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SECTION 6

INSTRUMENTATION

Page

AN IMPROVED BEDLOAD SAMPLER --
Jack Lewis..... 6-1
USING REMOTE SENSING TO EVALUATE SHORELINE RECESSION --
J. Craig Fischenich..... 6-9
SCALE EFFECTS IN CALIBRATION OF A BEDLOAD SAMPLER --
Dou Fang and C. P. Zhang..... 6-16
EVALUATION OF THE SUSPENDED SEDIMENT SAMPLERS --
Zhaonan Li and Yuqian Long..... 6-24
SAMPLING DIFFERENCES OF THE HELLEY-SMITH AND BL-84 BEDLOAD SAMPLERS --
Dallas Childers..... 6-31
AIRBORNE LASER STUDIES OF THE LANDSCAPE --
Jerry C. Ritchie, Thomas J. Jackson, James H. Everitt, D. E. Escobar, Joseph B. Murphey and Earl H. Grissinger..... 6-39
PARTICLE SIZE DISTRIBUTION BY PIPET AND SEDIGRAPH --
Rollin H. Hotchkiss..... 6-47
THE COMPARISON TESTS OF THE GRAVEL BED LOAD SAMPLERS --
Huanjin Gao..... 6-55

AN IMPROVED BEDLOAD SAMPLER

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ABSTRACT

Improvements upon the Birkbeck bedload sampler (Reid et al., 1980) were implemented in the North Fork of Caspar Creek, a gravel-bedded stream draining 383 ha in northern coastal California. Bedload sediment falls through a slotted plate covering a 0.5-m^3 steel box set within a formed concrete pit in the streambed. In the original Birkbeck design, a water-filled pressure pillow beneath the box responded to the weight of accumulating sediment and the overlying water column. The hydraulic pressure was communicated via tubing to a pressure-bulb transducer, which was in turn connected via a set of mechanical linkages to a chart recorder. In two seasons of experimentation at Caspar Creek, the pillow and hydraulic and mechanical linkages of a Birkbeck-like sampler were replaced with an electronic load cell and an electronic data logger, resulting in more trouble-free operation, greater precision, and reduced background noise. Low-profile fences were erected along the cover plate slots to prevent material from entering traps across the lateral slot boundaries. Data were collected at 2-minute or 5-minute intervals from four bedload pits and recorded on non-volatile memory chips. Because of rapid filling of the boxes, a suction dredge was used to empty sediment from boxes during storms.

INTRODUCTION

The tremendous temporal and spatial variability of bedload transport rates (Carey, 1985; Hubbell, 1987) in streams gives rise to large sampling errors. To lessen these errors, pit or trough samplers have been designed to provide a continuous or nearly continuous record of bedload transport.

The earliest documented apparatus was used in Mountain Creek, South Carolina (Einstein, 1944). Modifications proposed by Hubbell (1964) would have made it portable and easy to install in low-velocity streams. However, because it is difficult to lift coarse sediment with a pump, and the apparatus requires continuous pumping from a hopper located in the streambed to a weighing tank on the bank, its application is limited to sand-bed streams.

The most elaborate sampler design (Emmett, 1980) consisted of a concrete trough constructed across the riverbed, covered by a series of eight hydraulically actuated gates which could be opened or closed individually. A conveyor belt beneath the trough carried the trapped sediment laterally to a weighing hopper where the weights were recorded once each minute. Such a system would be impractical to implement on a limited budget.

A vortex-tube bedload trap (Klingeman and Milhous, 1970; Hayward and Sutherland, 1974) caught sediment in a diagonal trough in which a streamflow-induced vortex evacuates the sediment to the bank. This system, however, does not allow separate measurements of transport rate at different locations along a cross-section.

The Birkbeck pit sampler (Reid, Layman, and Frostick, 1980) allows continuous measurement of bedload at several locations within a cross-section. It is not suitable for measuring the entire cross-section, but it is the only sampler that does not require removal of the material from the channel for weighing. Bedload sediment falls through a slotted plate covering a box which rests within a formed concrete pit in the streambed. A water-filled pressure pillow beneath the box responds to the weight of accumulating sediment and the overlying water column. The hydraulic pressure is communicated via tubing to a pressure-bulb transducer, which is in turn connected by a set of mechanical linkages to a chart recorder. A continuous record of stage is needed to correct for varying pressure head due to the overlying water column. Like most other trap samplers, the Birkbeck sampler is not portable, but it is less expensive to install and operate. This paper reports modifications of the Birkbeck sampler which increase its resolution, accuracy, dependability, and usefulness.

FIELD INSTALLATIONS

First Year Setup

The sampler was placed in the North Fork of Caspar Creek, a gravel-bedded stream draining 383 ha in northern coastal California. Our design (Fig. 1a) was similar to the original Birkbeck design except that an additional water-filled pressure pillow was placed in a stilling well and was connected to each of 4 differential pressure transducers (Model P305D, Validyne Engineering Corp., Northridge, California[1]) that were connected to the pillows in the pits. Thus the effect of water pressure was removed, and deflection of the transducer diaphragm produced a voltage proportional to the submerged weight of the sediment-filled box. The volume of the collecting box was 0.125 m^3, and the slot in the pit cover was 20 cm by 40 cm with the short side transverse to the flow. The analog signal from the transducer was converted by an electronic data logger (Easy Logger, Omnidata International, Inc., Logan, Utah[1]) to digital values which were encoded onto an EPROM (erasable programmable read-only memory) module at 2-minute or 5-minute intervals. Time resolution was thus much improved while eliminating the labor of manually extracting chart data. (At Birkbeck College, transport rates were manually integrated over 30-minute periods.) The EPROM modules were later read onto magnetic disk and erased for reuse. The boxes were winched from the pits after storms by a system of cables suspended from two towers on opposite banks of the creek.

First Year Performance

In the first year of operation, a number of difficulties were encountered.

1. **Punctured and collapsed pillows.** It is possible that the pillows may have been punctured by sediment entering the pits through inadequate seals beneath the pit covers. The seals were eventually improved by gluing neoprene to the underside of the pit covers.

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[1]Trade names are used for information only and do not constitute endorsement by the U.S. Department of Agriculture

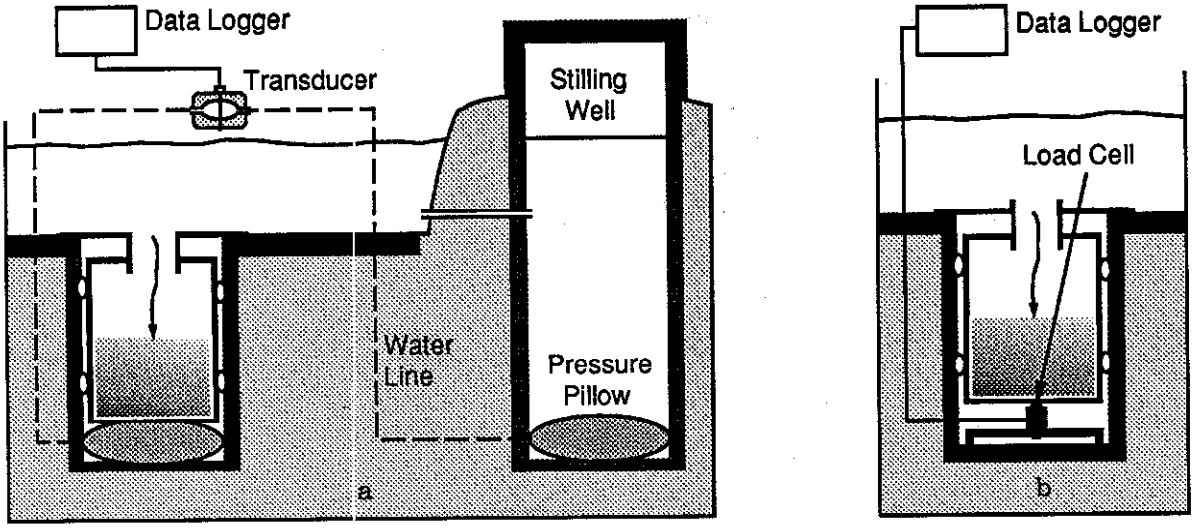

Figure 1. Bedload sampler. (a) First year design employed water-filled pressure pillows and differential pressure transducer. (b) Simplified design used load cell in place of transducer and eliminated hydraulic system.

2. **Air entering fluid lines through faulty connections and pillow valves.** In order to obtain valid data, air had to be bled regularly from the fluid lines. Experimentation with different types of connectors yielded some improvement, but the leakage problem is inherent to any system with numerous hydraulic linkages. This is particularly true where fluid is under tension, as in this application, because the transducers are at a higher elevation than the pillows.
3. **Transducer diaphragms overstressed.** Bleeding air from the system involves applying a suction to fluid lines to withdraw air and water. If done carelessly, excessive pressure can warp transducer diaphragms.
4. **Pillow calibrations unstable.** For a given change in weight, transducer output was found to change from storm to storm. Thus it was necessary to calibrate each pit after every storm.
5. **Boxes filling with sediment early in storms.** In the only two significant storms, all the boxes filled with sediment. In the first storm of the year, one box was filled within 30 minutes of the initiation of bedload movement, and all boxes had filled within an hour. Thus no bedload data were collected for most of the storm.
6. **Cable system failure.** Because of improper design, one of the towers supporting the cable system became unstable and could not be used.

Modifications After the First Year

In the second year of operation, solutions to all the above problems were found. First, one pillow was replaced with an electronic load cell. (In the third year, all the pillows were replaced with load cells.) A load cell is essentially an electronic strain gauge, which incorporates a Wheatstone Bridge circuit across which a fixed excitation voltage is applied. Minute deflections of a strain member result in the generation of a millivolt output proportional to an applied force. Net deflection due to hydrostatic forces is zero; hence output does not need to be corrected for stage. The load cell, placed beneath a sampler box (Fig. 1b), is wired directly to the data

logger, thus eliminating all problems associated with hydraulic systems and pressure transducers. The cell we chose (Model BSP-0.5A, Hardy Instrument Co., San Diego, California) is stainless steel and hermetically sealed for underwater applications. Its performance seems unaffected by two years of immersion. According to the manufacturer, when the load is applied in the correct manner, it is accurate to 0.23 kg without calibration; and with careful calibration, errors may be reduced by as much as a factor of 10. Unless the maximum load is exceeded, a load cell should never have to be recalibrated.

To deal with the problem of inadequate box capacity, we began using a suction dredge to evacuate boxes during storms without removing them from the pits. In Caspar Creek, flows rarely exceed 0.5 m in depth and 1.5 m/sec, so with proper safety precautions, it is possible to work in the stream during storm flows (Fig. 2). A centrifugal pump, powered by a 5-horsepower gasoline engine, moves sediment in an arrangement commonly used by placer gold-miners (Fig. 3). The gravelly bedload material never enters the pump. Instead, water is pumped through the jet, creating a venturi effect which draws a slurry from the suction hose and discharges it downstream.

To reduce the need for frequent pumping and concomitant instream disturbances, the slot width was narrowed from 20 cm to 10 cm. Only about 1% of the bedload, by weight, is coarser than 10 cm, based on pebble counts of material deposited in a delta just downstream of the bedload sampling station. The refitted slot is thus still capable of capturing nearly all particles transported across it.

Another modification which reduced the amount of material entering the pits was construction of low-profile fences along the cover plate slots to reduce the potential for lateral entry of material into the pits. Emmett (1980) compared transport rates from summing individual gates to determinations with all gates open and discovered that the gates, when opened individually, consistently overestimated transport rates by a factor of 1.3, because of lateral entry of sediment. His slots were 1.83 m by 0.25 m, oriented transverse to the flow, compared with our 0.10 m by 0.40 m, oriented parallel to the flow. Therefore, our oversampling would probably be greater than 1.3 without some sort of barrier. A fence height of 5 cm was estimated to be tall enough to block most bedload while minimizing hydraulic disturbance. The upstream edge was cut back at a 45° angle in order to reduce the potential for material lodging against it and blocking the slot.

The overhead cables and tripods were replaced by an I-beam bolted to two steel columns on opposite streambanks. After a storm, the boxes are now easily and safely removed from the pits using a chain hoist suspended from a carriage that rolls along the I-beam on two wheels (Fig 4). After each storm, the boxes are removed from the pits, weighed with a dynamometer, and dumped into a basin on the streambank where the sediment is mixed and subsampled for particle size analysis.

Performance After the First Year

In the second and third years of operation we were able to obtain nearly complete records from all pits in six of seven bedload-moving storms. One or more pits had to be pumped out in five of the seven storms, and one pit was pumped out twice in a storm. In the biggest storm, however, large particles

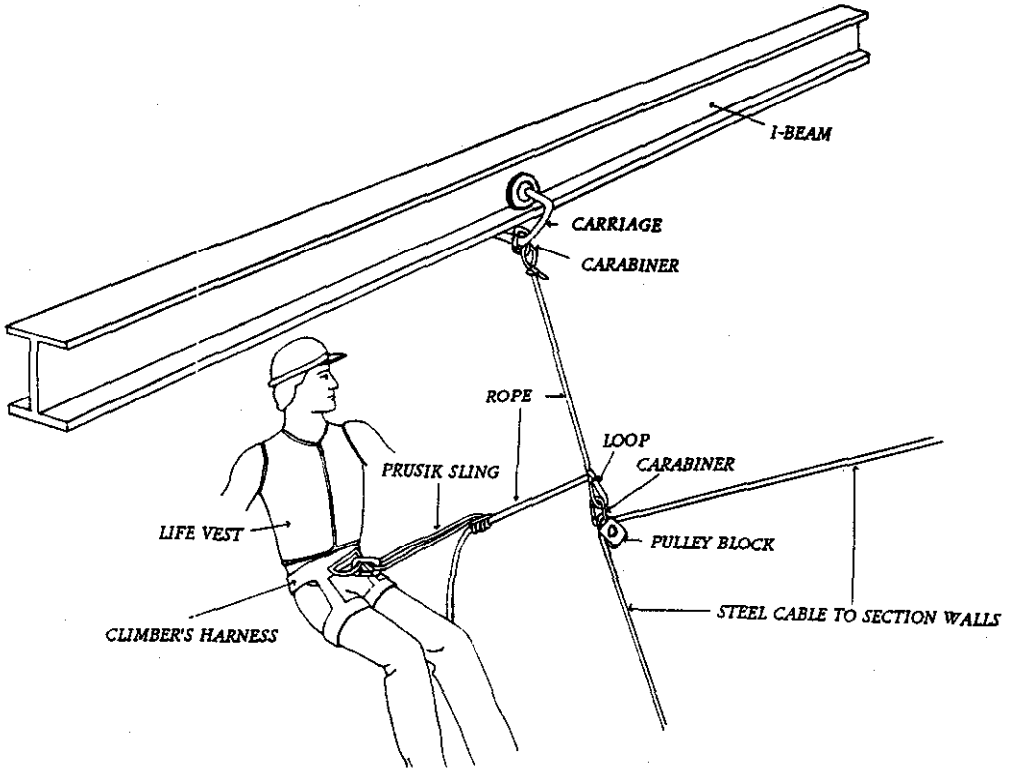

Figure 2. Harness system increases range of flows in which a person can safely work in the stream channel to pump sediment from pits. Pulley block and carriage allow lateral movement. Prusik sling holds weight in tension, but can be slid along rope to adjust distance from cable.

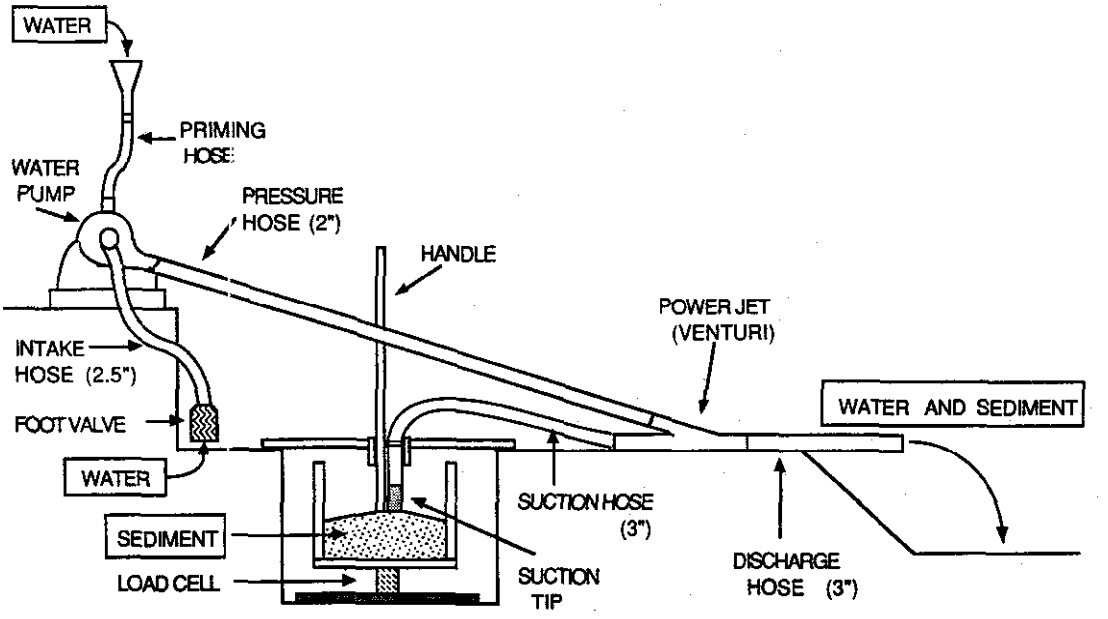

Figure 3. Centrifugal pump and power jet use venturi effect to extract sediment from bedload trap.

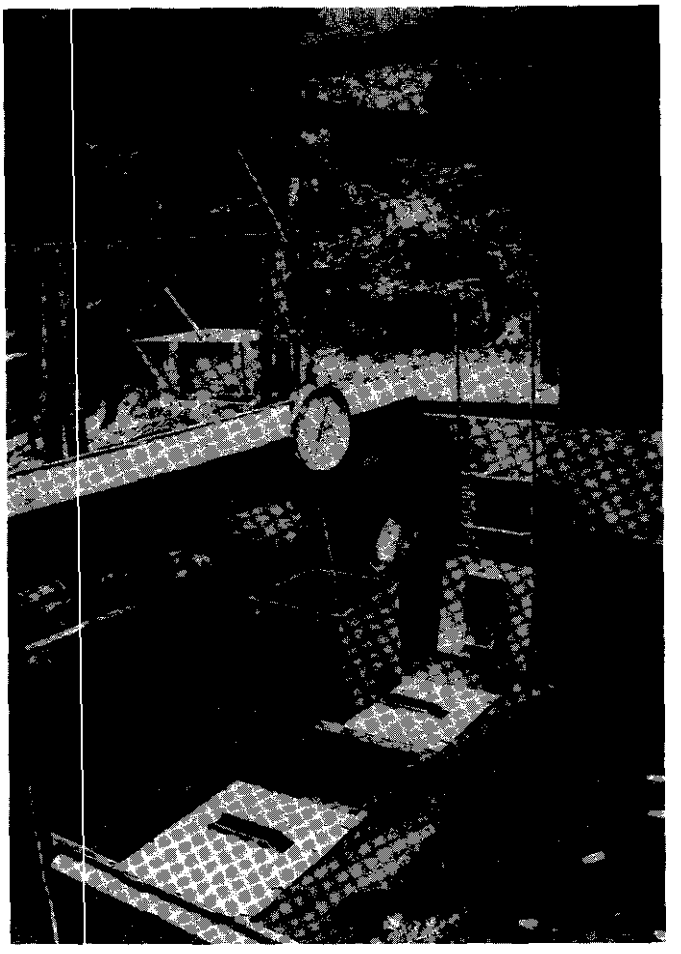

Figure 4. Sediment-filled box is removed from pit with chain hoist and weighed with dynamometer suspended from I-beam.

plugged the intake nozzle of the suction hose and the strong current made it too difficult to repeatedly clear the nozzle.

An examination of a storm trace (Fig. 5) shows the load cell output to be less noisy than the pillow/transducer output, even though the most sediment was collected in the pit with the load cell. The point is further illustrated by comparing the traces when there is a disturbance in the channel. Between hours 10 and 11 the author was working in the stream channel, and caused hydraulic changes that produced spiking in the stage and pillow traces without affecting the load cell output. Disturbances from pit pumping, Helley-Smith sampling and discharge measurements, and from debris lodging in the vicinity of the pits cause similar spiking.

An additional advantage of using load cells is that they are not as subject to temperature effects as pressure transducers. Besides being less sensitive to temperature, they are subjected to smaller temperature changes by being submerged in water. The contrast is evident on traces showing diurnal

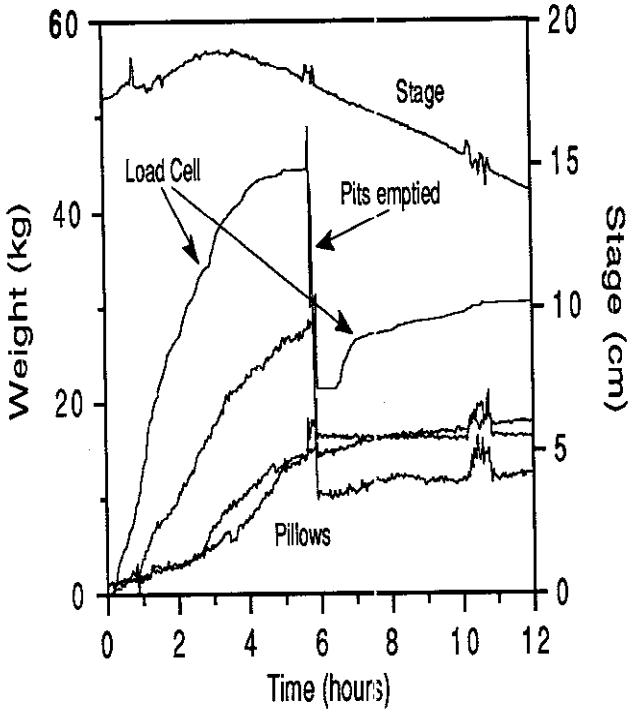

Figure 5. Storm plot of accumulating sediment. One pit was instrumented with a load cell and 3 with pressure pillows.

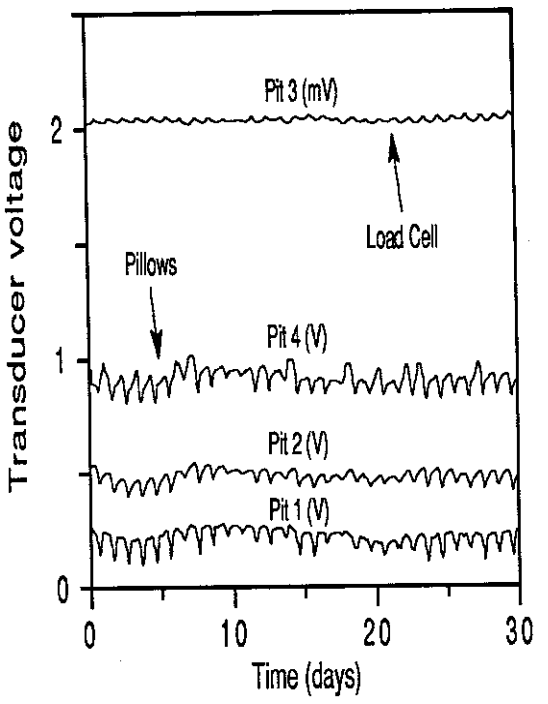

Figure 6. Diurnal temperature effects on load cells and pillow-transducers.

fluctuations (Fig. 6). Such temperature effects may, however, be unimportant when considering transport rates over small time periods, because the error from a significant temperature change will be distributed over many time intervals.

All pits were calibrated five times during the second year and the stability of the load cell was compared with that of the pillow arrangements. The coefficients of variation for calibration slopes were 1.8, 2.1, and 3.4% for the pillows, compared to 0.6% for the load cell. The median standard errors of estimate were 0.50 kg for pillows and 0.40 kg for the load cell, but the calibration accuracy was limited by the fact that our calibration weights were known only to the nearest 0.25 kg. In the third year of operation, we used load cells in all the pits, and the median standard error of estimate from 8 load cell calibrations was reduced to 0.22 kg by simply standardizing the calibration procedure. More precise calibration should be possible, but may not be warranted for this application.

SUMMARY

Continuous measurements of bedload are needed to overcome large sampling errors associated with highly variable transport rates. Because it automatically weighs sediment in the stream, the Birkbeck bedload sampler is perhaps the most practical method in use today for obtaining continuous records of bedload transport and its variation across a stream channel. At Caspar Creek, the water-filled pressure pillows, pressure transducers, and chart recorders of the original design (Reid, Layman, and Frostick, 1980)

were replaced with electronic load cells and data loggers. The electronic system requires less effort to operate and maintain, and produces very high-quality data with excellent time resolution. A centrifugal pump was used to empty boxes when they filled during storms, and an overhead I-beam was installed to facilitate weighing and subsampling of box contents after storms. Oversampling due to lateral entry of material into slot samplers should be recognized and avoided by experimenters measuring bedload transport rates. Our solution was to erect low-profile lateral fences along the slots, but their effect on hydraulics and sampling efficiency has not been tested.

ACKNOWLEDGEMENTS

This study is being carried out in the Jackson Demonstration State Forest in cooperation with the California Department of Forestry and Fire Protection. It was initiated and directed through the first winter by Jeffrey Albright (hydrologist now with the National Park Service). Additional funding has been provided through a Humboldt State University McIntire-Stennis grant.

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USING REMOTE SENSING TO EVALUATE SHORELINE RECESSION

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ABSTRACT

The Omaha District of the Corps of Engineers is analyzing erosion along more than 2,000 miles of shoreline on Lake Oahe in North and South Dakota. Conventional means of data acquisition and analysis are both cost prohibitive and impractical for this study due to the scope of the project. Remote sensing using aerial videography is proving to be the most effective way to acquire data. Remotely sensed data is being evaluated to measure historic erosion rates and to develop an erosion prediction algorithm for Lake Oahe. Information such as fetch length, sediment size and type, beach slope, bank orientation and armor capacity are being analyzed with respect to measured erosion rates to define and calibrate the algorithm.

Components of the video and microcomputer systems used for this analysis include an off-the-shelf color composite video camcorder, a portable color video monitor, an IBM PC/AT-compatible microcomputer, a video frame grabber, an analog color monitor, and an image processing software. Video is obtained by mounting the camcorder over a port in the fuselage of a small fixed-wing aircraft. The entire reservoir bankline is videotaped at a medium scale. Larger scale footage is also acquired at fifty control sites for detailed analysis. Tapes recorded during the flight are later played on a camcorder attached to a video frame grabber mounted in a personal computer (PC). Images are selectively captured, processed, and integrated into an electronic database. The processing software used is the Map and Image Processing System, a proprietary image processing and geographic information system software.

INTRODUCTION

Erosion of banks along rivers, lakes, and reservoirs is caused by a variety of mechanisms which interact in complex ways. The complexity of these processes has prevented the development of methods which accurately predict bank erosion. Estimates to establish erosion limits and reservoir capacity depletions are currently based upon either infrequent inspections or upon predictive techniques known to be in error by as much as 50 - 100%. Neither of these methods is based upon sufficient data to address the significance of the various mechanisms involved. Remote sensing techniques provide the most efficient and cost effective method to obtain enough data to define the complex processes and relationships contributing to bank erosion.

The Omaha District of the U.S. Army Corps of Engineers is using remote sensing techniques and geographic information systems (GIS) to better assess erosion along the shoreline of Lake Oahe in North and South Dakota. Figure 1 shows the study area. We use a color composite video camera to obtain footage of the entire shoreline through a fuselage port

in a light aircraft. Video images are later played and selectively frame-grabbed for interpretation and incorporation into a GIS. Aerial videography is low cost, flexible, real-time, and amenable to computer assisted analysis, giving it several advantages over other remote sensing techniques.

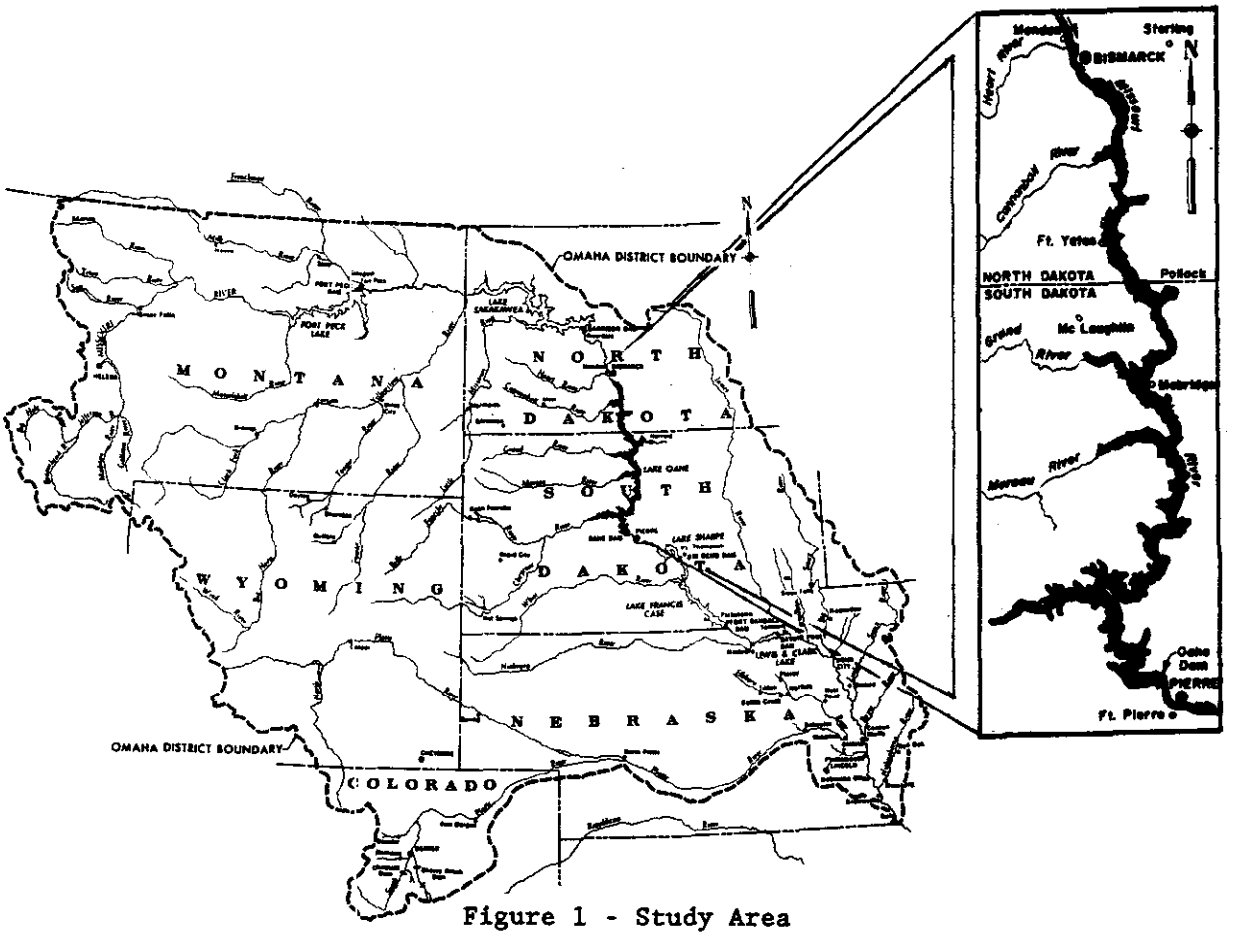

Figure 1 - Study Area

The purpose of this paper is to discuss the applicability of aerial videography technology for sedimentation and water resources analyses. This paper focuses upon the equipment, principals, and methodology employed to accomplish the Oahe Shoreline Erosion Analysis Study. At the time this paper is prepared, the Oahe study is not complete. A similar pilot study was, however, conducted for a portion of Lake Sakakawea in North Dakota in 1989. While the focus of the paper is on the methodologies used, a description of the erosion study is presented.

STUDY DESCRIPTION

An analysis of erosion processes and rates for Oahe Reservoir is being conducted to determine the adequacy of existing taking lines, to estimate reservoir storage loss due to erosion, and to develop an algorithm capable of predicting erosion. Remote sensing techniques are being used to assist in the analysis, and a GIS is being developed for data storage and manipulation. This approach improves the statistical accuracy of the study over conventional methods by virtue of the considerable data that is acquired and processed.

Fifty sites representing a wide array of conditions along the reservoir are being analyzed. Our objective is to establish a statistically sound database by evaluating enough sites that most physical conditions occurring along the reservoir are represented. Historic erosion rates and erosion potential are being evaluated for each site. Data sources for the analysis include scanned USGS 7.5' topographic maps, pre-construction 7.5' topographic maps, SCS soil maps, scanned airphotos for three time periods, frame-grabbed aerial video, and geodetic and sediment data in existing Dbase III files.

We measure eroded areas along the reservoir by simply comparing images of the same area for four different times. Frame-grabbed video images and rectified scans of airphotos are co-registered and overlapped with our processing software and moved with a mouse until we get a good fit between common features. Areas along the bankline which do not match because erosion has caused feature changes are readily apparent and are measured. Dividing the total eroded area by the time period of the analysis yields the average erosion rate.

Several variables affect the rate of shoreline erosion. They include soil type, fetch length, bank orientation, armor capacity, bank height, and bank and beach slope. We measure these parameters for each site, either from the scanned data, the captured airvideo, or from ground truthing and field data collection. Regression analyses are conducted to establish the relationships between erosion rates and these various parameters. We are also classifying the entire bankline into various categories based upon site conditions and erosion potential.

All information generated from the investigation, including raster and vector objects developed from scans and captured video images, database objects and text objects are being assembled into a GIS. Because of the difficulty in predicting erosion, we anticipate the need to update the database periodically with new airvideo, so continued reassessment of our predictions for each site and for the whole reservoir will be made.

VIDEO ACQUISITION

Our airborne video system consists of a color composite video camcorder, a color monitor, and a remote power supply. The system is portable and can be installed in virtually any aircraft with a fuselage port. Total cost of the video acquisition system is $2100 (1990 prices used throughout the paper). Flight costs are $62 per hour.

We use a Panasonic AG-160 camcorder ($1200) to record to 1/2 inch broadcast quality VHS tapes. A custom mount ($250) holds the camera vertically over a hole in the rear seat area of a Cessna 172 airplane. The mount allows vertical and horizontal adjustments to the camera position. A JVC TM-22U 5-inch color monitor ($500) attached to the camera and placed in the forward area of the aircraft allows both the pilot and an observer to monitor the flight. Both the camcorder and monitor are powered by a deep cycle 12-volt gel cell battery ($150). Similar video systems are being used by the US Fish & Wildlife Service (Cowardin, 1989; Sidle, 1990), by the US Bureau of Reclamation and by other non-federal agencies (Miller, 1990).

Our camera's zoom lens has a focal length of 9.0 - 54 mm. We use the widest angle (9.0 mm) and fly low to the ground to maximize image resolution and color quality. At this focal length, the captured ground width is roughly equal to the altitude above ground. Ground resolution with our equipment is approximately 1/1000 of the altitude above ground level (AGL). In other words, at 1500 feet AGL, we capture approximately 1/4 mile per frame at a ground resolution of slightly more than 1 foot.

Planimetric location and object color are the two fundamental variables that we measure from the color composite video. Planimetric location is controlled by flight operation and later software processing. Accurate color reproduction requires adjustment of the camera's white balance prior to the video acquisition. Our camera has a white balance sensor located next to the lens and automatically adjusts to changes in color temperature of the scene. We usually operate the white balance in automatic mode because changing light conditions (like intermittent cloud cover) cause changes in the scene color which in turn affects the quality and consistency of the video. A problem we experience with the automatic white balance mode is that occasional glare from the water surface causes the camera to adjust balance, effectively "washing out" shoreline features. In early morning, late afternoon, and under cloud cover this is not a problem. When it does occur, it is apparent on the monitor and we remove the camera and manually adjust the balance.

During the flight, the observer controls the video equipment, notes location and shoreline conditions, and assists the pilot in navigation. The observer uses a headset microphone attached to the camera to continuously narrate field conditions and location on the tape. Both the pilot and observer watch the color monitor to check that the camera's field of view is consistent with the flight objectives. To minimize distortion caused by rotation of the camera's axis, every effort is made to maintain a wings-level flight. We turn the aircraft to follow the shoreline by slipping it using the rudder and opposite ailerons to make a level turn.

For shoreline erosion studies, we fly the aircraft at about 90 knots ground speed. This is slow enough to minimize blurring effects on the tape. At this speed, we could record slightly more than 200 miles on a single tape. However, we have found that we often need to turn around because we missed a section of bank, or because supplemental coverage at different altitudes is needed. Therefore, we usually record about 150 miles on each tape. We obtain video footage of the entire bank at 2800 feet AGL. In addition, we fly our study sites at both 1500 and 500 feet to obtain higher resolution images for photo interpretation.

VIDEO PROCESSING

We use the Map and Image Processing System (MIPS) software ($4000), a proprietary image processing and geographic information system software, to capture, rectify, and analyze the video images and other data used for our studies. Our processing platform is a Dell System 310 microcomputer. It has a 105-megabyte (Mb) fixed drive, 640 Kilobytes (Kb) RAM, 3 Mb extended memory, math coprocessor, mouse, and MS-DOS V4.01 operating system. This is the standard PC for our engineers and also serves other

normal office functions. It was not purchased for image processing, and thus is not included in the total system cost. Other required hardware include a display circuit board ($1500) and a medium resolution analog monitor ($1000). Because the images require considerable storage space (490 Kb each), we use an optical disk drive ($2000) and 400 Mb optical Disks ($120 each) to store data.

Our image processing system uses two screens. Program menus and textual information are displayed on the standard PC monitor (either color or monochrome). Video images or other raster or vector objects being acted upon are displayed on the analog monitor via the display board. The board is a graphics display device installed in the microcomputer that converts incoming analog signals to digital, stores grabbed images in memory, and displays images on the analog monitor. We connect our camcorder to the board with a standard BNC cable and view the video on the monitor. When an image we wish to process is on the screen, we capture it with a keystroke.

Airvideo images are always geometrically distorted from panoramic and perspective factors. The MIPS software is used to rectify these distorted images. We overlay the video image (a raster object) with a calibrated vector object having features identifiable in the raster image. Sources of these calibrated vectors include existing MOSS or ARC/INFO files, scanned USGS topographic maps converted to vectors, and ground control provided before the flight. The vector features are pulled and stretched with a mouse to match the corresponding features in the underlying raster. The distorted video is then resampled or rubbersheeted to fit the geometry and ground calibration of the vector object. Once rectified, the video image is ready for multitemporal comparison. The rectified image can also be used to update and correct features on the vector object used for the calibration. For example, new roads evident on the image can be added to the vector object and exported in its native format. MIPS supports most of the popular vector formats including MOSS, GRASS, ARC/INFO, TIGER, and USGS DLG.

The MIPS software has virtual display capabilities, meaning that the object being operated upon can exceed the size of the display screen. This is a useful feature for our projects since the size of the study reaches often exceeds that covered by a single video frame. Individual frames are calibrated, resampled, and warped into a spatially correct image, then combined into a single large object by mosaicing. A similar process called tiling assembles scanned portions of large maps.

Once the images are grabbed, rectified, and mosaiced, we assemble them into project files for later analysis. The project files consist of the grabbed images, scanned airphotos, scanned topographic maps in both raster and vector form, scanned soil maps, and associated vector, database, and text objects. Information contained in the project file is used to compare subsequent dates of aerial photography and videography to measure erosion, and for on-screen measurement of parameters considered important in the erosion processes. These parameters include fetch length, soil type, bank orientation, beach and bank slope, armor capacity, and bank height. Separate regression analyses help define the relationship of these parameters to erosion rate.

We use the hyperindexing utility of MIPS to organize and access the hundreds of video frames, scanned airphotos, vector data sets, symbol overlays, and other associated database and text files. This utility allows the construction of large visually indexed electronic atlases. Our top in the hyperindex level is a scanned map of the Omaha District. Mouse clicks on specific areas of the image bring up successively smaller scale images and data such as state highway maps, project maps, 7.5' USGS and army topographic maps, and video images.

CONCLUSIONS AND RECOMMENDATIONS

Aerial videography is an inexpensive and easy-to-use tool. This paper describes the equipment needed and the principals and techniques used to acquire and interpret color composite video for the analysis of shoreline erosion. We are using this technology to assess erosion along 2250 miles of shoreline on Lake Oahe in North and South Dakota. We play video tapes on a camcorder through an IBM compatible microcomputer equipped with specialized hardware and peripheral devices, and capture selected frames for analysis. Existing airphotos, soil maps, and USGS topographic maps are scanned and assembled with the video images and other database and text objects into an electronic project file. An image processing software is used to analyze the images and other data to determine historical erosion rates along the reservoir shoreline and to assist in the development of an erosion prediction algorithm.

The use of video allows us to conduct this analysis at a considerable cost savings over conventional methodologies. Video equipment cost necessary to conduct this type of analysis is $2,000 - $3,000. Required computer hardware and software costs another $6,000 - $7,000 exclusive of the PC (which should already be available). Options including scanners, printers, and optical storage devices enhance the workstation for proportionally higher initial costs. With a total cost for this type of processing station varying from $8,000 to $25,000, it is very cost effective and pays for itself in data acquisition savings by using video rather than still photography. We obtain full video coverage of Lake Oahe at several scales for about $1,500. Comparable coverage using airphotos at a single scale is over $20,000. Because video is inexpensive, we are much more likely to acquire current data.

Recent improvements in the quality, size, and expense of video equipment has increased the practicality of using color composite aerial videography as a water resource management tool. This remote sensing instrument should be considered for other similar projects. Video technology is rapidly evolving. Developments such as Super VHS, high resolution display devices, and better media are steadily improving the quality of aerial videography. Erasable optical drives and optical jukeboxes are removing storage-related barriers. Perhaps the most important developments are in the integration of Loran and Global Positioning Satellite systems with video. The US Fish and Wildlife Service is developing a system whereby more than 55,000 images can be grabbed real-time aboard the aircraft and stored on a single 8-inch optical disc. Each image has a latitude and longitude within 10 feet assigned with GPS. These type of developments greatly enhance the future of aerial videography for sedimentation and water resources studies.

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SCALE EFFECTS IN CALIBRATION OF A BEDLOAD SAMPLER

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ABSTRACT

By means of conducting a series of flume tests using three different scale models of MB–2 type gravel bedload sampler in three laboratory flumes with different width, two dimensionless parameters which can affect the reliability of the sampling efficiency determined from flume calibration were obtained, i.e., the ratio of the width of calibrating flume to the width of sampler entrance, B/b; as well as the Sampler Reynolds Number, $U_* b/\nu$. The former reflects the blockage effect in flume calibration, and the latter is related to the scale effect. Results from these tests indicate that large scale effects will coincide with a reduction in scale, and the oppsite is true for blockage effects.

INTRODUCTOIN

The accuracy determination of total sediment discharge in rivers is a significant problem faced by hydrologists and river engineers. Since the suspended sediment discharge can easily be measured, the main problem is the determination of bedload discharge. There are several ways to determine bedload discgarge: By applying an appropriate sediment transport formula; by making use of equilibrium sediment transport tests either in a movable–bed river model or in a laboratory flume from which a relationship between flow discharge and bedload transport rate could be established (IWCEP,1983); by indirect measurement of some sediment process; and by direct measurement method with a certain kind of sampler which accumulate bedload during a measueemnt period. The last way is, so far, still the most basic and imreplaceable method to obtain field data of bedload(BHYVO, 1987). However, with this method, the sampler must rest on the stream bed, thus, the flow pattern and the bedload movement in the vicinity of the sampler will certainly be disturbed to some extent. As a result, samplers have to be calibrated to determine their sampling efficiencies, so that the sampler rates can be yield estimated true rates. Since the sampling efficiency is highly variably and uncertain with different hydraulic and sediment conditions(Hubbell, 1964), therefore the method of its calibration itself is a complex problem.. The sampling efficiency of a sampler can be determine through several ways, such as conducting calibration tests in a laboratory flume which is wide enough to accummodate a prototype sampler (Hubbell, and the others, 1987); a propriate reach of stream installed with expensive flow and sediment control system to carry out a field calibration(Emmett, 1980); making use of field comparisions of bedloadf samplers, in which one of their sampling efficiency had already known (Childers and the others, 1988). But usually, the sampling efficiency of a sampler can be obtained by tests in a laboratory flume with a scale–down sampler model(Novak and the others, 1975). Unfortunately, the sampling efficiency determined from this way is found quite different from that in nature river. As a result of this defect, in the last decade, there has been a trend of suspecting the reliability of the sampling efficiency of sampler, particularly when dimension of calibration flume is rather small and must use a smaller

scale ratio(model to prototype). The paper of this investgation is to explore initially the main cause of difference in sampling efficiency between flume and natural river, so that to give at least a rough idea of how to extend the results sampling efficiency in flume to the true process in natural rivers.

DIMENSIONAL ANALYSIS

The sampling efficiency of a sampler involves a complex relationship between the hydraulic characteristics of the flow, the roughness of the bed, the size of the material in transport and the physical dimensions and characters of a sampler. In flume calibration, the sampling efficiency of the sampler, E, can be defined as the ratio of the measured transport rate, g_s, to the actual transport rate, g_t, if the sampler had not been there(Hubbell, 1964), then

$$E = \frac{g_s}{g_t} \times 100\% \tag{1}$$

In general condition, the factors which effect the bedload discharge can be grouped into three categories: (1)variables decsribing the flow charater, i.e., velocity v, flow depth h, water surface slope s, and acceleration of gravity g; (2) factors describing the physical features of flow and sediment such as the specific weights of water and sediment γ and γ_s, kinematic viscosity of flow ν, and the diameter of bed material D; and (3) variables denoting the boundary condition, for example, the width of channel or flume B, the non–uniform coefficient of bed material, $\psi = D_{84} / D_{16}$, in this expression, $D_{84}$and $D_{16}$are the particle sizes, in millimeters, for which 84% and 16% of the material is finer respectively, and then

$$g_T = f_1(\nu, h, s, g, \gamma, \gamma_s, \gamma_s - \gamma, D, B, \psi) \tag{2}$$

The factors which effect the quantity of sediment entered the sampler will be: the oncoming sediment in flume, g_t, sampling time t, and the physical dimensions related to the geometric feature, such as the length, width and height of the sampler. The width of sampler entrance,b, was taken as the characteristic length to represent all other sampler dimensions. Thus

$$E = f_2(\nu, h, s, g, \gamma, \gamma_s, \gamma_s - \gamma, D, B, \psi, t, b) \tag{3}$$

Taking the variable b, v, and γ as the basic physical quantities. Using the π theorem for dimensional analysis and rearranging some of the dimensionless variables, Eq.(3) can be written as

$$E_s = f_3\left(\frac{B}{b}, \frac{h}{D}, \frac{b}{D}, \frac{v^2}{gh}, \frac{\gamma_s - \gamma}{\gamma}, \frac{u_* t}{b}, \frac{u_* b}{\nu}, \psi\right) \tag{4}$$

in which u_* is the shear velocity.

Under the condition of open channel flow, using Froude' similarity law, and taking natural sand as model sand, the items $\frac{h}{D}, \frac{b}{D}, \frac{v^2}{gh}, \frac{\gamma_s - \gamma}{\gamma}$,t and ψ in Eq.(4) for both flume and natural river, can be considered similar. Therefore, from the point of view of restricting the effection on the study of the difference of sampling efficiency between flume and natural river, the effects of those items above mentioned could be ignored. Then, Eq.(4) becomes

$$E = f\left(\frac{B}{b}, \frac{u_* b}{\nu}\right) \tag{5}$$

Eq.(5) indicates that in flume calibration, there are two parameters which can effect the reliability of sampling effeciency determined from flume. since these two parameters in flume can not be equal to that in natural river, their varying from prototype will certainly result in corresponding vary of sampling efficiency in flume. Because the calibration is performed in the laboratory flume, and therefore, is a confined environment limited by solid walls. This confinment varies with the value of B / b for a giv-

en scale ratio, or varies with scale for a constant size flume and can modify the flow pattern in the front of the sampler entrance; the larger the ratio B / b is, the less the disturbing to the flow by sampler will be. This is refered to as blockage effect(Bugler and Tatinclaux, 1974). In calibration, the B / b should be large enough so that the embient flow around the sampler to be practically unaffected, thus mitigating of blockage effect. The parameter, $u_* b / \nu$, can be named of Sampler Reynolds Number. The characteristic length, b, in the Number can also be expressed by using the opening diameter of the sampler, or the thickness of the bottom net,Δ , so as to reflect flow condition near the bed more appropriately. In flume calibration, the smaller the scale ratio is, the Sampler Reynolds Number will be, hence it reflects the scale effect.

RESULTS OF EXPERIMENTAL STUDY

General

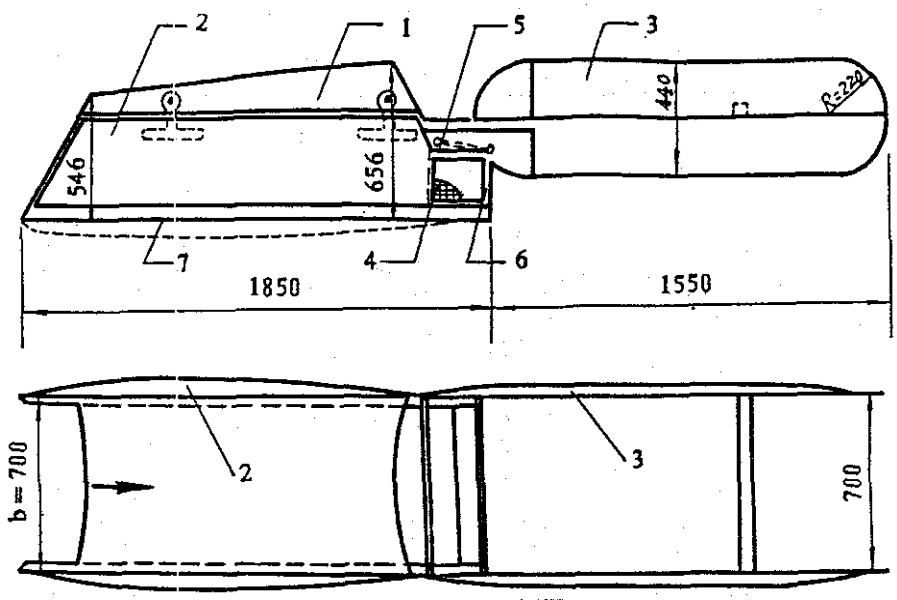

Fig.1 Schematic diagram of MB–2 gravel bedload sampler. (a)side view, (b) top view; (1)sampler body, (2) streamlined shell with cast lead, (3) tailfin, (4) side net, (5) back net, (6) tail net, and (7) bottom net(all dimensions are in millimeters).

The flexible–bottom Minjiang river number two bedload sampler(MB–2) (see Fig.1) has been selected for the investigating . The reason for such a selecting is because of the current interest in the use of the MB–2 Sampler in the southwestern part of China, where gravel and cobble bedload is dominant in rivers. It is also because of according to Annex 4, Coorperative Project on Sediment Transport, between China and U.S.A, a field comprasion of MB–2 bedload sampler and Touttle River 2 (TR–2) bedload sampler which was developed by the U.S Geological Survey is conducting in both countries. The experiment of the present study was carried out in three titling flumes which was available in the Laboratory of Sediment Reseach at Chengdu University of Science and Technology. They are 30,40 and 50 centimeters wide; 40, 40 and 50 centimeters deep; and 16, 22, 23 meters long respectively.Three models of different scales were used, their scale ratios are 1:7, 1:10, and 1:14 respectively, the dimentions of them are shown in Table 1. Each of the flumes consists of a sediment trap beneath the floor of the flume. The model sand can be supplied uniformly across the entire width of the flume at a described

rate from a feeder. Velocities were measured by the CDL–86 Type Douple Ultrasonic Velocity–meter. The scope of tests are as follows: water discharges have the range of 6.13–63.8 liters per second; flow

Table 1. Dimensions of models of bedload samplers

Scale ratio λ_e	Width of entrance (centimeters)	Height of entrance (centimenters)	Thickness of bottom net (millimeters)	Opening entrance of bottom net (millimeters)
1 : 7	10	7.2	2.7	0.8
1 : 10	7	5.0	1.9	0.5
1 : 14	5	3.6	1.3	0.4

depth 6.7–18.8 centimeters; and mediam diameters of bedload in flumes 0.94–2.7 millimeters. Tests include hydraulic characteristics and sampling efficiency. The former was conducted under the condition of uniform flow. Velocity distribution, turbulent intensity, as well as water surface elevation under both sampling state and having not sampler in flume for each model of different scales were observed. The layout of points for the volocity measurement is shown in Fig.2. Tests on sampling efficiency were performed under the conditions of rigid bed with similar bed roughness and equilibrium sediment

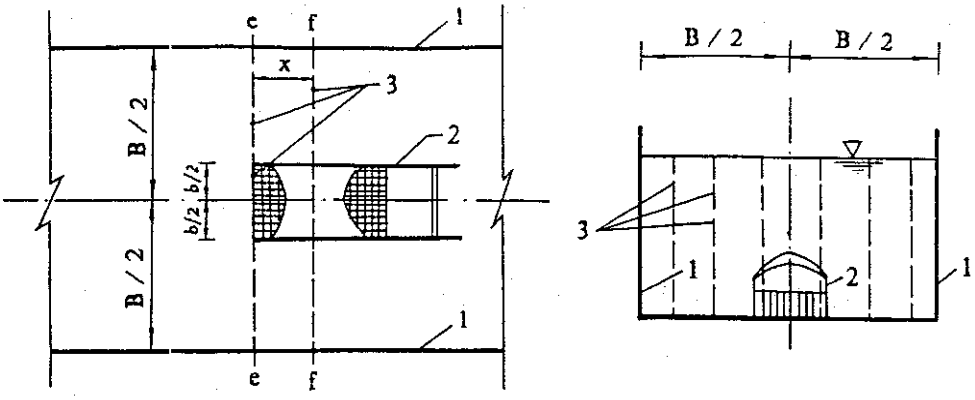

Fig.2 Layout of points for velocity measurement. (a) plan view, (b) front view, (1) wall of calibration flume, (2) sampler, and (3) verticles for measurement.

transport. The mean value of 3 repeated samples from the sand receiver was taking as the ture bedload rate, g_t; and the mean value of 9 samples which consist of 3 different positions on the sampling cross section(left, center and rigth) with each repeated three times was taking as the sampled rate, g_s. And the sampling efficiency can be obtained by Eq.(1).

Results of hydraulic character test

Table 2 Velocity coefficient of sampler at entrance cross–section

Scale ratio λ_l	Mean velocity under sampling state (m / s)	Mean velocity under nature state (m / s)	Velocity coefficient K_v
1:7	0.485	0.554	0.875
1:14	0.345	0.386	0.894

The isovelosities in the entrance cross–section of different scale models are shown in Fig.3. It indicates that the sampler makes the main velocity shifting to both sides of it,so that a zone of reterdation and

divergence of flow exists immediately before the entrance of the sampler. The situation of the velocities at the entrance section can expressed by velocity coefficient, K_v, the ratio of the mean velocity of water

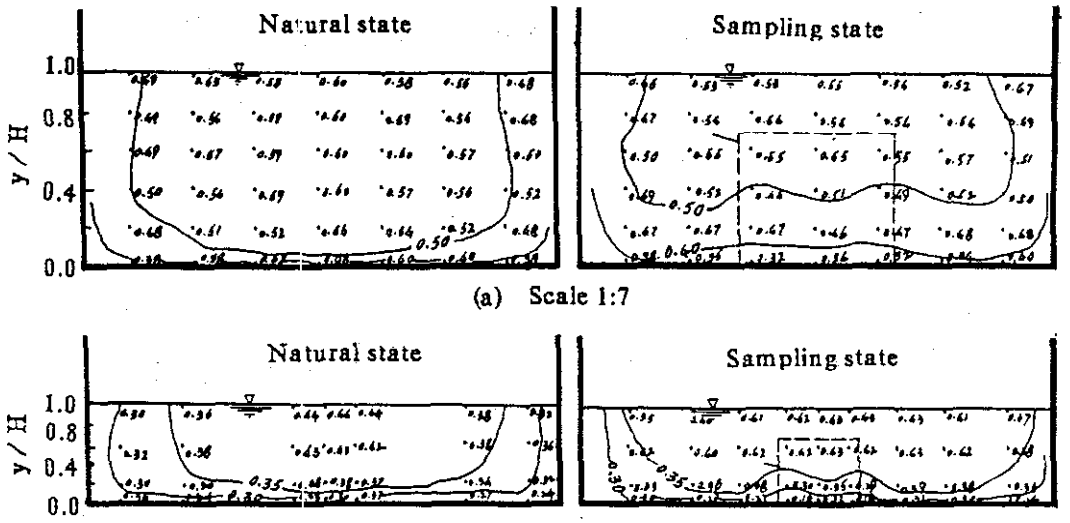

Fig.3 Isovelocities in entrance cross–section. (a) scale 1:7, (b) scale 1:14, unit of velocity–m / s; flow depth, H = 0.938m; discharge per unit width, q = 1.52 m^3 / s–m (all in prototype); s denotes sampler.

Table 3 Comparision of velocity at center verticle of entrance cross–section

Scale ratio λ_l	Situation of measurement	Relative flow depth, h / H 0.00	0.05	0.40	0.60	1.00
	Natural state	0.49	0.50	0.60	0.60	0.60
1:7	Sampling state	0.34	0.40	0.51	0.55	0.55
	K_v	0.69	0.80	0.85	0.92	0.92
	Natural state	0.31	0.33	0.41	0.43	0.45
1:14	Sampling state	0.17	0.24	0.40	0.42	0.43
	K_v	0.57	0.73	0.98	0.98	0.96

discharge througth the sampler to that of the discharge through the same area had the sampler not been there, and can also expressed by comparing the corresponding point velocities (See Tables 2 and 3).Table 2 indicates that the difference of the value of$K_v$are not distinct under different scale ratios. But it is obvoius from Table 3 that when the relative depth, h / H, is less than 0.1, i.e., within the nearbed zone, the corresponding point velocities and their values of $K_{vp}$of the model of scale 1:7 are larger than that of the model of the scale 1:4. Fig.4 shows that the comparision in turbulent intensity at the entrance cross–section between two different scale models. It indicates that the turbulent intensity of flow in the vicinityof entrance is more stron under sampling state than that of natural state; the amplitude of increase at the lower part or in case of larger model scale is larger than that at upper part or that of smaller model scale. The maximum turbulent intensities at the bottom of the two models of scales 1:7 and 1:14 are 0.22 and 0.14 repectively. The comparision of water–surface elevation between sampling state and nature state of differentscale models in a given flume, which means that the value ofB is constant

but the ratio B / b is a variable, is shown in fig.5. It shows that after a sampler was tested on the flume bed, the water surface elevation above the entrance inceases, the larger the size of the model is, the more the increase of elevation will be. It implies that the amplitute of blocked up of water surface elevation is mainly varied with the value of B / b.

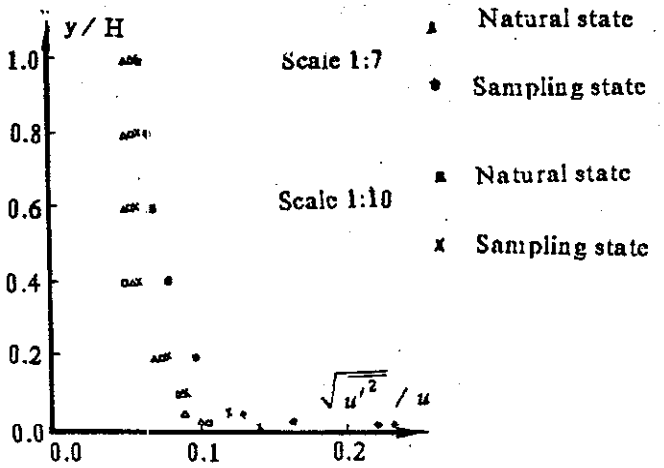

Fig.4 Variations in turbulent intensity

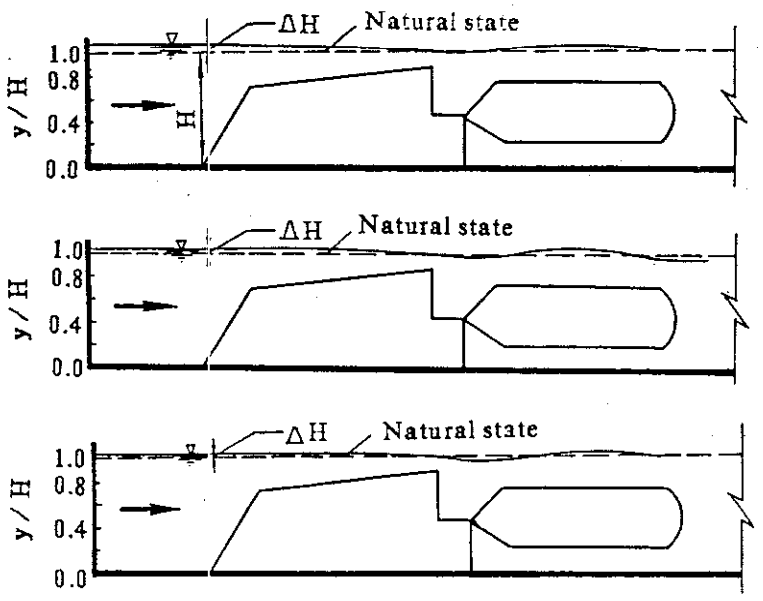

Fig.5 Comparision of water surface elevations betweem sampling state and natrual state of different scale models(all extended to the dimensions of prototype in this figure). (a), (b), and (c) denote the scale ratio to be 1:7, 1:10, and 1:14 respectively; the solid lines and dashed lines represent natural state and sampling state respectively.

Results of Sampling tests

The sampling experiments are summarized in Table 4, and its data are plotted in Fig. 6. It can be seen from Fig.6 (a) that the value of E increases as the value of B / b increases in case of constant scale. The amplitute of the the change E is depended on the value of B / b. When the value of B / b is smaller, the effect of B / b on E is more notable. Also from Fig.6(a), it is expected that in case of constant scale, when the value of B / b is large enough, the value of E may no longer change with the value of B / b.

This value of B / b, if any, can be considered as the critical value of B / b, when the value of B / b in the flume calibration is larger or equal to this critical value, the blockge effect is negligible. Fig.6(b) and (c) demonstrated that when the model scale used for flume calibration is too small, there will be a siginificant differecne between E obtained from different scales. Under constant value of B / b, the value of E increases as the value of Sampler Reynolds Number increases, the less the Sampler Reynolds Number is, the more the extent of its effect on E will be.

From the point of view of mitigating the blockage effect, the model scale will be selected as samll as possible to obtain a larger value of B / b; on the other hand, from the point of view of mitigating the scale effect, the selecting of scale will be in the opposite direction. these two effects, however, are not of the same magnitude, and therefore, for a given flume, there should be an optimum scale at which the combined scale and blockage effects are minimum.

Table 4 Data on measured sampling efficiency

Scale ratio λ_l	Water discharge per unit width (m^3 / s–m)	Sampler Reynolds Number $u_*\Phi/\nu$	Sampler reynolds Number $u_*\Delta/\nu$	Sampling efficiency width of flume (cm) 30	40	50
1:7	0.1275	39	132	52	59	64
1:10	0.07475	20.4	77.7	45	52	57
1:14	0.04513	13.8	44.8	38	44	48

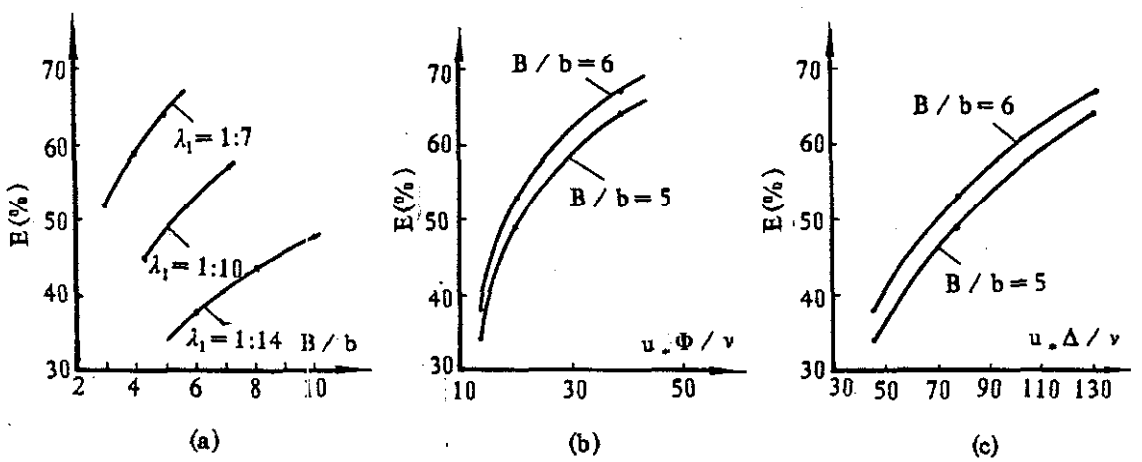

Fig. 6 Relationship between E and B / b, or $u_*\Phi/\nu$, or $u_*\Delta/\nu$.

Need not to say, in addition to the scale and blockage effects, some other causes may also important effect on the reliability of sampling efficiency, such as the condition of bed configuration and the fluctuation of bedload discharge. More experimental work needs to be undertaken in this problem. Even though for determining the critical value of B / b, and the optimum scale, larger model scale and wide enough flume should be needed to study the topic more deeply and thoroughly.

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Evaluation of The Suspended Sediment Samplers

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Abstract

This paper provides information about the performance of suspended samplers in field conditions. Some of the samplers developed and popularly used in China were compared with the USP-61 or USP-63 samplers. Range of sediment concentration in streams during the period of comparative work was about 0.5 to 326 kg per cubic meters. Major results may be summarized as follows: (1) measured concentrations agree with each other within tolerance limit of random error and no systematic deviations could be found, (2) for samplers that the pressure difference is adjusted by a chamber in the sampler body, the use in sampling of heavily sediment ladened flow is not recommended due to the decreasing sampling efficiency and the deposition in the pressure chamber, (3) all the samplers show a trend of decrease in its hydraulic efficiency as the sediment concentration goes up, however, the collapsible bag sampler shows a less decrease beyond a concentration of 50-100 kg per cubic meters. No systematic bias could be found in the sediment concentration even though the hydraulic efficiency was quite low at field site where the sand fraction constitutes about 10-20% of the sediment load.

Introduction

According to the project on intercomparison of suspended sediment samplers initiated respectively by World Meterological Organization (WMO) and Ministry of Resources of China, the Zhutuo hydrometric station on the upper Yangtze River and the Tongguan hydrometric station on the middle Yellow River were selected as two test fields during 1986-1988.

In the first phase of intercomparison,34 sets of measurments were taken for six Chinese samplers and the sampler USP-61, provided by United states Geological Survey, and in the second phase of intercomparison, 67 sets of measurements were taken for seven Chinese samplers and the sampler USP-63, also provided by USGS, 23 samples were taken in parallel for each set, in which 20 samples were for determining the sediment concentration, and 3 for grain size analysis. Purpose of project conducted are as follows: through the intercomparison, the interrelationship between the results obtained by different samplers and USP-61 or USP-63 are established. Based on the intercomparison result, sampling accuracy and scope of application of each sampler could be evaluated to facilitate the selection of samplers in use reasonably.

The intercomparison work includes comparative measurement of sediment concentration, evaluation of the velocity coefficient (the ratio of intake velocity and natural velocity at sampling point) and comparative analysis of grain size ditribution.

Suspended sediment samplers

Test Samplers

A variaty of samplers is available for use in the intercomparison work, from the simple mechanical horizontal trap-type and bottle type samplers to the point integrating samplers, of which the pressure difference is adjusted by a chamber in the sampler body and bag samplers, of which the pressure difference is adjusted by collapsible bags. These samplers have been verified and evaluated, currently being used in hydrometric stations.

Horizontal trap-type sampler

The horizontal trap type sampler consists of two plane valves on both ends of a horizontal pipe can be closed suddenly to trap samples. Using this sampler, an instantaneous water-sediment sample is collected.

Bottle type sampler

The common bottle sampler consists of a bottle with intake and exit nozzles, which is placed inclined in a container. This sampler can only be used to take depth-integrating samples.

JX, FS and LSS Samplers

These are point-integrating samplers whose main characteristics is similar to that of the US-P61. However, the three versions of samplers could not only be used on board a gaging boat, but also used on the cableway.

LS-250 Sampler

Ls-250 Sampler was developed at the Liaoning Province Hydrological Service, and is a semi-bag sampler which could only be used to take depth-integrating samples.

ANX 3-1 Collapsible bag sampler

This collapsible bag sampler used in this work was provided by the Sanmenxia Reservoir Experiment Station, YRCC. Volume of the bag is 3 liters. An electro-magnetic device is used to open or close the intake tube. Either point integration or depth integration may be used in taking samples.

Techniques for intercomparison test

A prerequisite for the test is that the depth and time of sampling of the samplers to be compared should be the same.

Comparison between the USP-61 Sampler and the horizontal trap sampler

Samplers for intercomparison were placed on a metal frame. USP-61 was placed at the center and two horizontal instantaneous samplers are installed on each side. Distance between two samplers from center to center is 0.5 m. During the period of sampling of the USP-61 sampler, one horizontal sampler takes a sample at the beginning, another takes a sample at the end. The average concentration of these two samples will be compared with the concentration sampled by the USP-61 sampler.

Comparison between USP-61 sampler and other point integrating samplers

Two samplers are installed in parallel on a metal frame with a distance of 0.8 m between the center of two samplers. Location of sampling point is 2-3 m below water surface. When half of measurements are made, the left and right positions of two samplers should be exchanged.

Comparison between USP-61 sampler and the depth integrating sampler

When the method of depth integration was adopted, two samplers were lowered and lifted in a round trip with uniform speed by speed ragulator in bath direction, exchanging the positions (right and left) when half of measurements are made.

Result of comparison

Sediment concentration

During the intercomparison at Zhutuo and Tongguan stations, the velocity varied from 0.86-2.14 m/s and the maximum and minimum sediment concentration amounted to 0. 5 and 326 g/l respectively. No systematic error can be detected from the comparative results. Figure 1 represents the results obtained at both stations. It seems that sediment concentration obtained by USP61 (Or P63) sampler and other Chinese samplers are almost the same.
At Zhutuo station and Tongguan station, majority of the sediment to be sampled is less than 0.05 mm in size as indicated by size analysis that the portion of sediment less than 0.05 mm amounted to about 85-95%. Comparison for silt fraction between the tested samplers and the USP61 sampler is shown in fig. 2. still no systematic deviations could be found. Figure 3 shows that the data points are slightly scattered for the sand fraction.

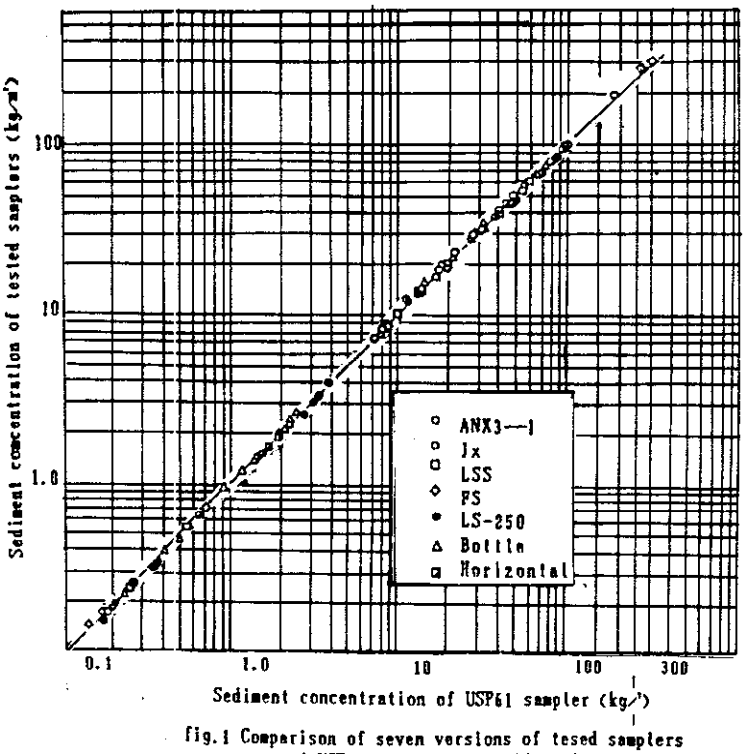

fig.1 Comparison of seven versions of tesed samplers and USP61 sampler in field conditions

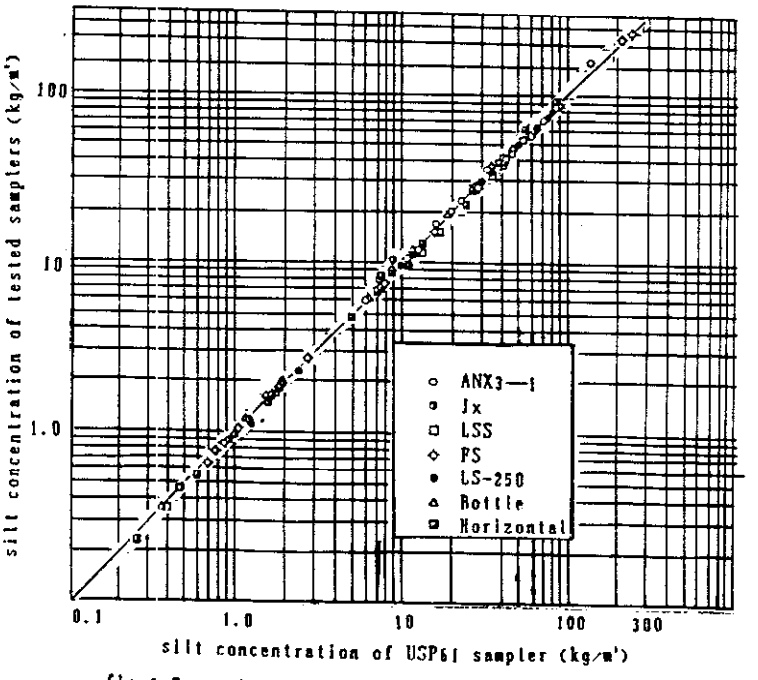

fig.2 Comparison of seven versions of test samplers and USP61 samplers in field condition

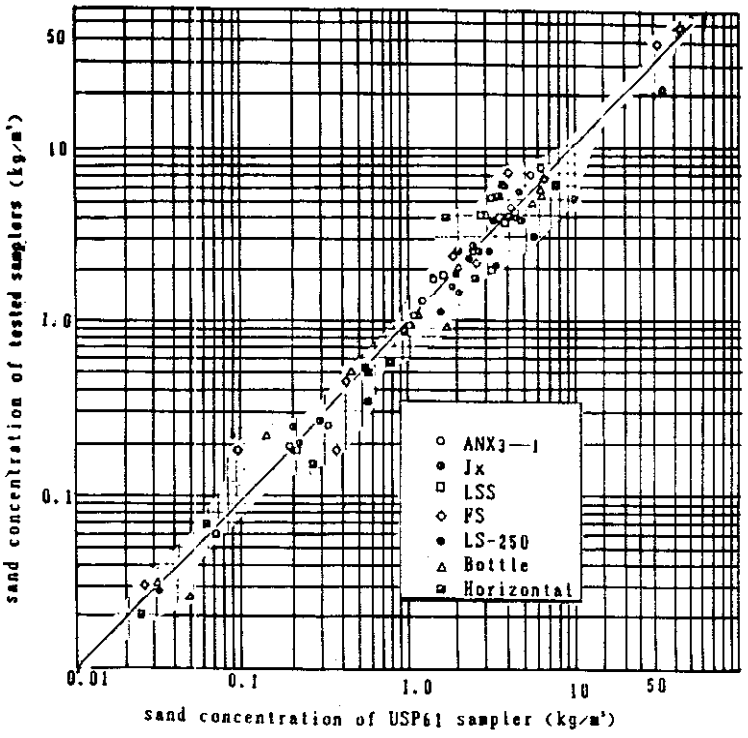

fig.3 Comparison of seven versions of test samplers and USP61 samplers in field condition

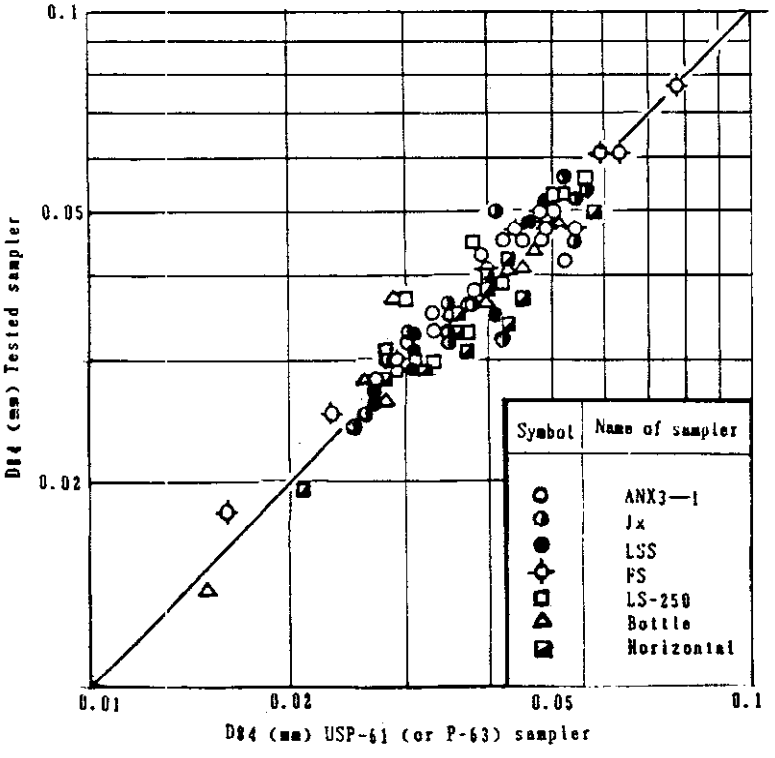

fig.4 Comparison for size by tested samplers and control sampler

Comparison for size

Range of D84, that is, sediment size at which 84% is finer, during the period of comparitive work was about 0.025-0.06 mm. Figure 4 represets the comparative result of D84. It seems that for most samplers used in the test, there is no systematic deviation except the horizontal instantaneouse sampler, of which, the size is less than that of sampled by the US-P61 sampler systematically.

Test of hydraulicefficiency on natural stream

At Zhutuo station, method for examining the hydraulic efficiency was as follows: the current meter and sampler are suspended on the metal frame in parallel, and the central distance between them is 0.5 m; the velocity measurement and sediment sampling are conducted by current meter and sediment sampler simultaneously at 0.2 relative depth at a selected vertical with large depth; thus the hydraulic efficiency of sampler on nature stream is determined. At Tongguan station, the current meter was fixed on the middle of the frame, the velocity measurement and sediment sampling of USP61 sampler and tested samplers are conducted by current meter and sediment samplers simultaneously. many tests for hydraulic efficiency were carried out in the field. Figure 5 represents the results that the coefficient of intake velocity of all samplers nearly equal to 1, but the trend of decreasing hydraulic efficiency with increasing sediment concentration is clearly demonstrated when the sediment concentration in stream tends to be greater than 50 g/l.

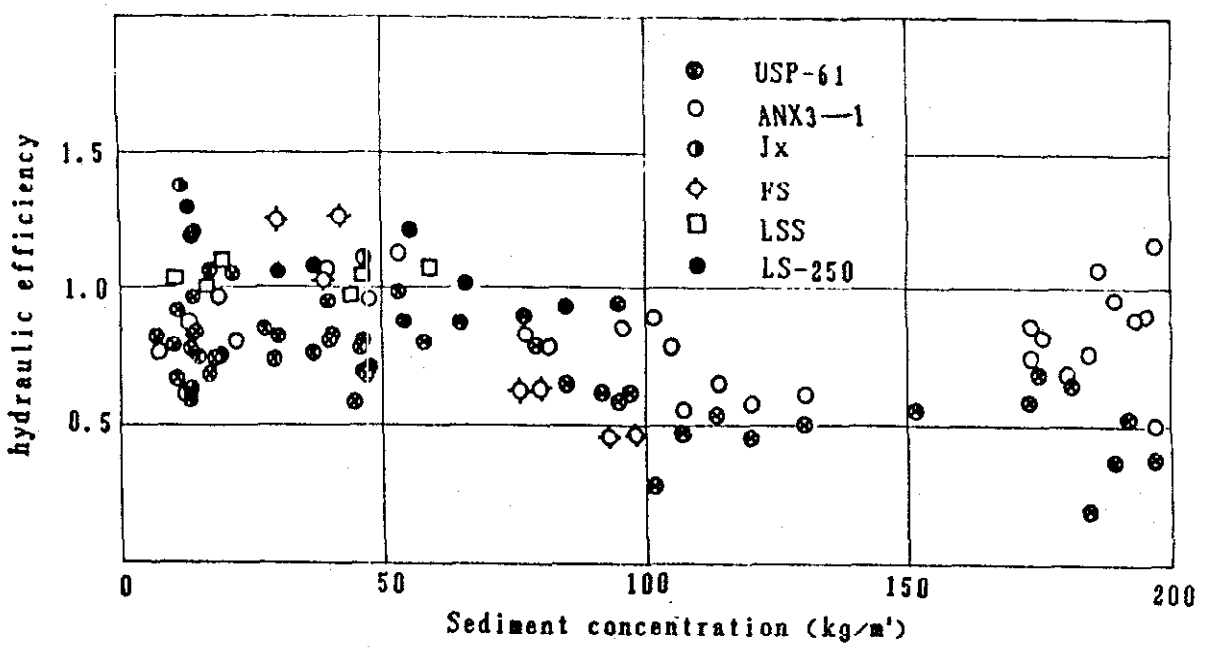

fig. 5 Relation between hydraulic efficiency and sediment concentration

Conclusions

The information presented in this paper can be summarized as follows:

1. Measured concentrations agree with each other within tolerance limit of stochastic error, and no systematic deviation could be found.

2. For pressure regulation and time integrating samplers, the use for sampling in heavily sadiment laden flows is not recommended due to the decreasing sampling efficiency and the deposition in its pressure chamber. It has been proven through the preliminay field comparisons that the collapsible bag sampler is suitible for taking samples with high sediment concentration.

3. Although all the samplers show a trend of decrease in its hydraulic efficiency as the increase of sediment concentration, however, no systematic bias could be found in the sediment concentration sampled even the hydraulic efficiency was quite low at a field site where the sand fraction constitutes about 10-20% of the sediment load.

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SAMPLING DIFFERENCES BETWEEN THE HELLEY-SMITH AND BL-84 BEDLOAD SAMPLERS

by Dallas Childers

ABSTRACT

The Helley-Smith pressure-difference bedload sampler was developed in 1971 to sample bedload. In an effort to improve sampling accuracy, a new pressure-difference bedload sampler, designated as the BL-84 sampler by the Federal Interagency Sedimentation Project, was developed in 1984.

Nine field tests were conducted in 1986 and 1987 to determine sampling differences between the Helley-Smith and the BL-84 bedload samplers. The characteristics compared were sampled bedload rates and particle-size distributions. During the tests, the Helley-Smith sampler collected bedload at a mean rate that was 1.1 to 3.0 times the rate collected by the BL-84 sampler. Mean particle-sizes collected by the Helley-Smith sampler were larger than mean sizes collected by the BL-84 sampler during 8 of the 9 field tests.

During each field test between 13 and 40 bedload samples were collected by each sampler from a fixed point above the streambed. This collection technique, and use of a tether line during 5 of the tests, resulted in samples being collected at a common point on the streambed during each test. Sampling times were held constant during each test but ranged between 10 and 60 seconds for different tests.

Field conditions for tests included depths ranging from 0.44 to 3.29 meters and depth-averaged mean velocities that ranged from 0.64 to 2.59 meters/second. Mean sampled bedload rates for the two samplers ranged from 18.48 to 3,306 grams/second-meter and mean bedload particle sizes ranged from 0.31 to 11.7 millimeters.

INTRODUCTION

Since 1971, the Helley-Smith pressure-difference bedload sampler (Helley and Smith, 1971, Emmett, 1980) has been used widely for collection of bedload samples. In an effort to improve sampling accuracy, a new pressure-difference sampler, designated the BL-84 sampler by the Federal Interagency Sedimentation Project, was developed in 1984 to sample bedload (Hubbell and others, 1985). The two samplers (table 1) have the same nozzle entrance width and height of 76 x 76 millimeters; however, their hydraulic and sampling efficiencies are different. Hydraulic efficiency is the ratio between the flow velocity averaged across the nozzle entrance area to the velocity averaged across the same area without the sampler in place. This ratio of velocities is related to the sampler area-expansion ratio, which is the ratio between the exit area at the rear of the sampler nozzle and the entrance area at the front. The Helley-Smith sampler nozzle has an area-expansion ratio of about 322 percent and hydraulic efficiency of about 1.54. The BL-84 sampler nozzle has an area-expansion ratio of about 140 percent and hydraulic efficiency of about 1.35.

Table 1.--*Description of the Helley-Smith and BL-84 bedload samplers*
[mm=millimeters]

Sampler	Entrance size width (mm)	Entrance size height (mm)	Nozzle area expansion (percent)	Hydraulic efficiency
Helley-Smith[1]	76.2	76.2	322	[2]1.54
BL-84[3]	76.2	76.2	140	[4]1.35

[1] Sampler tested by Emmett, 1980, and sampler number 1 in Hubbell and others, 1985.
[2] Druffell and others, 1976.
[3] Sampler number 3 in Hubbell and others, 1985.
[4] Hubbell and others, 1985.

Field calibration of the Helley-Smith bedload sampling efficiency was conducted by comparing sampling rates of the Helley-Smith sampler with those of a 14.6-meter-wide bedload trap in a river (Emmett, 1980). The sampling efficiency of the Helley-Smith bedload sampler was determined to be about 100 percent. Sampled bedload was between 0.5 and 16 millimeters in size and the sampled bedload rate ranged from about 1.5 to 3,020 grams/second-meter.

Flume calibration of the Helley-Smith and BL-84 bedload samplers was conducted by comparing sampling rates of the two samplers with those of a 2.7 meter wide bedload trap in a laboratory flume (Hubbel and Stevens, 1986). The sampling efficiency of the Helley-Smith bedload sampler ranged from 100 to 208 percent and that of the BL-84 bedload sampler ranged from 100 to 182 percent. Sampled bedload was between 1.4 and 32 millimeters in size and the sampled bedload rate ranged from near zero to about 3,000 grams/second-meter. Bedload sampling efficiency increased for both samplers as mean bedload particle size decreased.

The nine field tests described in this paper were designed to determine the sampling differences between the two bedload samplers under field conditions by comparing the bedload rates and particle-size distributions collected by each.

TEST CONDITIONS AND PROCEDURES

Data were collected at three sites near Mount St. Helens, Washington, and at one site along the East Fork River, Wyoming, under a variety of field conditions (table 2). Samples collected were oven-dried and bedload rate and particle size were determined by weighing and sieving each sample.

Table 2.--*Field data and laboratory results of field tests*

[m=meters, m/sec=meters per second, mm=millimeters, g/sec-m=grams per second-meter, and HS=Helley-Smith]

Test	Total number of bedload samples collected	Depth of flow (m)	Mean flow velocity (m/sec)	Median sampled bedload particle-size (mm) Bedload sampler HS	BL-84	Mean sampled bedload transport rate (g/sec-m) Bedload sampler HS	BL-84
Toutle River at Coldbank bridge near Silver Lake, Washington							
P1	48	-	-	10.1	10.6	2,966	2,643
Q1	48	1.31	2.59	11.7	7.52	3,306	2,005
Toutle River near Castle Rock, Washington							
B3	30	2.13	-	0.99	0.87	2,011	1,562
D3	32	2.38	1.60	0.73	0.72	1,396	476
Cowlitz River at Castle Rock, Washington							
H3	40	3.29	1.23	0.36	0.31	519	296
East Fork River, Wyoming							
I3	60	0.44	-	0.55	0.49	47.89	29.98
J3	60	0.73	0.64	0.56	0.42	31.10	18.48
K3	80	0.73	0.79	0.67	0.58	126.82	52.74
L3	60	1.01	0.92	0.72	0.62	81.76	64.96

During each field test, bedload was sampled by alternately suspending each sampler from a fixed point above the streambed for equal periods of time. When the suspension line was long and stream velocity was high, a tether line was attached to the sampler to prevent the sampler from being pulled downstream by the flow. This procedure enabled the collection of samples from a common point on the streambed.

When bedload transport rates were low and bedload consisted predominantly of sand-sized sediment, each sampler was fitted with a sample catchment bag having a mesh size of 0.25 millimeters and designed to trap a maximum of about 2,000 grams of bedload. When bedload rates were high and bedload consisted predominantly of gravel-sized sediment, each sampler was fitted with a large-volume sample catchment bag having a mesh size of 1.00 millimeter and designed to trap a maximum of about 6,000 grams of bedload.

RESULTS

During each experiment, maximum bedload rate sampled by the Helley-Smith sampler ranged from 2.0 to 3.8 times the mean for the 9 tests. Maximum bedload rate sampled by the BL-84 sampler ranged from 2.2 to 3.7 times the mean for 8 of the 9 tests. In representative tests, showin in figures 1 to 3, the mean bedload rate sampled by the Helley-Smith bedload sampler is greater than that sampled by the BL-84 bedload sampler.

The bedload rates from test Q1, shown in figure 1, are in the same range as bedload rates sampled during test P1 (not shown). Tests P1 and Q1 were collected when mean sampled bedload rates were the highest sampled during the 9 tests. Bedload consisted of poorly sorted mixtures of coarse sand to coarse gravel; bedforms could not be detected by depth soundings taken during sampling.

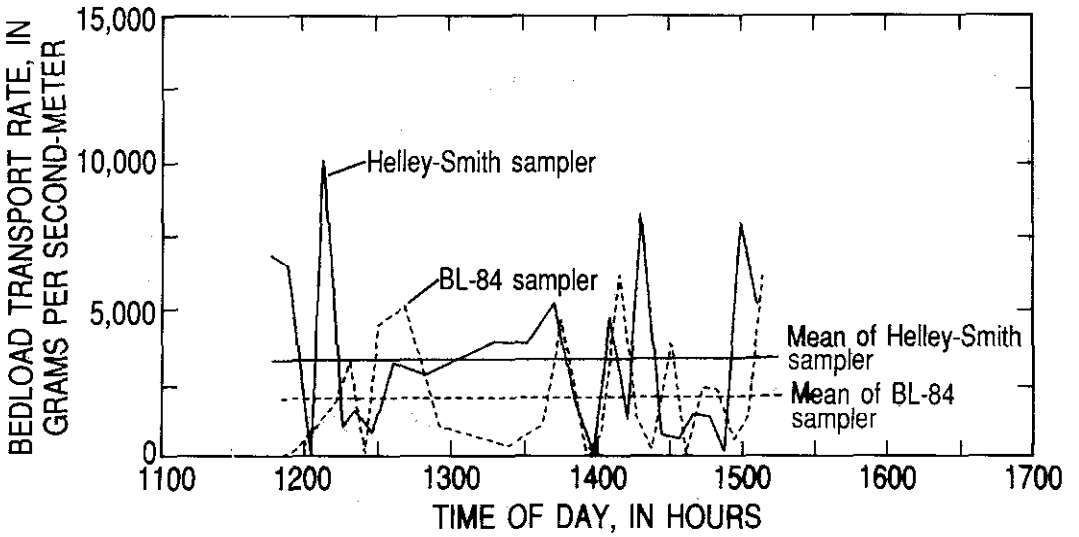

FIGURE 1.--*Sampled bedload transport rate, test Q1, Helley-Smith and BL-84 bedload samplers.*

The bedload rates from tests H3, shown in figure 2, are in the same range as bedload rates sampled during tests B3 and D3 (not shown). Tests B3, D3, and H3 were collected when mean sampled bedload rates were in the middle range of those sampled during the 9 tests. Bedload consisted of bimodal mixtures of well-sorted coarse sand and poorly-sorted medium gravel; dune-shaped bedforms were detected by depth soundings taken during sampling.

Bedload rates from tests J3 are shown in figure 3. The data are in the same range as bedload rates sampled during tests I3, K3, and L3 (not shown), when bedload moved as dunes. Tests I3, J3, K3, and L3 were collected when mean sampled bedload rates were the lowest sampled during the 9 tests. Bedload consisted of well-sorted mixtures of medium and coarse sand; dunes were observed visually on the streambed and were detected by depth soundings taken during sampling. The sampled bedload rate varied with the position of the sampler nozzle on the bedform as the dune migrated past the sampling point.

Mean particle-size distributions of sampled bedload for four of the nine field tests, plotted in figure 4, include the range of bedload particle sizes sampled during all 9 field tests. The median diameters listed in table 2 indicate that the Helley-Smith sampler collected larger-size bedload than the BL-84 sampler during 8 of the 9 tests.

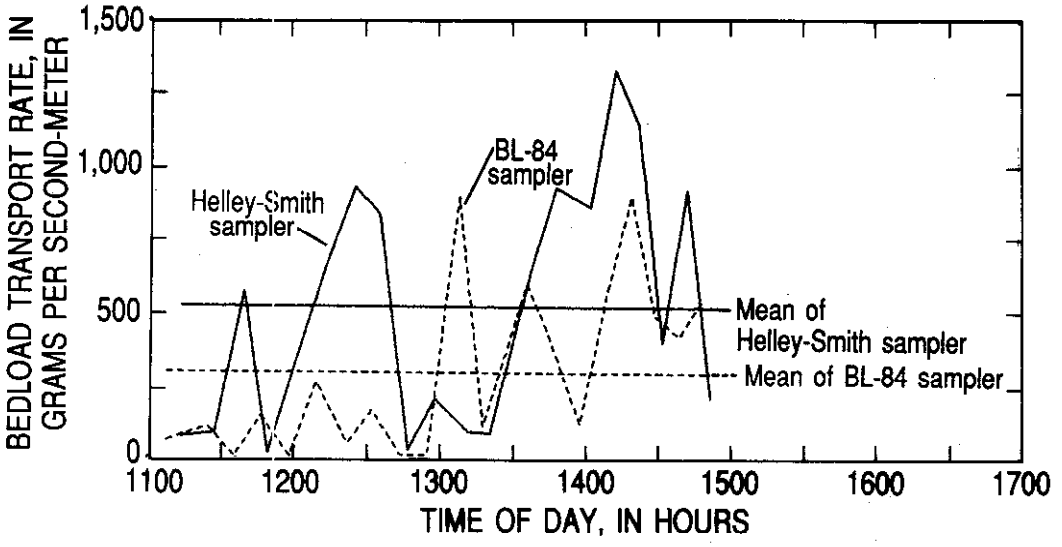

FIGURE 2.--*Sampled bedload transport rate, test H3, Helley-Smith and BL-84 bedload samplers.*

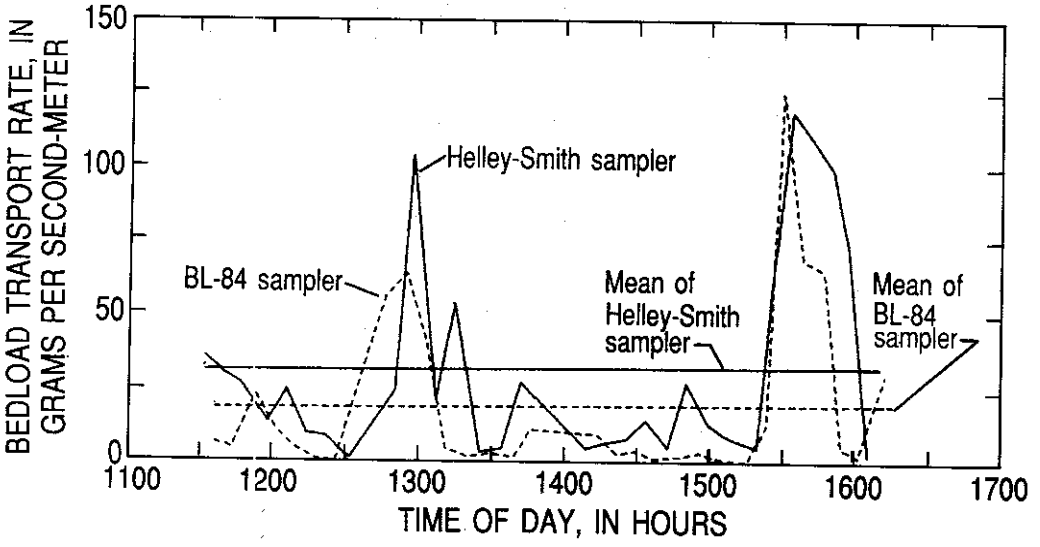

FIGURE 3.--*Sampled bedload transport rate, test J3, Helley-Smith and BL-84 bedload samplers.*

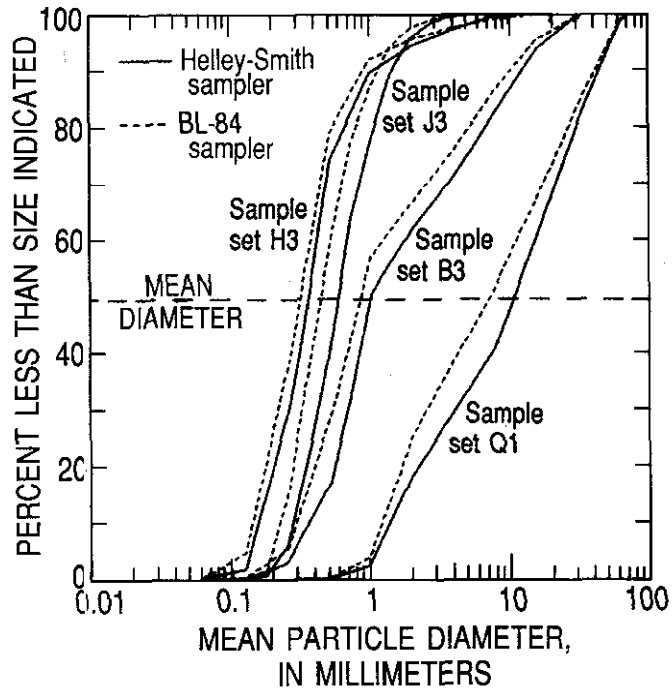

FIGURE 4.--*Mean particle-size distributions of 4 sets of bedload samples collected by the Helley-Smith and BL-84 bedload samplers.*

Sampling ratios were computed by dividing the mean sampled bedload rate of the Helley-Smith sampler by the mean sampled bedload rate of the BL-84 (table 3). Bedload sampling ratios were computed for each size class, for samples excluding sediment finer than sample bag mesh, and for the whole sample.

When a bedload sample is collected, sediment finer than the sample catchment bag mesh is trapped among the larger-size sediment; but the percentage of finer sediment trapped in this manner is not consistent among samples. All sampling ratios computed from these tests are greater than 1.0, ranging from 1.12 to 2.93 when computed from total bedload rates. The sampling ratio was highest when bedload consisted of coarse sand to medium gravel and stream velocity and sampled bedload rates were high (tests B3, D3, and H3, table 2). The sampling ratio was lowest when bedload consisted of poorly sorted sediment sizes from coarse sand to coarse gravel and stream velocity and sampled bedload rates were high (tests P1 and Q1, table 2). The sampling ratio was between these two extremes when bedload consisted of well-sorted medium and coarse sand and stream velocity and sampled bedload rates were low (tests I1, J1, K1, and L1, table 2).

Table 3.--*Mean sampling ratios by size class for each field test*

[sampling ratio = mean bedload rate sampled by the Helley-Smith sampler divided by the mean bedload rate sampled by the BL-84 sampler]

Field test	Bedload sampling ratios by size class, in millimeters						Ratio[1] excluding bedload finer than bag mesh	Ratio[2] of total bedload
	.25-.50	.50-1.0	1.0-2.0	2.0-4.0	4.0-8.0	8.0-16.		
P1	-	-	1.00	1.19	1.67	1.10	1.21	1.12
Q1	-	-	0.96	1.10	1.42	2.27	1.39	1.65
B3	1.04	1.60	1.52	1.33	1.33	1.57	1.38	1.29
D3	2.42	3.25	3.96	4.07	3.95	2.61	3.00	2.93
H3	1.87	1.75	1.77	1.88	1.83	0.75	1.81	1.75
I3	1.40	1.74	1.96	2.73	3.00	-	1.62	1.60
J3	1.55	1.64	2.02	2.11	2.22	-	1.71	1.68
K3	2.35	2.62	2.46	2.26	1.88	-	2.46	2.40
L3	1.27	1.31	1.24	1.15	1.17	-	1.26	1.26

[1] Sampling ratio for bedload rates excluding sediment finer than the mesh of the sample catchment bag.
[2] Sampling ratio for total bedload rates in table 2.

The inconsistency in sampling ratios may be caused partly by natural variations in bedload rate as the bedload moves in clusters or bedload sheets. When bedload moves as dunes, the inconsistency in sampling ratios also may be associated with variations in bedload rate caused by the sampling location on the dune. During all tests, the combination of bed roughness and the rigidity of the sampler frame and nozzle may have caused undersampling at times as a result of an occasional poor fit between the bottom of the sampler entrance and the uneven streambed surface.

SUMMARY

Nine field experiments were conducted to determine sampling differences between the Helley-Smith and BL-84 bedload samplers. The wide range of sampling conditions included flow depths ranging from 0.44 to 3.29 meters, velocities ranging from 0.64 to 2.59 meters per second, individual sampled bedload rates ranging from zero to 10,100 grams per second-meter, and bedload particle sizes ranging from medium sand to coarse gravel.

Under conditions encountered during the field tests, as stream velocity, bedload rate, bedload particle-size distribution, and bed roughness varied, the Helley-Smith sampler consistently collected bedload at a mean rate greater than that collected by the BL-84 sampler. When the sampling ratio was computed from total bedload, the ratio of the mean rate collected by the Helley-Smith sampler divided by the mean rate collected by the BL-84 sampler ranged from 1.1 to 2.9. Mean particle-sizes collected by the Helley-Smith sampler were larger than mean sizes collected by the BL-84 sampler during 8 of the 9 field tests.

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AIRBORNE LASER STUDIES OF THE LANDSCAPE

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ABSTRACT

The Agricultural Research Service is using an airborne laser profiler to study landscape features related to erosion and hydrology. The airborne laser profiler makes 4000 measurements per second with an accuracy of 5 cm on a single measurement. Data are recorded and analyzed with a personal computer. By analyzing these laser profiles, surface features of the landscape can be determined. Airborne laser profile data acquired between 50 and 200 m altitude were used to detect ephemeral gullies in a fallow level field and in a field with mature soybean plants. Laser profiles have been used to measure stream channel cross sections on Goodwin Creek in Mississippi. Canopy height has been determined in studies in south Texas and Mississippi. These canopy height data were used to determine shrub cover in a rangeland ecosystem in South Texas. Laser measurements of shrub cover along a 6580 m transect were 3% lower than field measurements. While these measurements can be made with conventional ground based techniques, the airborne laser profiler technique has the advantage of collecting data faster, with a greater density, and in areas that are essentially inaccessible for ground surveys. Landscape data obtained using an airborne laser shows the potential of the laser system to quantify landscape features related to erosion and runoff. These data should be useful to managers for decision making or as input to natural resource models.

INTRODUCTION

Since the development of the laser in the early 1960's, lasers have come to be used routinely to determine distance along survey lines. The adaptation of laser distancing technology for airborne profile surveys (Jepsky 1986) offers the potential for rapid and accurate assessment of many landscape features that are difficult, time consuming, and expensive to measure with ground-based technology. Airborne laser profilers have been used for sea ice roughness mapping (Ketchum 1971), topographic mapping (Krabill et al. 1984), forest surveys (Nelson et al. 1988), bathymetric surveys (Penny et al. 1989), and ephemeral gully measurements (Ritchie and Jackson 1989). This paper describes studies using an airborne laser to measure landscape features related to erosion and watershed runoff.

METHODS AND MATERIAL

Measurements of landscape profiles were made using an airborne laser mounted in small aircraft flying at altitudes between 50 and 350 m and at speeds between 20 and 100 meters per second (mps). The laser is a pulsed gallium-arsenide diode laser, transmitting and receiving laser pulses at a wavelength of 0.904 micrometers with a field-of-view of 1.3 milliradians. The laser was operated at a rate of 4000 pulses per second for all studies. Measuring accuracy of the laser system is 5 cm for a single pulse. Digital data from the laser are recorded directly with a portable personal computer and stored on a fixed disk. A laser measurement consists of the time between the transmitting of a pulse by the laser and the receiving of that pulse reflected by a landscape feature. This time is converted into distance between the aircraft and the landscape feature reflecting the laser beam. Recorded data from a gyroscope and accelerometer allows for the correction for pitch, roll, and acceleration of the aircraft. A video camera, borehole sighted with the laser beam, is used to record an image of the flight line. Each video frame is electronically numbered and this number is also recorded with the laser data to allow the co-location of the laser data with the video data. All analyses of the laser data can be done with a personal computer.

RESULTS AND DISCUSSION

Examples will be used to describe studies using an airborne laser profiler to illustrate the potential of this instrument for measuring ephemeral gullies, landscape topography, stream channel cross sections, canopy height, and canopy cover.

Airborne laser profile data were collected at aircraft altitudes of 100 and 200 m over simulated gullies prepared by plowing shallow ditches across a level, uniform field. Data were analyzed using a 21 point moving average filter to show the location, depth, and cross section of simulated gullies (Fig. 1). The three gullies were 50 to 80 cm wide and 20 to 30 cm deep. Other simulated gullies with depths between 15 and 30 cm and widths between 20 and 80 cm were detected in other parts of the same field using the laser profile data.

Field measurements were made by digitizing photographs of a grid board placed in the gullies. By comparing 100 measurements from the digitized field photographs with airborne laser measurements across the gully (Fig. 2), a mean difference of 4.6 cm and 2.1 cm was found between the field and laser data taken at aircraft altitudes of 100 and 200 m, respectively. This study shows that gullies with depths greater than 20 cm and widths greater 30 cm could be located and measured accurately with airborne laser profile data.

Airborne laser profile data were collected across a soybean field in Goodwin Creek watershed in northern Mississippi on October 26, 1989. Most of the leaves had dropped from the soybean plants but the beans had not been harvested. An ephemeral gully had been documented and was being studied in this field. At an aircraft altitude of approximately 200 m with a speed of 75 mps, airborne laser profile measurements were made across the field. A south to north laser profile across the field (Fig. 3) closely matches a profile taken from a topographic map with 0.3048 m (1 ft) contours prepared using stereophotograph and photogrammetric methods. The data (Fig. 3) are plotted with the lowest point in the profile set to 0.0 m. A slope of 8.2% was calculated for the north part of the field with a slope of 2.1% for the south part of the field. These slope measurements can be compared with measurements of 6.1 and 1.0%, respectively, calculated from the topographic map.

The center 20 m of the profile (insert, Fig. 3) was analyzed using an 11 measurement moving average filter. This profile shows the presence of a gully in the field which can be seen on the video data taken concurrently with the laser data. The gully is approximately 20 cm deep and 60 to 70 cm wide. The potential for detecting and monitoring ephemeral gullies under normal farming conditions is illustrated by the profile. These results show the potential for using airborne laser data to monitor ephemeral gully erosion and to study topographic relief. Better data on soil loss from ephemeral gullies will allow conservation agencies to make better conservation assessment and plans for controlling soil loss.

Stream cross sections are tedious to measure in the field. With airborne laser data it was possible to measure a stream cross section (Fig. 4) of an S-shaped bend on Goodwin Creek in Mississippi. The profile starts over a soybean field, crosses a natural levee before dropping 5 m into and then across the Goodwin Creek channel. It then proceeds over an overgrown sandbar (tree height between 3 and 8 m) and just reaches topbank before again dropping into the channel, then crosses a wide flat sandbar between the channels before crossing the channel again, up another overgrown sandbar before reaching a cotton field. It took 3 seconds to make the 12000 laser measurements analyzed to develop this channel cross section. Such measurements can be used to follow changes in the morphology of the stream channel and to calculate cross sectional area of the channel.

In airborne laser profiles made across a south Texas rangeland, the presence of objects above the ground surface are evident in the original laser data (Fig. 5). The three objects have been identified as shrubs or small trees from the video image obtained concurrently with the laser measurements. Standard deviations between 0.12 to 0.14 m were calculated for the ground

surface between shrubs and trees on different segments and represent variation due to the laser system and to ground surface roughness.

Ground surface topography was determined using a moving minimum filter of 20 measurements and assigning the minimum value as the ground surface for the first measurement of those measurements. By subtracting the minimum measurement from the laser measurement, a flat surface with elements above this surface could be defined. A value of zero was assumed to be the ground surface. Since there were no man-made structures along the flight line, any value greater than zero was assumed to be vegetation.

Using this data, canopy cover was determined for different canopy heights by determining the number of measurements greater than a height and dividing by the total number of measurements. Canopy cover was determined for canopy heights greater than 0.5 m and 1.0 m. By combining data from seven 940 m segments, canopy cover was determined for a 6580 m flight line.

Field measurements of canopy cover were made along the same flight line using the line intercept method. Three, randomly selected, 30.48 m (100 ft) segments were measured on each of seven 940 m line segments for a total of 21 for the total flight line. An average of the 3 measurements was used as representative for the canopy cover for the 940 m line segment. An average of the 21 measurements was used as the canopy cover for the 6580 m flight line.

Canopy cover measured with laser data for vegetation greater than 0.5 m tall showed a range from 17.8 to 41.9% for the seven line segments with an average canopy cover of 23.9% for the total flight line. Canopy cover for vegetation greater than 1.0 m tall showed a range from 3.7% to 29.7% for the seven line segments with an average canopy cover of 15.7% for the total flight line. Line segments 4 and 5 had the least canopy cover while line segments 6 and 7 had the greatest. Only 0.13% of the measurements for the total flight line were greater than 6 m tall. For the total flight line, 15.7% of the measurements were greater than 1 m high and 6.8% of the measurements were greater than 2.0 m high. These data indicate the sparse shrubby nature of the vegetation.

A comparison of the field measurements with the laser measurements of canopy cover shows that the averaged field measurements (26.7% and 18.3% for vegetation taller than 0.5 m and 1 m respectively) were slightly higher than the laser measurements (23.9% and 15.7%) of canopy cover. However on each of the 7 segments at least one of the field measurements was lower than the canopy cover measured using the laser data.

The differences between the field and the laser measurements of canopy cover may be due to the comparison of an average measurement for twenty-one 30.48 m field measurements with the 6580 m laser segment measurements. A field measurement of the canopy cover on a 6580 m transect would be too time consuming and costly; thus a comparison can only be made for segments of different lengths. The difference may also be from the location of the 21 randomly selected field measurements. By randomly selecting different starting points from the laser data, the range of canopy cover calculated (Fig. 6) was between 0 and almost 90% depending on where a 30.48 m segment starts along the 6540 m flight line. A field measurement of canopy cover using the line intercept method is highly dependent on where sampling starts. Thus the question becomes whether 21 randomly selected 30.48 m field segments can adequately characterize the canopy cover. If it is assumed that 21 randomly selected 30.48 m segments did adequately characterize canopy cover, then canopy cover calculated from the laser data underestimated the actual canopy cover by an average of about 3%. Nevertheless the laser data can give data on the spatial distribution of the cover that is not possible with field measurements.

CONCLUSIONS

Airborne laser profile data can provide an abundance of data on landscape features. In the studies reported here, it has been shown that this type of data can be used to obtain data on ephemeral gullies, stream cross sections, topography, and vegetation cover. Such data could be used to make better assessments of conservation needs, as input to natural resource models, and to study spatial patterns across the landscape.

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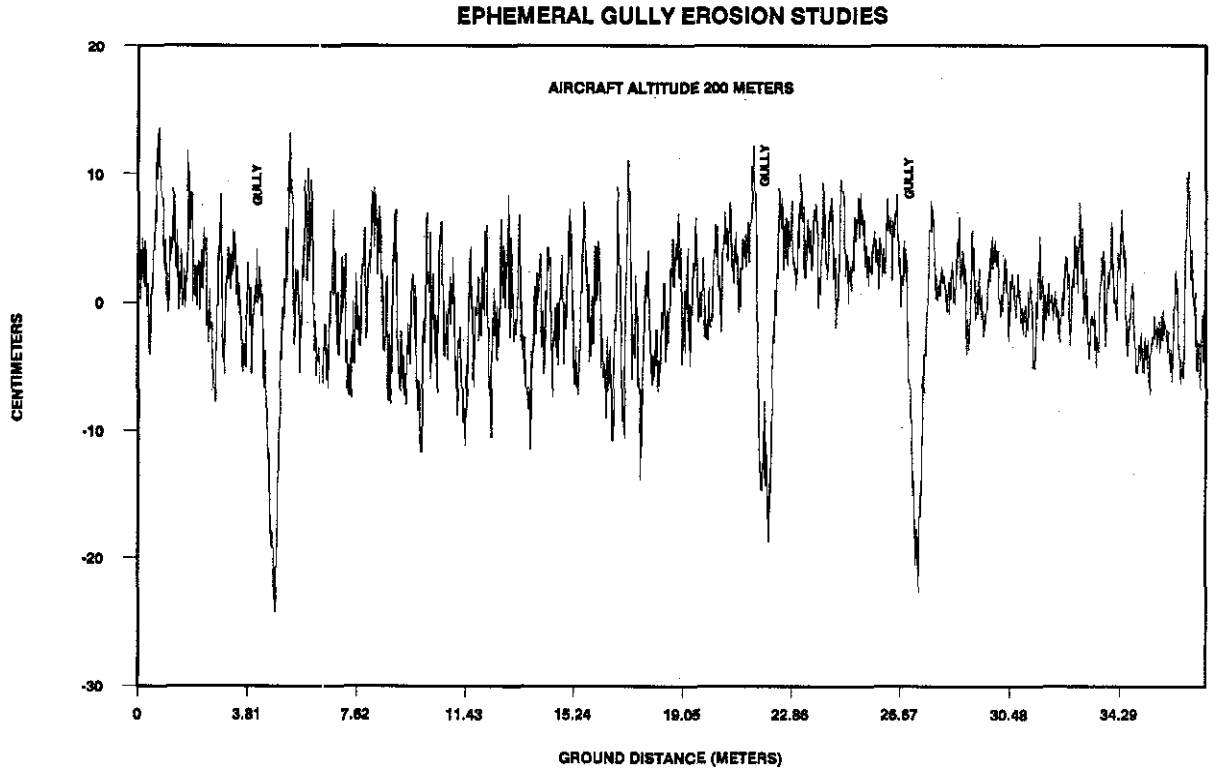

Figure 1. Airborne laser measurements across simulated ephemeral gullies.

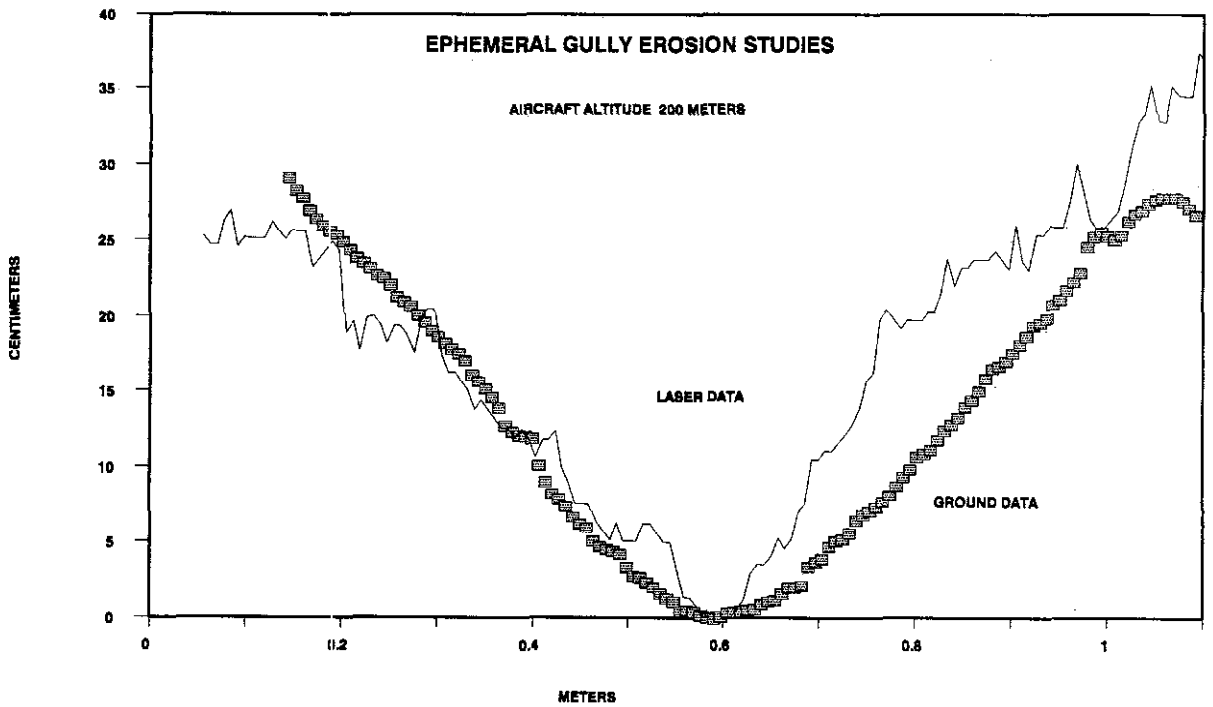

Figure 2. Comparison of airborne laser and field measurement of one of the simulated ephemeral gullies in Figure 1.

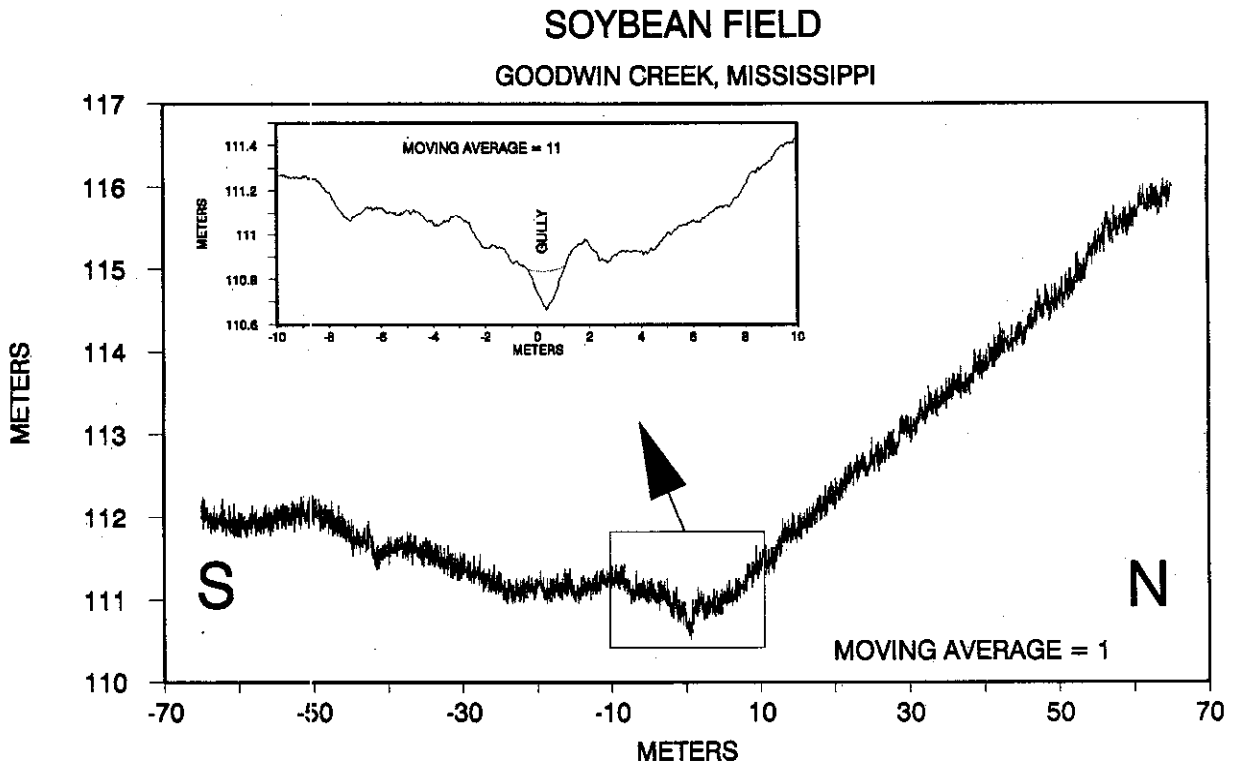

Figure 3. Airborne laser measurement across a soybean field in Mississippi showing an ephemeral gully and topography.

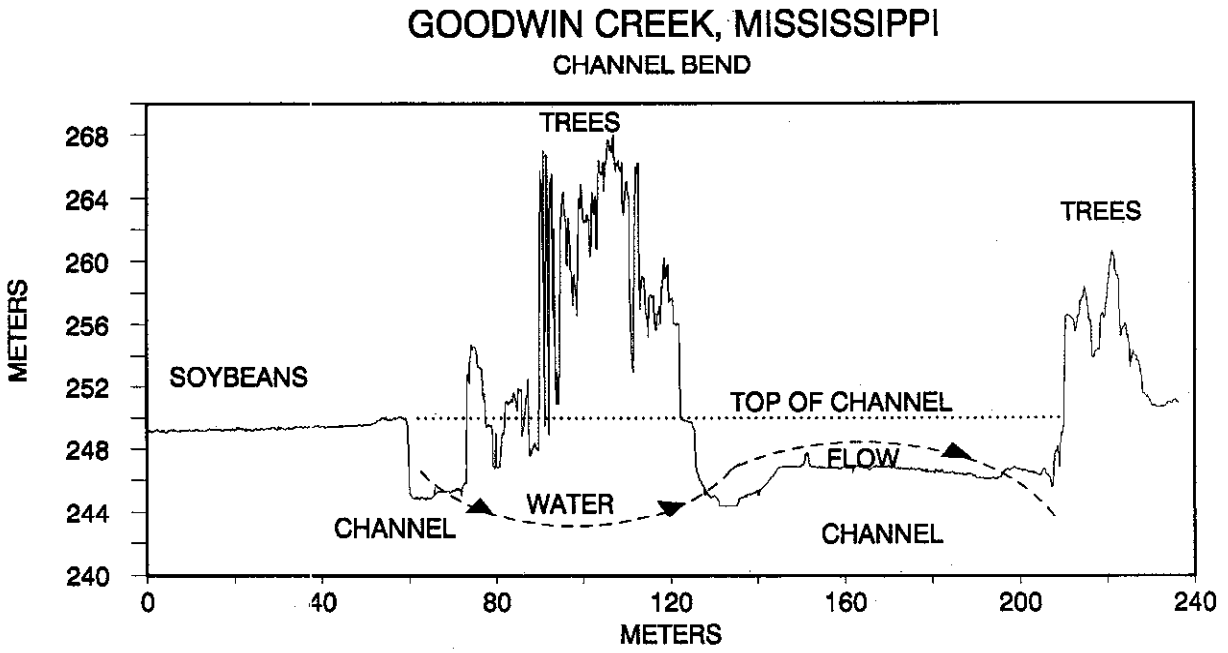

Figure 4. Airborne laser measurement of a cross section of the Goodwin Creek channel in Northern Mississippi.

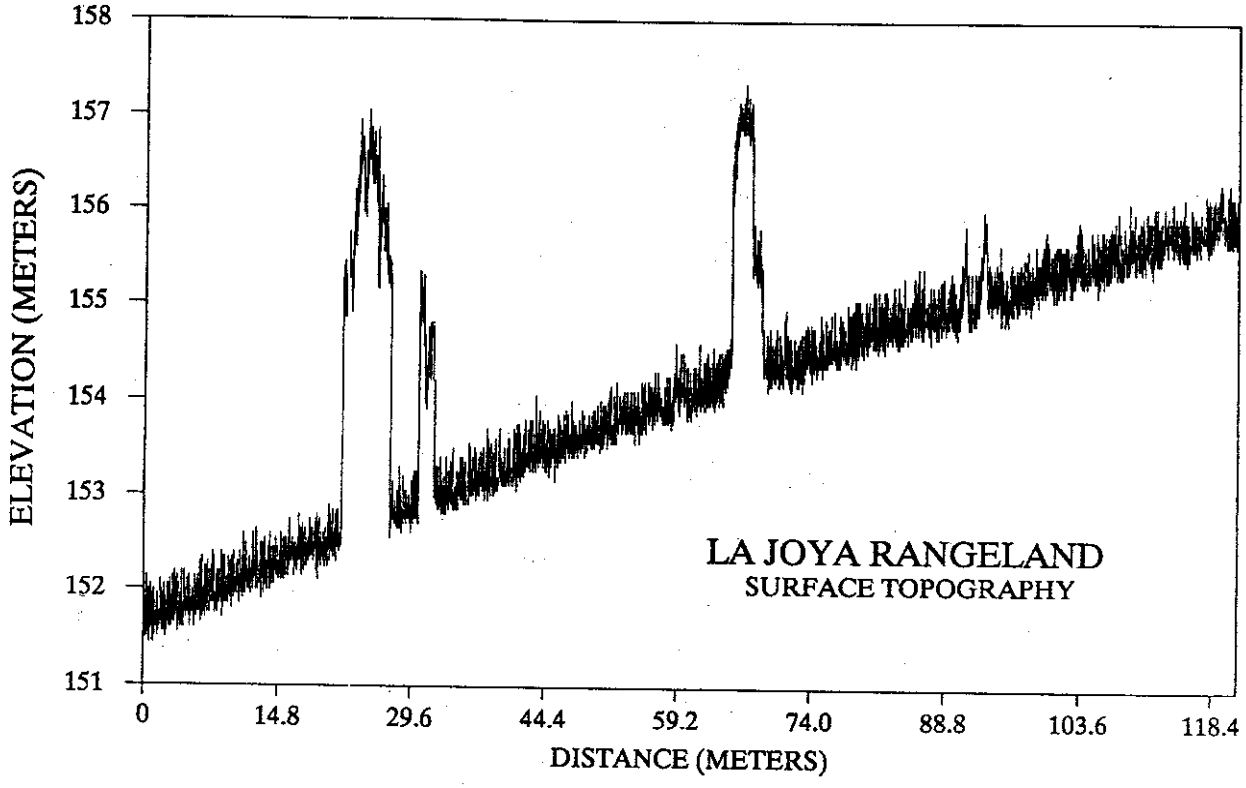

Figure 5. Airborne laser measurements of landscape features for a rangeland site near La Joya, Texas.

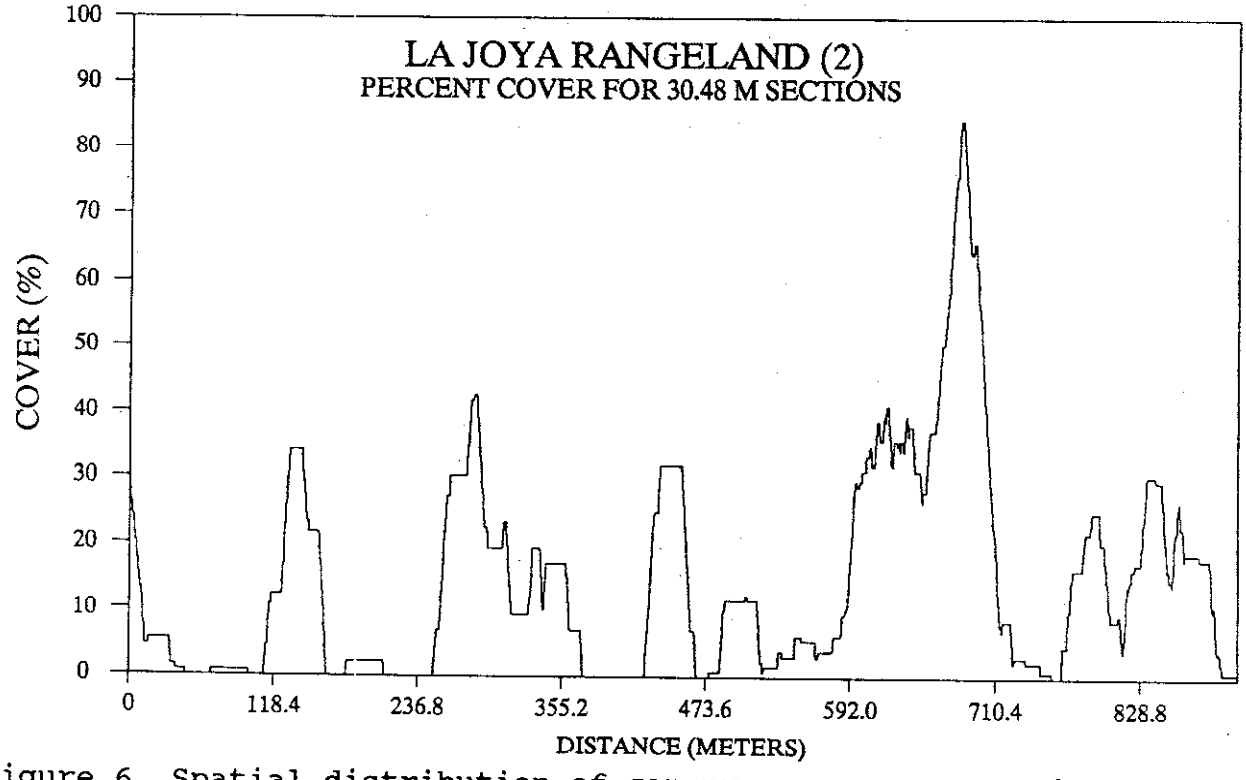

Figure 6. Spatial distribution of canopy cover measures from laser for a 940 m line for the La Joya rangeland site.

PARTICLE-SIZE DISTRIBUTION BY PIPET AND SEDIGRAPH

By Rollin H. Hotchkiss, Assistant Professor, Department of Civil Engineering, University of Nebraska-Lincoln, Lincoln, Nebraska

ABSTRACT

The pipet and Sedigraph are two commonly used instruments for measuring the size of sediment particles in the subsieve (<62 μm) range. It has been proposed that the Sedigraph be adopted by the U.S. Geological Survey because 1) analysis time is decreased fifty percent; 2) only modest training is required for use; and 3) all samples could be analyzed at one laboratory, thus reducing errors due to operator and equipment differences.

Potential errors are identified for both the pipet and Sedigraph instruments. The Sedigraph produces finer particle size curves for certain sediments due to hindered settling. Tests are recommended for identifying problematic sediments and for refining concentration limits for the Sedigraph.

Accuracy of the instruments is not well documented. It is proposed that results of replicate analyses be used to compute standard deviations at each measured breakpoint value. These standard deviations can then be used to plot error bandwidths on the many existing single test comparisons. Evaluation of these comparisons will make it possible to determine whether or not the Sedigraph should be accepted as a standard instrument.

PIPET AND SEDIGRAPH

The pipet and Sedigraph[1] are two commonly used instruments for indirectly measuring the size of sediment particles in the subsieve (<62μm) range. Both instruments use the sedimentation method to determine the equivalent spherical diameter or Stokes diameter of settling sediment particles.

Use of the pipet is described in Guy (1977). The Sedigraph (Micromeritics, undated) passes a finely collimated X-ray beam through the sediment-fluid suspension. The beam measures the transmittance of the suspension relative to the clear suspending fluid. The relative transmittance is a function of the weight concentration of the solids in suspension. Results are automatically plotted .

It has been proposed that the Sedigraph be adopted by the U.S. Geological Survey as an alternative to the pipet for determining particle-size distributions because 1) analysis time is decreased fifty percent; 2) only modest training is required to use the

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[1]The use of the brand name is for identification only and does not constitute endorsement.

Sedigraph; and 3) all samples could be analyzed at one facility due to the short sampling time required, thus reducing errors due to operator and facility differences.

PROBLEMS AND PURPOSE

Several issues, however, remain unresolved. The Sedigraph consistently predicts a finer particle-size distribution than the pipet in the coarser particle size range (see Figure 1 for a typical example). Also, the effect of sediment chemistry on Sedigraph X-ray beam attenuation is not well documented. It is possible, for example, that the Sedigraph yields different percent-finer curves for samples with identical particle-size distributions but different chemical compositions. Finally, accuracy limits for tests on natural sediments using the pipet and Sedigraph have not been established.

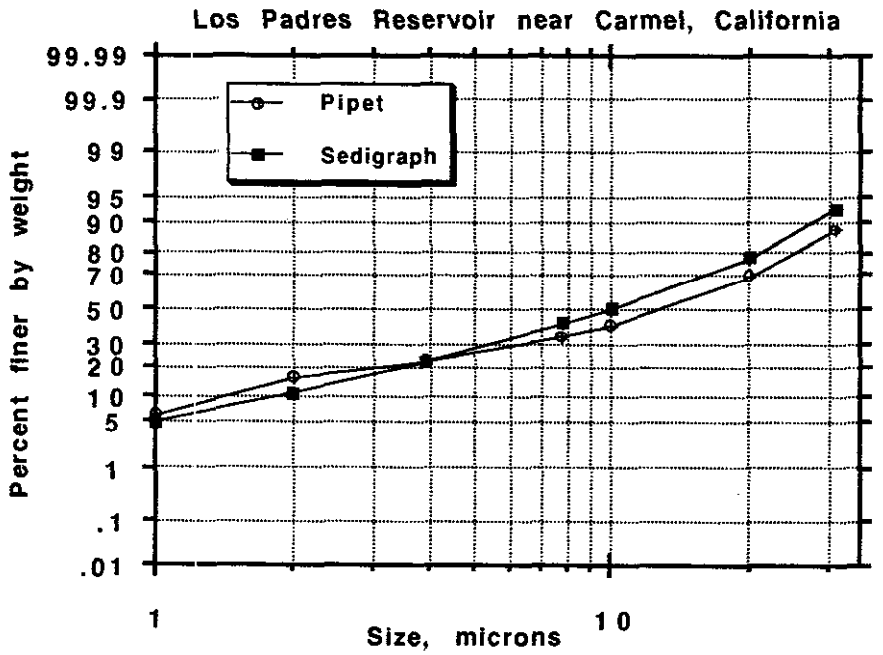

Figure 1. Particle Size Distribution by Pipet and Sedigraph

The purposes of this paper are to:

1. assess sources of error when using both instruments,
2. evaluate methods for comparing test results, and
3. propose specific tests to resolve the above issues.

For more detailed information, see Hotchkiss (1990).

POTENTIAL ERRORS

Both the pipet and Sedigraph are subject to errors due to violating the assumptions underlying the sedimentation method. Then, because each instrument is unique, there are potential errors associated with the pipet and with the Sedigraph.

Common to Both Instruments

The basis for the sedimentation method of particle-size analysis is Stokes Law. Table 1 assesses the relative importance of each variable in Stokes Law for contributing to errors. Each variable is discussed briefly.

Stokes Law is valid for a range of particle diameters from about 1-2 μm to 50 μm. Brownian motion affects smaller particles and larger particles do not settle in a laminar manner.

The largest diameter present in a subsieve analysis is 62 μm, only slightly larger than the approximate upper bound for laminar motion. Results should not be adjusted for this small difference.

Variable	Potential for Error in	
	Pipet	Sedigraph
Particle size	Low	Use 1-2μm as lower limit
Fluid density and viscosity	Low	Low
Sediment concentration	Use recommended limit	High
Electrical charge effects	Unresolved	Unresolved
Wall effects	Low	Low
Sediment density	Intermediate	Intermediate

Table 1. Potential Sources of Error in Sedimentation Methods

Allen and Baudet (1977) demonstrate that Brownian motion affects results for particles diameters less than 1-2 μm. Errors are greatest for non-uniform samples settling a short distance. The Sedigraph, for example, underpredicted the percent finer curve by about five percent for a 0.7 μm diameter clay. Pipet results in the 1-2 μm range are reportedly not affected due to longer settling depths.

Stokes Law assumes each sediment particle settles independently. If sediment concentration is too high, particle interaction occurs and hinders, or slows, settling. Sediment concentrations of 0.08 - 0.2 percent by volume (2,000 - 5,000 ppm) are recommended for the pipet (Guy, 1977), and the Sedigraph manual (Micromeritics, undated) recommends 0.88-1.84 percent by volume (22,000-46,000 ppm). It is generally accepted that a concentration of 1-2 percent by volume (25,000-50,000 ppm) does not produce significant hindered settling (Weaver and Grobler, 1981; The Society of Analytical Chemistry, 1968). A 1943 Interagency study generally agrees that for the pipet, hindered settling is not significant at volume concentrations of 1 - 2 percent.

Several researchers tested similar concentrations with the Sedigraph with mixed results. Kaye (1981) contends that a concentration range of 0.5 to 3 percent by volume surely produces hindered settling, while Lara and Matthes (undated) tested a similar concentration range that showed no change in results. Welch, Galindo, and Allen (1979) found that concentrations of 3.7 and 5.6 percent by volume produced significantly finer curves than a 1.8 percent concentration sample. Weaver and Grobler (1981) recommend a volume concentration of 1.5 percent for the Sedigraph after tests with concentrations ranging up to five percent.

The disagreement amongst Sedigraph users about acceptable concentrations is linked to sediment chemistry, discussed later.

Research on the effects of electrical charge on sediment particles and dispersants is incomplete. Davies and Dollimore (1976) and Sansone and Civic (1975) initiated work in the area. Effects, although not quantified, should be similar in both pipet and Sedigraph tests.

Although sediment samples are rarely homogeneous, a specific gravity of 2.65 is generally assumed for both pipet and Sedigraph samples. Grindrod (1968) found up to a twenty percent difference in percent finer curves for particles varying in specific gravity from 2.3 to 3.15. Errors in the standard assumption should be similar for both the pipet and Sedigraph.

Weaver and Grobler (1981) demonstrate that wall effects do not influence Sedigraph results. Pipet test cylinders, 3-4 cm in diameter, do not induce wall effects. Likewise, fluid viscosity and density are not affected for either instrument unless sample temperature varies by about 20 °C during a test.

Unique to Pipet

Withdrawing samples from the pipet cylinder disturbs the fluid-sediment medium. Irani and Callis (1963) tested a 10 μm flour sample with a pipet, sedimentation balance, and a microscope, and showed the pipet results "deviated" from the results using the other two methods "presumable because disturbance of the suspension occurred during the withdrawal." Stockham and Fochtman (1978) also complain of disturbing the sample during withdrawal, but provide no error estimates.

DallaValle (1948) showed that the withdrawal zone for a pipet analysis extends from about 1 cm above to 3 cm below the tip. Faster withdrawal would affect a larger zone, and slower withdrawal would allow fine particles to enter the zone from above. The U.S. Geological Survey (Guy, 1977) recommends an 8 - 12 second withdrawal time. The withdrawal method was identified as a possible explanation for differences between pipet and Sedigraph results by Schiebe, et al (1983).

The pipet is not universally accepted as an accurate measuring device. In a 1968 report, the Society for Analytical Chemistry stated, "A large group of workers in size analysis has accepted the method [pipet] uncritically as a standard method, without adequate recognition of possible errors. On the other hand, some workers have stated that it is so prone to error as to render it inapplicable as a standard method. There seems to be a case for suspending judgment until more evidence is available on its accuracy and reproducibility."

Unique to Sedigraph

Sedigraph sample concentration is determined by X-ray attenuation. Micromeritics (undated) suggests enough sample be suspended to produce between a 40 and 60 percent attenuation. Allen and Baudet (1977) show that for certain sediments, e.g. kaolinite, the necessary sediment volume to produce the recommended attenuation results in hindered settling and finer particle size curves. Skinner (1983, 1985) recognized the relationship between sediment chemistry and X-ray attenuation, explaining that the influence of sediment chemistry on attenuation is very strong for X-ray energy levels of between 0.01 and 0.05 millivolts. The Sedigraph X-ray energy level is 0.01 millivolts. Micromeritics acknowledges that elements with an atomic number less than 13 absorb X-rays poorly, and that hindered settling may result when using sufficient sediment volume to produce recommended attenuation.

The Sedigraph X-ray system is supplied with 13,000 volts. The stability of the energy is rated at ± 5 volts, so induced errors due to energy source instability are negligible.

Likewise, the heat input to the sample during analysis may raise the temperature of the fluid only 1.2×10^{-4} °C, producing insignificant changes in test results.

METHODS FOR COMPARING RESULTS

Test results are usually plotted on lognormal probability paper. If the data plot as a straight line, it is assumed that the lognormal distribution describes the parent material. Pipet and Sedigraph results may be plotted on the same page and compared. Are both from the same parent distribution? Three methods of statistical tests are commonly used to qualify the answer: goodness-of-fit tests, confidence intervals, and hypothesis testing. See Hotchkiss (1990) for examples of these methods applied to pipet and Sedigraph results.

Unfortunately, these three classes of tests require multiple tests of the same sample and the assumption that the data are from a particular probability distribution. The assumption of an underlying parent probability distribution is weak because often a significant portion of the sample is finer than 1-2 μm and is therefore untested. Assumptions and tests for a particular

statistical distribution could be drastically altered if the untested portion were included in results.

An alternate method, not requiring any assumptions about underlying distributions, is proposed. Available comparative tests are described in the next section. Many of the tests were repeated several times, producing a mean and standard deviation for each break point value. It is proposed the standard deviation of breakpoint values be plotted for pipet and Sedigraph results. The resulting envelope, similar to a confidence interval, can be used to compare the two testing instruments. Figure 2, a composite example of many data, shows a pipet standard deviation bandwidth compared to standard deviation bars for the Sedigraph. In this case, the pipet standard deviation is greater than the Sedigraph standard deviation. The Sedigraph standard deviation fits within the pipet bandwidth except at the larger sediment particle sizes. If this comparison technique is adopted, the U.S. Geological Survey will need to determine what kind of overlap would constitute grounds for accepting the Sedigraph.

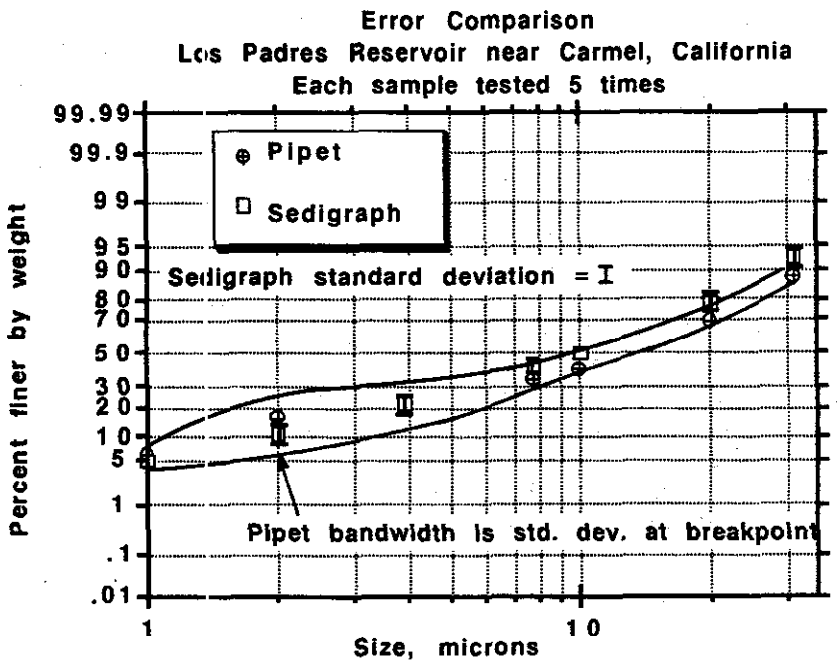

Figure 2. Proposed Method for Comparing Results

AVAILABLE TEST DATA

Appendix 2 of Hotchkiss (1990) contains comparison data from pipet and Sedigraph tests. Data are included from 98 single tests and from several repeat tests. The data are summarized as follows:

1. Of the 98 single test comparisons, all but 10 show a finer particle size distribution for the Sedigraph than for the pipet.

2. Several pipet samples were divided and sent to different laboratories for "round robin" testing. Test results had larger standard deviations than when tested at one laboratory, reflecting

the differences in results when tested by different operators at different locations.

3. Sedigraph tests were run on seven different samples by Lara and Matthes (undated). Computed standard deviations at breakpoint values are shown in Table 2 and are compared to those from the "round robin" pipet tests.

	Standard deviation (μm) at indicated breakpoint diameter (μm)					
	1	2	4	8	16	32
Pipet	5.4	4.8	3.0	2.0	3.4	0.7
Sedigraph	1.9	1.6	1.3	1.4	1.3	1.6

Table 2. Standard deviations computed from seven samples at breakpoint values, pipet and Sedigraph

CONCLUSIONS AND RECOMMENDATIONS

Both the pipet and Sedigraph are subject to error. The Sedigraph, however, may systematically predict a finer particle size curve due to hindered settling of sediments that do not attenuate the X-ray beam well. It is recommended that several sediment samples be obtained from natural sources, emphasizing mineralogical variety. The samples should be split and tested on the Sedigraph and the Sedigraph 5500L, a light-based instrument well-suited for sediments with low X-ray absorption coefficients. Comparing results may reveal which sediments are not appropriate for Sedigraph testing. It is also recommended that during routine Sedigraph tests, samples be re-run at increasing concentrations to better document at what concentration hindered settling begins. A reference or experience library would thus be built that would be useful for future work.

It is also recommended that either the values in Table 2 be adopted for standard error estimates or more tests be performed to better define error limits. The pipet deviations, from "round robin" tests, are appropriate because pipet tests are still performed at several laboratories. The error estimates can then be applied to the 98 single test comparisons found in Hotchkiss (1990) to determine over what range Sedigraph results overlap pipet results.

Finally, it is recommended that discussion center on the use and utility of particle size test results, especially when considering that much of the sample often is too fine to be tested. Specifically, 1. acceptable test accuracy must be defined, and 2. criteria for accepting the Sedigraph as a standard test instrument must be clearly identified.

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THE COMPARISON TESTS OF THE GRAVEL BED LOAD SAMPLERS

By Mr. Gao Huanjin, Senior Engineer, Chongqing District Office, Bureau of Hydrology,
The Committee of Yangtze River Hydraulic. P.R.China.

ABSTRACT

Systematic comparison tests of the main samplers of two categories in natural river course and laboratory flume, have been carried out to study the performance of gravel and pebble bed load sediment samplers (here in below abridged as "samplers"). Analyzing the test results shows that the samplers of each category have their own strong points, but also some weakness, such as the low representativeness of the samples taken and even the infidelity of size grading. In this paper we analyze the cause of such weakness and find out the ways to solve these problems. On the basis of it, we have developed a new type sampler with good performance to achieve the goal of improving the representiveness of the taken samples.

1、Comparison Tests of The Samplers of Two Categories

(1) The samplers used for comparison tests

Several representative and commonly used samplers were selected from main samplers of pressure-difference type and basket type (no pressure difference) to have the comparison tests. Among them, the pressure-difference sampler is more widely used in U.S. (called as HS-3 sampler hereinbelow) and the TR-2 sampler recently developed in U.S.; the basket type samplers are Y64 sampler which has been used many years on the main stream of the upper reaches of Yangtze River, China, and Y80 and Y80-2 samplers which were developed in recent years. The major characteristics and technical parameters of the samplers compared are shown in Table 1 and Fig. 1a — 1d.

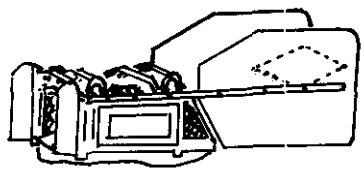

Fig.1a Y64 Sampler

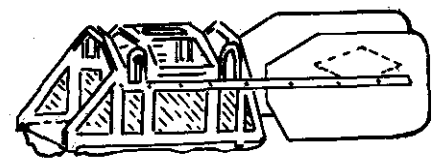

Fig.1b Y80 sampler

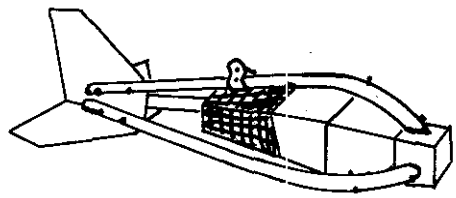

Fig.1c HS-3 Sampler

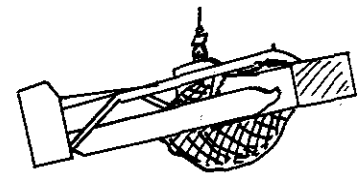

Fig.1d TR-2 Sampler

(2) . The comparison tests of full-size samplers in natural river course

The comparison tests of full-size samplers have been stations in Zhutuo, Cuntan and Fengjie on the main stream of the upper reaches of Yangtze river by the Bureau of Hydrolog, Yangtze Valley Planning Office (YVPO).

The two tested samplers were suspended on each side of the sounding boat according to their own technical requirements with the back space of 5 meters about. In order to

eliminate the influence of the pulsation of the bed load sediment, 30 repetetive samplings were taken as a comparison group and comparative analysis were made according to the average sediment delivery rate and particle-size distribution of the group. While making comparison tests, two samplers were operating synchronically or basically so, and thay were interchanged after sampling 15 times. The tests of every two samplers usually consisted of more than 30 groups of comparison,and the tests results, as a whole, are evenly distributed within the scope of the three grades — large, medium and small grades of sediment delivery rate. The data obtained were processed according to the grading limits applicable to various samplers before the comparison results were analyzed. The results after plotting and analysis are shown in Table 2.

Table 1. The Characteristics and Parameters of the Samplers compared

Char.& data / Item / Sampler		Body structure	Feature & dimensions (mm) of entrance	Bottom	Overall length (mm)	Gross weight (kg)	Grain size of sample to be taken(mm)	Sample containing device
Basket type	Y64	Frame model	Vertical entrance 500×500	Flexible net of interlinked steel-wire ring	1800	240	≥10	Sampler body
	Y80	Same	Oblique (45°) entrance 500×500	Flexible net of small steel plates interlinked with steel wire rings	2000	280	≥10	Sampler body
	Y80-2	Same	Oblique (45°) entrance 300×300	Nylon Fabric lain on the bottom net of Y80	1200	200	≥1	Nylon mesh sample catchment bag
Pressure difference type	HS-3	Sealed plated all around; outlet is larger than inlet	Vertical entrance 152×152	Steel plate	1900	200	≥1	Same
	TR-2	Same	Vertical entrance 304×152	steel plate	1800	200	≥1	Same

Table 2. The Results of Comparison Tests of the Sampling Efficiency of Full-size Samplers in Natural River Course

Serial number	Samplers compared	The relative efficiency(%) of various particle-size fractions (mm)									average relative efficiency(%)
		1-2	2-5	5-10	10-20	20-50	50-75	75-100	100-150	150-200	
1	Y80 / Y64			154	149	145	142	140	139	137	132
2	Y80-2 / Y64			154	183	218	232	244	258	268	220
3	Y80-2/HS-3	16.2	17.4	18.5	19.6	22.2	24.6	27.3	32.6		22.0
4	Y80-2/TR-2	33.4	35.2	36.8	38.5	42.5	45.4	48.6	55.0		46.0

(3) The comparison tests in model flume

The model experiments of Y80 and Y64 samplers on a scale of $\lambda = 5$ upon their total water resistance, flow velocity coefficient Kv at the sampler entrance and sampling efficiency based on the measuring pit were made in the large glass test flume with the width of 150 mm at the Institute of Hydraulic research, Chengdu University of science and Technology by the Bureau of Hydrology (YVPO) in 1981 and 1984, and the comparison tests of the samples taken by these two model samplers were also carried out at the same time. Recently, Professor Fang Tuo has carried out the model experiment of TR-2 instrument on a scale of $\lambda = 10$ upon its hydraulic characteristics and sampling efficiency based on the measuring pit in the 30 mm - wide glass flume at the Institute ofHydraulic Research. The results are shown in Table 3.

Table 3. The Results of Flume Tests of Y80, Y64 and TR-2 Model Samplers

Serial number	Item / Deta / Sampler	Flow velocity coefficient at the entrance Kv	The sampling efficiency % of various particle-size fraction (mm)							Average sampling efficiency (%)
			5-10	10-20	20-50	50-75	75-100	100-150	150-200	
1	Y64	0.89	32.2	24.5	39.2	44.2	47.3	46.7	38.5	41.9
2	Y80	0.92	49.6	50.8	53.6	56.2	58.0	56.0	47.0	53.5
3	TR-2	1.40	89.4	84.6	75.3	66.7	62.0			
4	HS-3	1.54	178	166	144	123	110			

Remarks:
1. The particle size has been resored to the original according to the scale.
2. The values of Kv for TR-2 and HS-3 are determined with the samplers minus the sample catchment bag by US.
3. The efficiency of HS-3 was deduced.

It can be seen from the comparison results listed in Table 2 and 3 that, besides some regularities, the results of Y80 and Y64 in field cmparisons are close to those in flume comparisons, which shows that these comparison are reasonably accurate, and the results of both field and flume comparisons may be compositely used to analyze.

2、The Interrelation of Sampling Efficiency

(1). The interrelation of average sampling efficiency

The average sampling efficiency listed in Table 2 has been converted into relative sampling efficiency based on HS-3 sampler, which is given in Table 4.

It can be seen from Table 4, Tables 1 and 3 that the sampling efficiency of one sampler with higher value of of Kv is usually higher than another different type, and with regard to samplers of the same type, under the condition of identical entrance size of the samplers, such as Y80 and Y64, the sampler with higher Kv has higher sampling efficiency, and under the condition of the same model, such as Y80 and Y80-2, the sampler with smaller entrance size has higher sampling efficiency.

Table 4. The Relative Sampling Efficiency in Field Comparison Tests, Based on HS-3

Sampler	Y64	Y80	Y80-2	TR-2
Relative efficiency(%)	10.0	13.2	22.0	47.8

(2). The interrelation of the sampling efficiency of various particle-size fractions

The sampling efficiency of various particle-size fractions for samplers Y80, Y64 and

TR-2, based on the sediment delivery rate in the measuring pit of the model flume, has been given in Table 3. By use of the interrelations of relative efficiency of Y80-2 / HS-3 and Y80-2 / TR-2 listed in Table 2 as well as the sampling efficiency of TR-2 in the measuring pit in Table 3, the sampling efficiency of HS-3 in the pit was determined by conversion and put in the serial number 4 of Table 3.

The sampling efficiency of the samplers with serial numbers of Table 3 in the measuring pit with respect to various particle-size fractions are plotted respectively in Fig.2. It can be seen that the variation trends of sampling efficiency with respect to various grain-size fractions of sediment for different samplers are different. While Kv < 1.0, the efficiency heightens with the increase of particle size when the size is small, and the heightening rate slows down with the increase ofparticle size; when the size increase to a given point, the efficiency becomes fixed basically, and it may decrease a little when the size continues to increase. While Kv > 1.0 , the sampling efficiency decresaes with the increase of particle size. The farther the value of Kv deviates from 1.0 is, the more apparent the phenomenon of the efficiency changing with the change of particle size is.

The variation of gravel and pebble bed load sediment delivery rate is often accompanied with the change of particle size distribution. The coarse fraction is larger when sediment delivery rate is high,and the fine fraction is larger, there is often no coarse fraction when that rate is low. Hence the sampling efficiency varies with the change of grain size and subsequently that of sediment delivery rate. Thus, not only the representativeness of the grain or pebble samples taken is decreased, but also much inconveniency is caused in correcting the efficiency of the sediment delivery rate measured in sites.

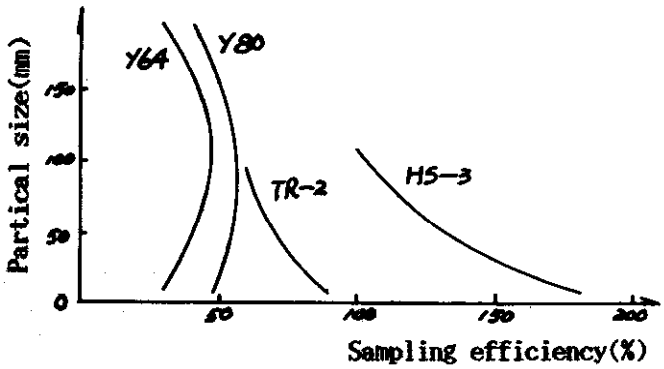

Fig.2 The partical size — sampler efficiency relation of several samplers

The above - mentioned phenomenon about sampling efficiency is an important problem and need to be resolved in the further research.

3、 The Analysis of Sampling Process and the Essence of Efficiency Phenomenon

Through observing the whole process of sampling in the flume, combination with analyzing the data of comparison tests in sites, it was founded that the sampler placed on the river bed must have disturbed water flow and formed a special flow field in front of the entrance , that pebbles entering the flow field will change their flow velocity and direction, and that moving pebbles need to be elevated a height at least equal to the thickness of sampler bottom in order to enter into the sampler. In this respect the sampler plays a leading role, because it interferes water flow and directly changes the movement of pebbles or indirectly do so through water flow.

(1). Basket type samplers

A retarded component flow field (Fig.3a) is formed in front of the entrance owing to the resistance F of the sampler itself and the small value of Kv (<1.0). Moving pebbles entering that field decrease their velocoty and deviate their direction in different degrees, which is the basic cause of the lower average sampling efficiency of Basket type samplers.

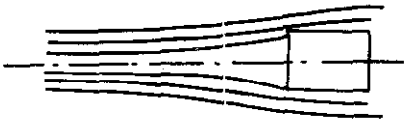

Fig.3a. The divergence of flow lines in front of the entrance of basket type samplers

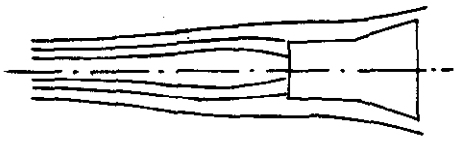

Fig.3b. The divergence and convergence of flow lines in front of the entrance of pressured-different samplers

Moving pebbles of different size possess different intertia forces, and therefore the degrees of movement change are different under the action of the same force of flow field: the smaller the grain size is, the greater the change is; and the lower the sampling efficiency is. The pebbles of larger size slow down their moving velocity under the effect of retarded flow, and in the critical state of transport may also cease to move; the sampling efficiency of the pebbles of medium size is relatively high. The larger the value of F is, the lower the value of Kv is, and the more apparent the above-mentioned phenomenon.

(2). Pressure-difference type samplers

The flow field formed in front of the entrance is more complex than basket type samplers owing to the resistance F of the sampler itself and the larger value of Kv (>1.0) . First, the action of F causes a retarded component flow against the water flow at a point a little far apart from the entrance, and due to Kv > 1.0 , results in acceleration of water flow and the convergence of flow lines (Fig.3b) near the entrance. Like in basket type samplers,moving pebbles slow down their velocity and deviate their dirction when they pass through the retarded component flow field formed by the resistance of the sampler itself. When arriving at the vicinity of the entrance, they undergo the effects of acceleration and convergence together with the water flow; the bottom sediment in front of the entrance which is originally in a still state is able to transport because of the increasing of flow velocity. Therefore, the average sampling efficiency of pressure-difference samplers are higher than basket type ones, and the larger the value of Kv (>1) is, the higher the sampling efficiency. Similarly, under the influence of the factors above mentioned, the fine pebbles with less intertia will first change their original state. The less their size is, the more the change is, and the higher the sampling efficiency is.

(3). The effect of the bottom of samplers and the requirements for it

With respect to basket type samplers, because of the velocity of moving pebbles decreases in front of the entrance, the pebbles which posses the kinetic energy necessary to elevate themselves a height equal to the thickness of the bottom of a sampler are reduced, which is an important cause of the drop of average sampling efficiency. Therefore, the requirements for the bottom are thinness and a good fitness to the streambed.

With respect to pressure-difference samplers, moving pebbles cause the acceleration of water flow in front of the entrance, and the pebbles possessing the necessary kinetic energy are increased. Therefore, the requirements for thickness and fitness of the bottom are relatively low. Thus, from the viewpoint of pebbles' entering into samplers, the requirements forthickness and fitness of the bottom are depend on the value of Kv. While Kv < 1.0, there are the requirements of the bottom to be thin and have a good fit to the streambed; while Kv > 1.0 , such requirements may be loosened; while Kv is much larger than 1.0 , the requirements may be cancelled. Above analysis with regarded to average sampling efficiency and the efficiency for various grain size fractions of basket type and pressure-difference samplers is just an explanation and description of the sampling

efficiency phenomena of various samplers and their interrelations shown in Table 3 and Fig. 2. This is not only proves the retionality and the reliability of the comparison test results, but also reveal the key factor on which sampling efficiency depends, thus providing correct direction and scientific basis for improving to a sampler of new model.

4、The Development of a Gravel and Pebble Bed Load Sampler of a New Model

It can be seen from comparisons and analysis that there are problems of low representativeness and poor fidelity of the samples taken by both basket type and pressure-difference type samplers used at present. Fig. 2 indicates that the errors of grain-size distribution in the samples taken by these two kind of samplers are just contrary, which suggests the possibility to develop a new model gravel and pebble bed load sampler with the sample having higher representativeness on the basis of incorporating the strong points of two kinds of samplers. The purpose of improving is from the necessity to measure in sites the bed load sediment under the main stream of the upper reaches of Yangtze River. In order to describe its conveniency, this new sampler is temporarily named as Y90 model gravel and pebble bed load sampler (called as Y90 sampler hereinbelow).

(1). Main points of the design of Y90 sampler

The designs of Y90 sampler should meet the general requirements for a bed load sampler, and at the same time decrease the resistance of its body to water flow and the influence of the resistance on its entrance. The value of Kv is to be adjusted, so that it is slightly larger than 1.0 only enough for overcoming the resistance for gravel or pebble sample to entering into the entrance of the sampler.

A. The general requirements for the design of Y90 sampler

(a). Proper dimensions of entrance. The entrance of gravel and pebble sampler should, in general, be larger than the largest grain size of the bottom sediment in the river section to be sampled.

(b).The alignment with flow lines of the body of the sampler immersed in water. Thus its entrance can face right to flow direction when the sampler falls on the bottom surface of streambed.

(c).Sufficient stabilizing moment. This can make the sampler locate stably on streambed to sample.

(d).Appropriate effective volume of sample. Thus the sample having entered into the sampler cannot be washed out.

B. The specification of the designs of Y90 sampler

(a).The value of Kv and basic construction

The value of Kv should be slightly larger than 1.0 according to above analysis. The part over 1.0 is theoretically equal to the kinetic energy necessary to overcome the resistance for pebbles to entering into the entrance, i.e. the energy have to do work to elevate the pebbles a height of bottom thickness and that to overcome the frictional drag between the entrance and the sample container. The increment of the flow velocoty coefficient at the entrance needed to elevate the pebbles a height of bottom thickness may be estimated from the following formula:

$$\triangle Kv = (2g \triangle H)^{1/2} / V_n \qquad (1)$$

Where , $\triangle H$ — bottom thickness, g — gravitional accleration, and V_n — natural flow velocity at the entrance of the sample. Table 5 is deduced from formula (1).

It can be seen from Table 5 that the value of $\triangle Kv$ is generally on the order of 0.2. The

Kv value of Y90 sampler is larger than 1.0, and the sampler belongs to pressure — difference type according to its basic construction. The Kv value is adjusted mainly by changing the ratio of inlet / outlet area of the sampler body.

Table 5 Estimated Values of △ Kv against Different △ H

△ Kv △ H (cm) / V_1 (M/S)	0.5	1.0	1.5
1.5	0.21	0.29	0.36
2.5	0.12	0.18	0.22
3.5	0.09	0.13	0.15

(b). Measures to decrease the resistance F of the sampler body and its effect.

The intensity of the retarded component flow field in front of the entrance is depend on the resistance of the sampler body when the Kv value has been determined. Main measures to decrease the resistance to water flow are keeping a correct streamline pattern of the whole sampler body , mutual shading of constructional arrangement, and decreasing local resistance and frictional drag. The measure to decrease the effect of resistance to water flow is to make the sampler entrance extend forward as far as possible so that the influence of flow field disturbance can be reduced relatively.

(c). The bottom of Y90 sampler

The sampler body must be tight because the sampler belongs to pressure-difference type.Therefore, the sampler must possess a rigid bottom plate,which cannot provide a good fit between sampler and streambed. The degree of unfitness is random under the condition of pebble streambed. Hence the sampling efficiency of the sampler with Kv value slightly larger than 1.0 tends to be unstable. For this reason, an inlet section is added in front of the sampler body and the bottom of that section consists of a flexible base net which can provide a good fit with streambed. The thickness of bottom is determined by the requirements of construction and strength.

(2). Y90 sampler

A. Main dimensions and construction of Y90 sampler.

The clear dimensions of the entrance are taken as 300(width)×280mm(height), because the largest grain size of the sediment under the main stream of the upper reach of Yangtze River is about 250mm, D95 is about 150mm. The least grain size of the sediment being able to be sampled is 5mm. The gross weight is taken as 320Kg and the whole length is 1710mm according to the requirements of its structure and stability under hydraulic conditions of the main stream of the upper reach of Yangtze River. The schematic drawing of constrution is given in Fig.4.

As shown in Fig 4, Y90 sampler consists of body, sample catchment bag, weighted lead, connecting bars, tail wings and suspension device. Body: It consists of three section: entrance, control and divergence sections. Entrance has flexible base net and 45° side walls in order to provide a good fit with streambed and decrease the resistance to water. In control and divergence, except inlets and outlets they are tightly enclosed all around with 12mm steel plates to form pressure difference and heighten Kv moderately. Sample catchment bag: It is a nylon net bag with aperture of 5mm. Weighted lead: It is connected to the top of body to shift forward the gravity of sampler and improve its stability; its upper part is streamlined to decrease the resistance to water. Connecting bars: There are four

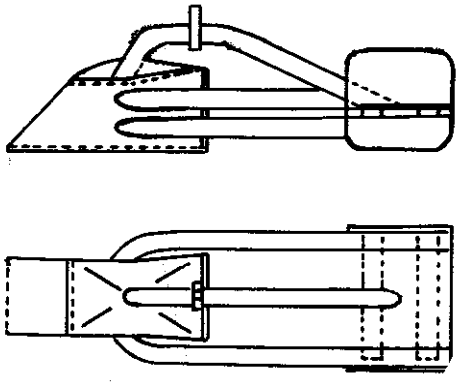

Fig.4 Y90 Sampler

connecting bars which are four steel pipes poured with lead. They connect the body and tail wings to form a whole entity. The amount and site of poured lead may be used to adjust weight and gravity of the sampler. They connect with the body at the rear of control section, so that the entrance may extend forward to a point farther apart from the largest cross section of the sampler to decrease the influence of reatarded component flow field. Tail wings: The consists of a double vertical tailwing and movable horisontal wing. Suspension device: It consists of a cantilever and a suspension loop. The loop can slide on the cantilever to adjust gravity.

B. The Kv value and the ratio of inlet / outlet area of Y90 sampler

The Kv is a main factor to effect the representativeness of the taken samples. The resistance of sampler body, the degree of its disturbing the flow field at the entrance, the fitness and thickness of bottom net are also some factors which can not be ignored. The main technical data to determining the value of Kv is that the ratio of inlet/outlet area of the entrance. Other factors such as the water permeability of sample catchment bag the frictional drag of inner walls of sampler body, and local divergence loss can also influence on Kv value; Therefore, the Kv value and the said area ratio should be determined by experiments. Through technical parameters of existing pressure-difference samplers have been referres, analyzed and calculated, experiments of four model samplers with different ratio of inlet/outlet area are to be carried out in the laboritory flume under other conditions of Y90 being constant. Purposes of experiments are determining the values of Kv to establish the relation between area ratio and Kv value, determining average sampling efficiency respectively for the four values of Kv to establish the relation between Kv value and average sampling efficiency, and determining sampling efficiency of various grain size fraction respectively for the four values of Kv to establish the relation between grain size and sampling efficiency under various Kv values. Analyze these relations comprehensively and take the Kv value under which sampling efficiency of various grain size fractions is ratio basically the same and the corresponding inlet/outlet area as design value of Y90 sampler. (The experiments are in preparation.)

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