsurface exchange. We will also compare the results of these experiments with the results of similar experiments conducted in the laboratory under completely controlled, abiotic conditions, as described in the next section.

Dissemination of results

Our results on the decrease of solute exchange due to siltation were presented at the meeting of the American Geophysical Union ("Interplay of stream-subsurface exchange, benthic delivery of particulate organic carbon, and stream bed siltation," J.S. MacKay, A.I. Packman, and J.D. Newbold, AGU Fall Meeting, San Francisco, Dec. 13-17,1999.) The audience at AGU was primarily geo-scientists and ecologists who are interested in geomorphology, geochemistry, and benthic processes. One important result for this community is our clear demonstration that stream-subsurface exchange can change considerably with time; previously, many of these researchers assumed that each stream reach had a unique, characteristic exchange rate.

We will also publish/present the results on particle deposition at a meeting of the American Society of Civil Engineers ("Variations in organic particle deposition rate and stream-subsurface exchange due to silt accumulation in a gravel bed," ASCE Water Resources Engineering Conference, Minneapolis, Aug. 2000, A.I. Packman, J.S. MacKay, and J.D. Newbold, accepted for presentation and publication in the proceedings.) These results will be of interest to civil engineers who are responsible for controlling the releases of fine sediments to streams. Our results will also be valuable to those working on stream restoration and naturalization (dam removal etc.) as the control of erosion and sedimentation is a core aspect of this work. Our paper in the ASCE conference proceedings will focus on the experimental procedures and basic particle deposition results. We also intend to write a comprehensive paper for a leading journal such as *Water Resources Research*, which will present our observations of stream-subsurface exchange and particle deposition, and discuss the larger implications of this work.

Laboratory Experiments

Laboratory experiments are extremely useful because they allow easy observation of flow patterns and particle concentrations, and complete control of the physical and chemical conditions in the stream and bed. A small recirculating flume will be the primary experimental apparatus used for this project. This flume has a 10m long by 40 cm deep by 20 cm wide stream channel which allows the establishment of stream flow over a sediment bed. The stream flow is controlled by a pump, and both water and sediments are returned by a pipe from the pump to the upstream end of the channel. Since flumes provide a good representation of the stream flow over the bed and allow extensive control of hydraulic conditions, flume experiments have long been used to study sediment transport processes. Previous research has further demonstrated that flume experiments are an extremely valuable tool for the identification and parameterization of stream-subsurface exchange processes (e.g., Elliott and Brooks, 1997ab). Allan (1995) also suggests that benthic boundary layer processes are best studied in flumes.

This work will draw on the PI's experience in conducting experiments on the exchange of clay and other fine sediments with a stream bed in a laboratory flume (Packman and Brooks, 1995; Packman et al., 1997; Packman et al., 1999b). These experiments established the basic methodology, which will be used to study the transport of high concentrations of fine sediments. However, all previous experiments were executed with relatively low sediment concentrations in order to examine basic colloid exchange with a clean sediment bed. The proposed investigation of the short- and long-term impacts of high sediment loadings will include:

1. Experiments with extremely high initial suspended sediment concentrations (>1000 mg/L), and

2. Experiments with lower concentrations (~200 mg/L) but with continuing input of additional fine sediments.

In both cases, the experiments will continue until there is significant siltation of the stream bed.

Flume experiments will be conducted using the methodology presented in Packman et al., 1997. The general flume experiment procedure is to 1) establish the desired uniform flow and water chemistry over a sediment bed, 2) add the particle suspension uniformly to the recirculating stream, and 3) observe net exchange with the bed by sampling the stream and pore water. Additional suspended sediments can be added to the stream later if desired. The suspended particle concentration can be measured with a spectrophotometer. Simple grab samples characterize in-stream concentrations, and a series of ports allow access to the pore water via syringe. Typically a conservative solute (such as dissolved lithium) is also added to the stream in order to provide a baseline for exchange. Figure 1 presents the results of a previous flume experiment on clay capture by a sediment bed—a comparison of lithium and clay exchange clearly shows that clay was extensively trapped in the stream bed. The proposed experiments with higher sediment loads should show similar trends, but it is expected that extensive accumulation of fines in the bed will cause a reduction of the rate of exchange.

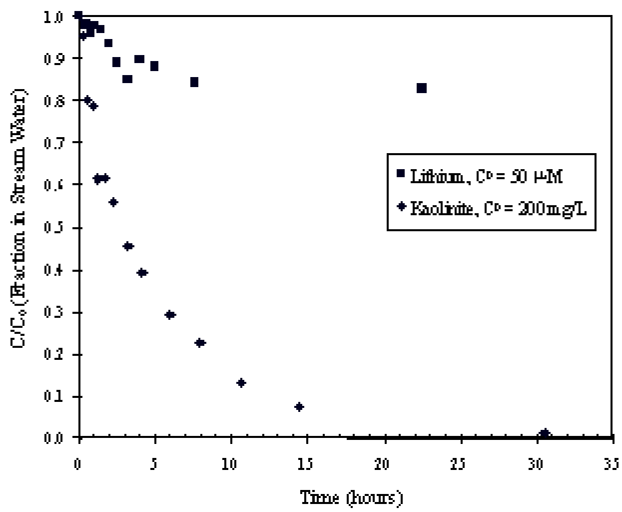

Figure 1: Experimental data on the exchange of a conservative tracer (lithium) and kaolinite clay between a stream and sand bed in a recirculating flume. Reproduced from Packman et al., 1999b.

While previous work was directed primarily at determining the impact of exchange on downstream transport, the proposed experiments will place much more emphasis on the alteration of the stream bed due to fine sediment input. The stream bed will be cored after each experiment to examine the accumulation of fine sediments in the bed. Since previous work predicts that fine sediments should begin to accumulate at the bed surface (Packman et al., 1999a), the cores will be sectioned to examine the vertical distribution of fine sediments. Direct pore-water sampling will also be used to evaluate the distribution of fine sediments that remain suspended in the pore water. Thus, coring should not require freezing or any other form of pore-water immobilization, though these procedures will be implemented if they prove necessary. Once cores are obtained and sectioned, it will be quite simple to elute accumulated fines from the bed sediment. Rinsing with a chemical agent may be used to aid the release of fine sediments (in previous work, simply increasing the pH was very helpful in removing kaolinite from sand). Fine sediment accumulation in the bed will also be evaluated by considering the mass-balance of added sediment as it becomes distributed throughout the closed flume system.

The transport of fine sediments through the stream bed is impacted by filtration—chemical attachment of the suspended sediment to stationary grains of bed sediment. Filtration is one mechanism for fine sediment trapping in the stream bed (Packman et al., 1999ab). Because filtration depends on chemical as well as physical processes, the bed sediment, stream water, and input suspension added must all be prepared and/or cleaned in an appropriate fashion. Again, previous work has established the necessary procedures (Packman et al., 1997). Bed sediment will be cleaned in an upflow washing apparatus, with acids and bases added successively to the rinse water in order to removed sorbed metals, organic matter, and attached colloids. Stream water will be taken from the laboratory deionized water supply, with NaCl, HCl, and NaOH used to control pH and ionic strength. Preparation methods for the fine sediments added to the flume will depend on the exact sediment that will be used, but the goal of these preparations will be to ensure that the surface-chemical state of the particles is always well-defined. Such preparation might involve disaggregation, acid washing to remove sorbed contaminants, ion exchange to homogenize surface species, and storage in deionized water.

Systematic variation of the hydraulic and chemical conditions in flume experiments aids the determination of the importance of individual mechanisms for the transport, exchange, and trapping of suspended sediments. The primary goal of the proposed experiments is to examine the transport of high concentrations of suspended sediments under different stream flow conditions. The concentration, input rate, and type of suspended sediments will be varied in order to examine the basic processes of fine sediment transport and accumulation. The stream velocity, bed morphology, and bed sediment size will be varied to investigate the importance of stream hydraulic parameters. Finally, the chemical conditions (pH and ionic strength) of the stream water will be varied to examine their effect on particle trapping and accumulation in the bed. In all cases, experimental conditions will be restricted to match those typically found in natural streams.

Three types of suspended sediments will be used: industrial colloidal silica will be used in initial experiments, followed by a “model” representative natural sediment such as kaolinite clay, and finally the transport of a complete soil sample will be observed. It is anticipated that the bed sediment for most experiments will be commercially available sand, though select experiments could be conducted with either gravel or mixed natural sediments. Both suspended and bed sediments will be characterized in terms of size distribution, composition, and surface-chemical/ electrostatic properties (e.g., zeta potential). In many cases the sediment properties will be known from literature (e.g., previous work by the PI on kaolinite), though careful attention must be paid to ensure that the sediment preparation methods are consistent.

Smaller batch and column experiments will be used to investigate physicochemical interactions between transported particles and the bed sediment. A column experiment involves pumping a suspension of fine sediment through a saturated column of bed sediment in order to observe the fine sediment retention in the column. These experiments indicate the extent of filtration that can be expected in the stream bed. Column experiments are extremely useful because they allow the investigation of particle capture by the bed without all the complications of the complete stream system. In particular, column experiments will be used to provide an estimate of the effect of particle plugging on the transport through the stream bed. The coupling of column and flume experiments is very important: this allows investigation of both the changes in hydraulic conductivity and filtration in the bed (observed in column experiments) and the net effect of these changes on overall transport of fine sediments (observed in the flume).

The proposed experimental work will be conducted in a new stream processes laboratory, housed within Drexel’s newly-renovated Woodring Civil Engineering Laboratories. Major research equipment for the proposed work is part of the Woodring hydraulics laboratory infrastructure. Of particular benefit is a new recirculating flume specifically designed for the study of the transport of reactive solutes and particles. This flume is being constructed with all chemically-resistant materials, and is sufficiently large to provide good hydraulic conditions, but sufficiently small to allow complete control of all chemical conditions (channel dimensions: 10 m x 40 cm x 20 cm). A suite of computer-controlled instrumentation supports the flume, including a digital flow meter, an acoustic Doppler velocimeter, a carriage-mounted laser bed profiler, and a pH meter with ion-specific electrode capability. A small water treatment station will provide deionized water for use in the flume, and an upflow washing apparatus will be used to clean the bed sediment. Significant analytical capability, including an ICP-MS, is available through Drexel's School of Environmental Science, Engineering, and Policy.

Modeling of Experimental Results

An existing model for fine sediment transport will be applied to the flume experiment results. The PI's model for particle exchange between the stream and bed is presented in Section 13, Related Research. This model combines a fundamental hydraulic description of stream-subsurface exchange with analysis of particle capture in the stream bed. When applied to flume experiment results, the model predicts the reduction in suspended sediment concentration in the stream based on measured hydraulic and chemical parameters. This model was successful in predicting the results of previous experiments on stream-subsurface exchange of fine sediments (Packman et al., 1999ab).

However, the model assumes that the characteristics of the stream bed remain constant—i.e., that fine sediment deposition in the bed is sufficiently small so that the composition of the bed does not change appreciably over time. As noted above, high suspended sediment loads will produce high rates of particle accumulation and eventually plug the bed, causing a reduction in hydraulic conductivity and a decrease in stream-subsurface exchange. The existing model will initially be used to evaluate the results of the proposed experiments. It is expected that the model will successfully predict the observed particle exchange for some time, until the bed becomes significantly plugged with accumulated fine sediment. After this point, the experimental data should increasingly deviate from the model prediction—the model will overpredict exchange because it will not consider the decrease in hydraulic conductivity of the bed sediments. The model will then have to be modified to account for the plugging of the stream bed. Existing functions which describe plugging of filter beds will be incorporated in the particle exchange model. As this proposal has a relatively-limited time-frame and is focused primarily on experimental work, model descriptions of filter plugging will be taken from the colloid filtration literature (e.g., Ives, 1987). However, the experimental data sets obtained in this work can serve as the basis for future model development (which would be the subject of a later proposal).

Related Research

Exchange between streams and the subsurface has become increasingly recognized over the last 15 years as a process that can significantly affect the transport, mobility, and fate of stream-borne substances. Prior to this relatively-recent interest in the application of stream-subsurface exchange to the transport of reactive species, physical exchange processes were considered in isolated classic studies in the fields of stream hydraulics and sediment transport. For example, Simons et al. (1963) observed in laboratory experiments that suspended clay can be transported into sand stream beds. Einstein (1968) later observed that silt-sized particles would readily settle through the large pore-spaces in gravel beds. While these and similar experimental studies demonstrated the existence of stream-subsurface exchange, extensive development of these ideas did not take place because stream-subsurface interactions typically have a relatively-minor impact on overall stream flow and sediment transport.

The implication of stream-subsurface exchange for the transport of reactive solutes and fine particles was noted essentially independently by researchers in several different fields. In the field of environmental engineering, stream-subsurface exchange has been shown to significantly influence downstream contaminant transport (e.g., by temporarily storing contaminants in the bed: Bencala and Walters, 1983), as well as the fate of contaminants in stream systems (e.g., due to long-term input of mining wastes or acid-mine drainage: Moore and Luoma, 1990; McKnight and Bencala, 1990), and the rate of contaminant release from bed sediments (e.g., release of arsenic from sediments contaminated by mine tailings: Moore et al., 1988; Nagorski, 1997). In addition, stream-subsurface exchange can be important whenever there is a significant chemical reaction in the subsurface (e.g., oxygen consumption in sediments: Rutherford et al., 1993, 1995). A review of the impact of stream-subsurface interactions on contaminant mobility, transport, and fate can be found in Rutherford (1994).

Stream-subsurface exchange has also been shown to be an important process controlling sediment transport and stream geomorphology. Experiments by the PI demonstrated that stream-subsurface exchange results in extensive trapping of fine sediments in the stream bed (Packman et al., 1997; Packman et al., 1999b). When the in-stream suspended sediment concentration becomes high, stream-subsurface exchange controls the rate of delivery of fine sediments to the bed. The impact of these processes on the composition of stream beds has not been investigated, but is likely to be important, especially in cases where the input of fines is high. Bed clogging due to periodic discharge of wastewater was observed to decrease the infiltration through the stream bed in the Salt River (Berestov et al., 1998). The need for improved understanding of the interaction of fine sediments with stream beds has been noted by USGS scientists (Jobson and Carey, 1989). Such sediment transport processes also have applications in environmental engineering (e.g., transport of mine tailings, plugging of fish spawning grounds).

Stream-subsurface exchange has an additional impact on stream ecosystems because subsurface processes tend to control the in-stream availability of nutrients. Much of the food supply for streams is derived from terrestrial sources, and exchange via the subsurface hyporheic mixing zone is an important pathway for the delivery of these materials to the stream. Dissolved nutrients, in particular, are primarily transported to the stream by subsurface flow (Gregory et al., 1991). Stream-subsurface exchange is also important in later cycling of both nutrients and organic carbon. Both sorption to bed sediments and uptake by microbial activity in the bed are important processes for the removal of nutrients and dissolved organic matter from the stream (e.g., Triska et al., 1993ab; Newbold et al., 1981, 1983). The dynamics of fine particulate organic matter are not well-understood, but clearly also involve interactions with the bed sediment (Cushing et al., 1993).

High sediment loads in streams can impact stream ecosystems by altering both the in-stream and benthic environments. Increased turbidity inhibits the growth of both phytoplankton and submerged aquatic vegetation (Allan, 1995). Excessive fine sediment loads also cause the loss of benthic habitat due to siltation of the interstices in the stream bed. This has a direct detrimental impact on benthic invertebrates (Peckarsky, 1985; Borchert and Statzner, 1990), and can prevent fish spawning (Berkman and Rabeni, 1987). In fact, the particle size distribution and texture of bed sediments are among the most important physical substrate characteristics for stream biota (Allan, 1995). Finally, siltation of stream beds is very disruptive to stream ecosystems because it inhibits the many important ecological processes that depend on stream-subsurface exchange (Brunke and Gonser, 1997). High suspended sediment and nutrients loads have had an adverse impact on the Chesapeake Bay ecosystem, and improved knowledge of sediment retention and transport in watersheds has been identified as a research need by the USGS Chesapeake Bay Ecosystem Program (Phillips and Caughron, 1997).

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