MONITORING INDIVIDUAL PARTICLE TRANSPORT IN A GRAVEL BEDDED STREAM USING A PASSIVE RADIO TRANSPONDER SYSTEM, CORVALLIS, OREGON

by

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Statement of Project

Gathering empirical data on the factors and processes affecting bedload transport in the field is difficult. This project conducted during the winter of 1996 field tested a new passive method of positively tracking individual particle movement. The project was conducted in Oak Creek, a gravel bedded stream, located in Corvallis, Oregon. This paper provides an overview of existing techniques of tracking bedload and individual particle movement and gives the results of the field test.

The new individual particle tracking technique utilizes a passive radio transponder which can be implanted inside of natural particles. The transponder consists of a microchip that has its own unique hexadecimal identification code. When exposed to a magnetic field the transponder emits a radio signal of the transponder's code which is interpreted by a receiver. This technique provides positive identification and has an estimated life-time of decades. The transponders are relatively inexpensive at approximately 6 dollars each, allowing a statistically significant number of particles to be utilized. A small (2.7 mm) diameter hole is drilled in the particles. There is no significant discrepancy in volume of the implanted particles.

This field test also utilized two other techniques of tracing gravels. A pre-existing vortex bedload sampler was used to capture bedload transport and the implanted particles were painted to aid in visual identification. Sixty-eight implanted particles were placed from November 1995 to February 1996. A large storm event, post placement, in February 1996 created discharges within the Oak Creek study reach. These flows caused scour and transport beyond the research design utilizing prototype equipment. Consequently, three of the implanted particles placed in February 1996 were located after transport, one particle was located twice.

The field test provided proof of concept that the passive radio transponder technology can be utilized to track individual particles in natural stream channels. Continued development of the technology is necessary to increase its ease and effectiveness of use.

The field test also showed that the efficiency of the passive radio transponder and other tracking techniques are enhanced when more than one monitoring techniques are employed. Empirical data gathered with this and additional techniques can potentially provide detailed information on the controlling factors and processes involved in particle transport in dynamic systems.

Introduction

Tracking the timing and trajectory of movement of individual particles in the field has had limited success. Existing methods of monitoring the transport of particles have limitations to their ability to collect complete information. The methods may also be limited by relative expense, required stream alteration, federal regulation, and safety. It is desirable to have a technique for tracking individual particles which is simple in design, provides positive identification, is relatively inexpensive, and can be used in a variety of environments. Other desirable features include minimal stream alteration and a long life-time.

This paper reports the preliminary results of a field test of new inexpensive, unobtrusive, low stream disturbance, passive radio transponder technique for positive identification of natural particles in gravel bedded streams. The paper also addresses the potential of its use in combination with other bedload monitoring techniques. A discussion of the capabilities and use of both physical capture and tracking methods are included in this paper.

Current techniques for developing empirical data on particle transport can be divided into two groups: physical capture and individual particle tracking (Table 1). The three primary methods of physically capturing bedload include the Helley-Smith type bedload samplers, the Vortex bedload sampler or other similar instream structures, and the use of sediment dams in ephemeral or semi-arid environments.

Individual particle tracking techniques includes passive techniques such as painted clasts, iron and magnetic tracers, and active techniques such as radio rocks. None of these techniques used independently provides complete low cost information on the timing and trajectory of individual particles (Table 1). A new passive tracking technique utilizing a radio transponder provides positive identification over a lifetime of years to decades (Rosenfeld et.al, 1996).

	painted clasts	magnetic clast and iron core	active radio rocks	magnetic sensor	transponder	bedload samplers	vortex bedload sampler
relative cost	$	$$	$$$$	$$$	$$$	$$	$$$
determinable travel length	Y	Y	Y	N	Y	N	N
individual identification	Y	Y	Y	N	Y	N	N
no background interference	Y	N	N	Y	Y	Y	Y
uninterrupted transport	P	P	P	P	P	N	N
known origin placement	Y	Y	Y	N	Y	N	N
density/mass relationship	Y	Y	N	N/A	Y	N/A	N/A
representative sample	Y	Y	N	N/A	Y	P	Y
semi-permanent	N	Y	N	Y	Y	Y	Y
timing of transport known	N	N	Y	Y	P	Y	P

P= possible	Y= yes	N= no	$-inexpensive	$$$-mod. expensive	$$$$- very expensive

Table 1. Comparison of bedload monitoring techniques. Only the passive transponder technique can potentially provide complete information. The use of one or more technique may provide additional information.

Physical Capture

The Helley-Smith type sampler and similar bedload samplers are designed to be manually operated in the field during times of particle transport. The Helley-Smith has a fixed standard calibrated orifice which severely limits the range of particle sizes possible to capture. The addition of size and bulk to the sampler to be useful in larger events makes the equipment cumbersome and may create altered hydraulics that effect transport around the sampler (Childers, 1996). Flows associated with transport may also make the use of these samplers hazardous and difficult to operate. Benefits of the Helley-Smith sampler include its mobility and its relatively low cost.

The Vortex bedload sampler is a permanent structure requiring substantial instream alteration and consequently is of relatively high initial cost. The permanent sampler is housed in a weir and captures all bedload until its capacity is reached. Once installed the sampler is a relatively low maintenance operation (Milhous, 1973). The sampler must be emptied during transport events to capture a continuous sample. The vortex bedload sampler is an example of an instream structure to capture bedload transport.

A third method of physically capturing sediment includes sediment dams. Sediment dams are most commonly used in ephemeral or semi-arid environments where transport is episodic. Usually the dam's design stops the flow of all material including woody debris and fine silt which may not be desirable. Although inexpensive, the lifetime of the sediment dam may be limited by capacity if the sediment is not periodically removed.

Tracking

The minimum information which is desired from tracking particles is positive individual identification, the timing of transport and the trajectory and distance of movement. It is highly desirable to utilize natural stream particles to approximate natural transport conditions. Individual particle tracking methods can be passive or active. Passive tracers are particles which are identifiable in the field and do not actively emit a signal. They may have a characteristic, such as a magnetic core, that makes them possible to identify during transport. Active tracers emit a radio signal which can be received determining the particles exact location.

Currently, active tracers involve the emplacement of a relatively large transmitter in natural or synthetic particles. The transmitter consists of a radio transmitter and a battery with approximate dimensions of 30 mm X 16 mm (Ergenzinger and Schmidt, 1990)(Schmidt and Ergenzinger, 1992)(Cacho, Burrows and Emmett, 1990). The radio signal of the particles is read with a computerized receiver, an antennae, and a data logger. The radio rocks are relatively expensive allowing only a small sample to be employed. The ability of current receivers to track numerous particles is limited (Burrows, 1996). The frequency of the radio signal must also comply with federal regulations. Battery life of the transmitter is dependent on the size of the battery and frequency of transmittal. The particles generally can only be used for a single flood event.

The simplest tracking method involves painting clasts (Leopold and Rosgen, 1991)(Lekack and Schick, 1995)(Laronne and Carson, 1976). Painting clasts for tracking is inexpensive and a large sample can be deployed. A benefit of painting clasts is that natural particles from the stream can be used. Particles can be color coded to different original stream formations, i.e. pool, riffle, lateral bar. Drawbacks include the limited lifetime of the method determined by the durability of the paint and the dynamic of transport. Locating painted clasts in the field is dependent on being able to see them. Turbid conditions, burial or active transport may make individual identification impossible.

Naturally magnetized particles and non-magnetic particles installed with an iron core can be preidentified and marked, and their post transport location identified with a metal detector type device (Schmidt and Ergenzinger, 1981). Artificial particles with magnetic cores can also be created. Benefits of this method include the relative inexpensiveness allowing large samples. The limitations include the method of preidentifying the particle, the strength of the metal detector, the sources of iron in the stream channel and the depth of burial of the particle.

An additional method has been developed involving an instream sensor which can quantify the amount of magnetized particles passing over the sensor (Spieker and Ergenzinger, 1990)(Ergenzinger and Custer, 1983). The sensor consists of an iron-cored coil of wire which identifies a permanent magnet passing over the sensor. This method quantifies the amount and timing of particles, but the individual identity of particles passing the sensor is not recorded.

A new passive technique field tested during the winter of 1996 involves a passive radio transponder. The transponder consists of a microchip wrapped with a copper coil that is sealed in a small (2 mm X 8 mm) glass ampule. Natural particles selected from the stream are drilled and implanted with the transponder which has a unique hexadecimal code. When the implanted particle is exposed to a magnetic field generated by an antennae it gives off a low frequency radio signal received by the antennae that is transmitted to a receiver for recognition. Benefits of the method include a long-life time of the transponder, lack of an internal power source, relatively low cost, little or no instream alteration. The field test of this method used visual identification of painted clasts which were then scanned and identified. The known original location and positive identification of the particle enable transport distance of the implanted particle to be tracked. The field test of this technology also utilized an in-place vortex bedload sampler to capture particles at the end of the study reach.

This technology has the potential to provide the most complete information available on individual particle transport. Used in combination with additional techniques, it is an inexpensive method of obtaining detailed transport information.

Field test

Oak Creek Study Site

The Oak Creek study reach consists of a relatively undisturbed forth order (Straggler method) gravel bedded stream draining the eastern Coast Range in Benton County, Oregon (Figure 1). The drainage basin area above the study reach is approximately 6.73 km^2. Mean annual precipitation is approximately 127 cm. The channel in the study reach consists of riffles or transitional with several pools (Milhous, 1973). The design of the field test of the transponders encompassed a relatively straight

55 meter stream stretch located directly upstream of a preexisting vortex bedload sampler (Figure 2). Within the 55 meter reach 14 randomly selected permanent transect location were established (Figure 3).

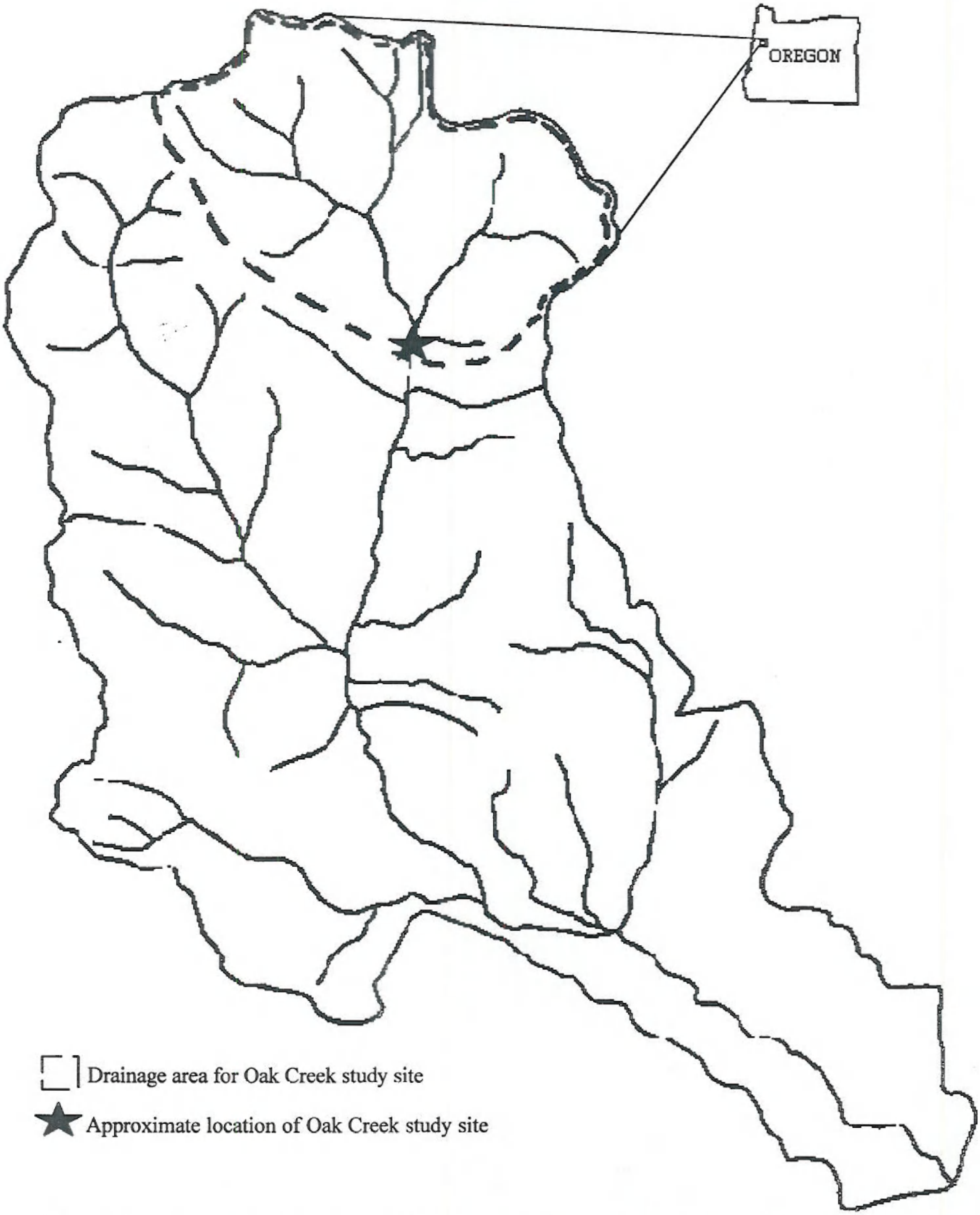


Figure 1. Location of the drainage area of Oak Creek study site and the relative position of the study site within the Oak Creek watershed.

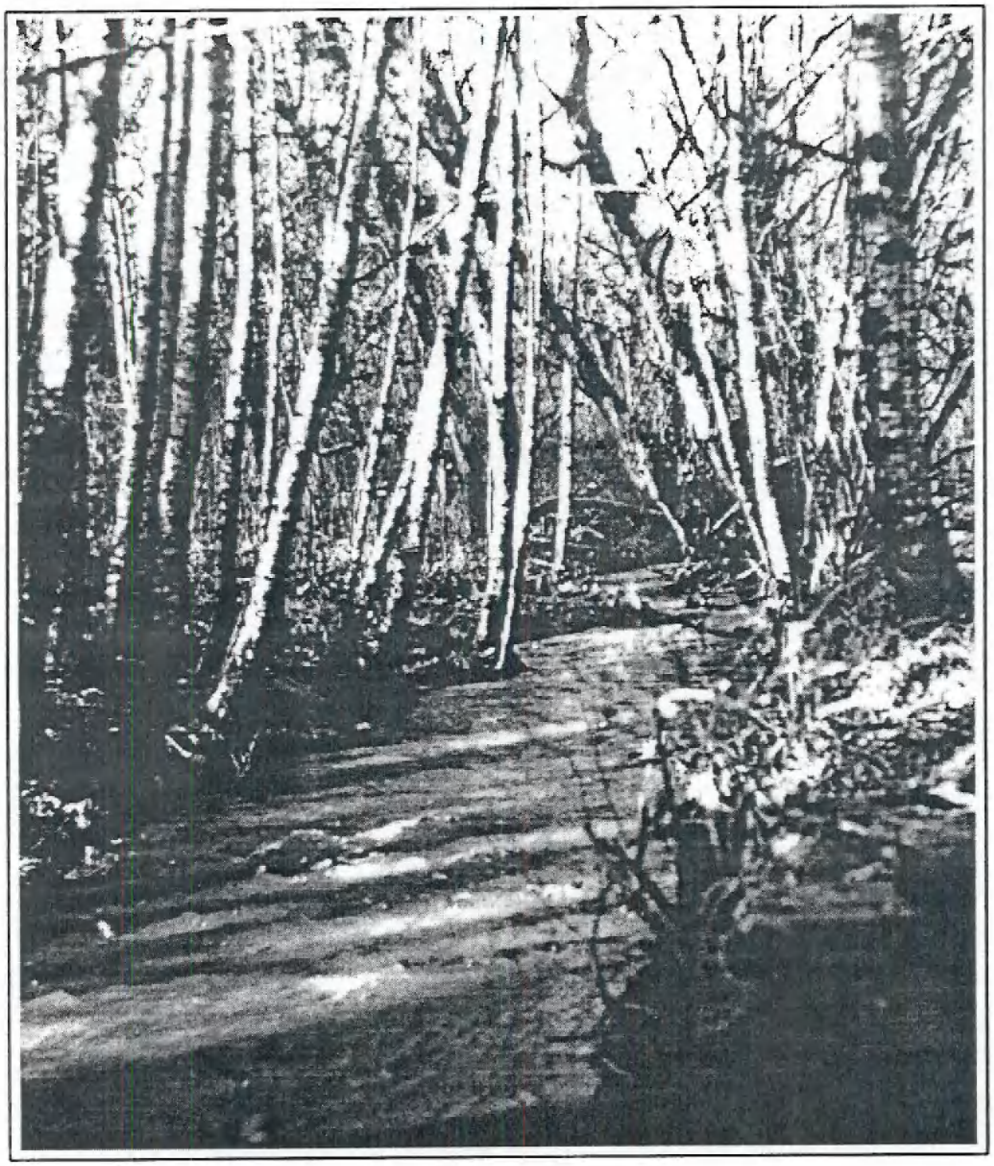


Figure 2. Upstream view of the 55 meter study reach from the wier of the vortex bedload sampler taken in November 1995. The streamflow is relatively high and the water is turbid.

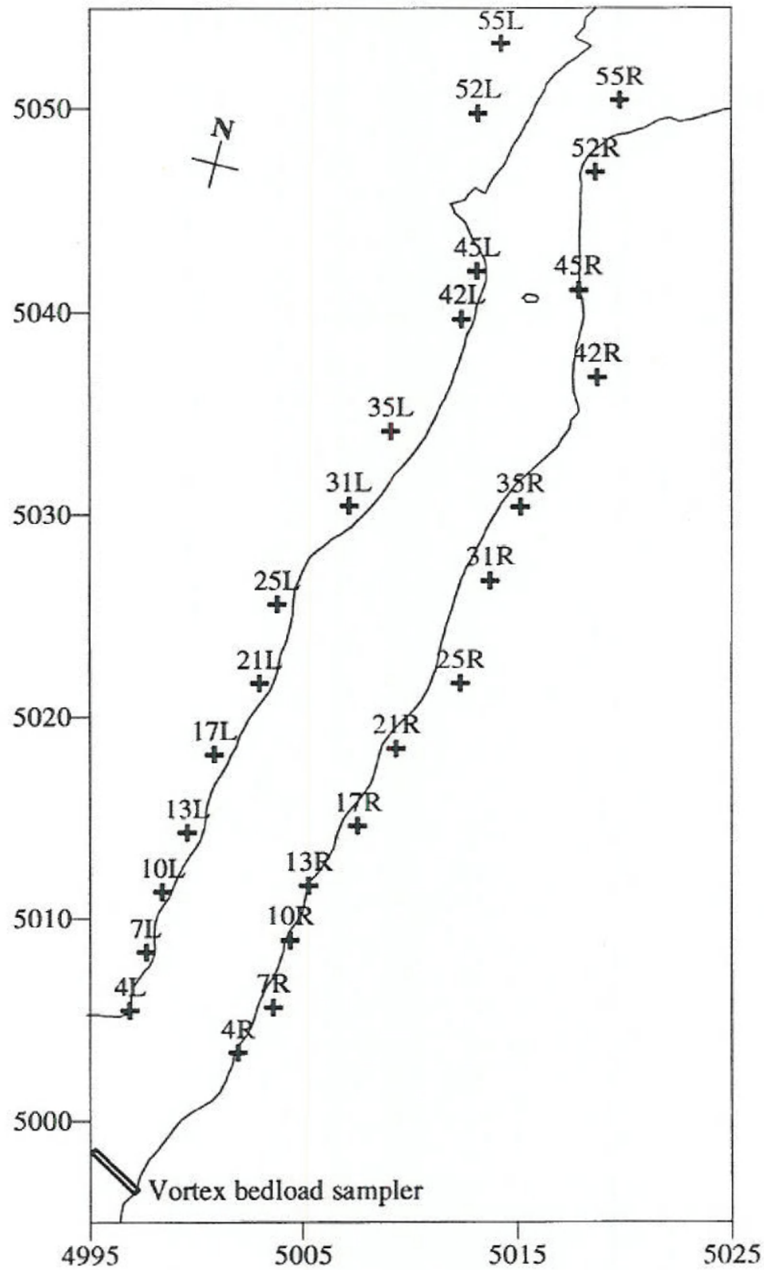
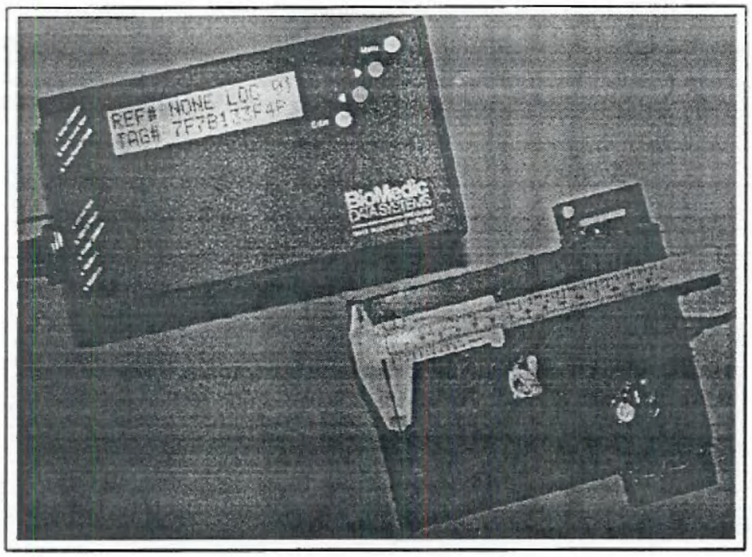


Figure 3. A reference grid (meters) showing position and number of permanent randomly selected transects. Surveying for this and other topographic plots was conducted from the relative coordinates 5000, 5000.

Radio Transponder Equipment

The transponder identification device, DAS4003 receiver and radio scanner was procured from BioMedic Data Systems, Inc. (Maywood, New Jersey). The DAS4003 consists of a microprocessor and low frequency radio scanner with an antennae for reading transponder identification devices (Figure 4). The transponder consists of a cold storage microchip and copper antennae coil sealed in a glass ampule. During manufacturing each microchip is encoded with an unalterable hexadecimal code. The radio scanner has an antennae which generates a pulsed 350 to 400 kHz magnetic field which stimulates the copper coil and cold storage microchip. When the scanner is brought within close proximity of a transponder, the hexadecimal code is read from the scanner and sent to the receiver. The receivers primary purpose is to receive and display the hexadecimal code (BioMedic Data Systems, 1991).

During set-up it is possible to store additional material (i.e. a reference number) about each transponder in the receiver as well as recording the time of scanning. The unit was not designed to be water-sealed and consequently a generous application of marine grade silica was applied to submersible areas of the antennae. During the study the unit was powered with AC wiring. Potentially the unit could be wired to a 12V battery powered system.



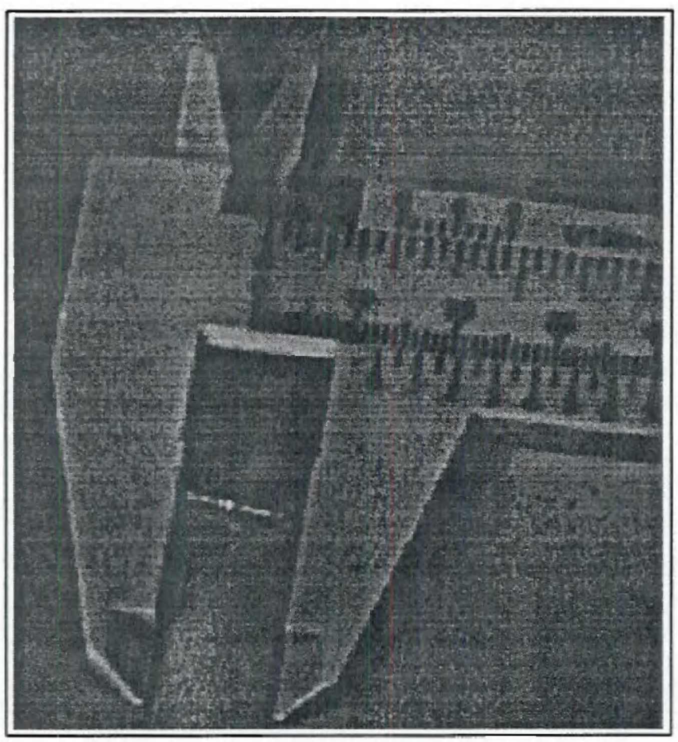


Figure 4. BioMedic DAS4003 radio transponder scanner and receiver. The receiver is showing the identification code of a radio transponder. The bottom image is a close up a radio transponder. The transponder consists of a microchip wrapped with a copper coil and sealed within a glass ampule. The scale on the calipers is in millimeters.

Methods

Sample Preparation

Seventy presorted particles representing a range of sizes from the creek were randomly selected to be implanted with the radio transponders. The particles were drilled with a 2.4 mm titanium or cobalt bit at a slow speed of less than 200 rpms. Holes were drilled to a minimum depth of 10 mm so that the implanted particle would not be exposed at the surface. Transponders were installed manually and sealed with a marine grade silicon. Particles were measured, weighed, spray painted, and photographed to assist with identification in the field. The mean density of the particles was computed by volume displacement.

Installation

Thirty particles were implanted in November of 1995 and thirty-eight particles were installed in February of 1996. During each installation the following procedure was used. The particles were sorted in 4 size classes based on b-axis diameter. During installation of the implanted particles in the study reach, an instream particle along the transect was blindly selected from the stream bed. The b-axis of the particle was measured with calipers and an implanted particle from the same size class replaced the removed particle. The relative location of each particle to a total station surveying device was recorded for tracking displacement from original location.

Monitoring

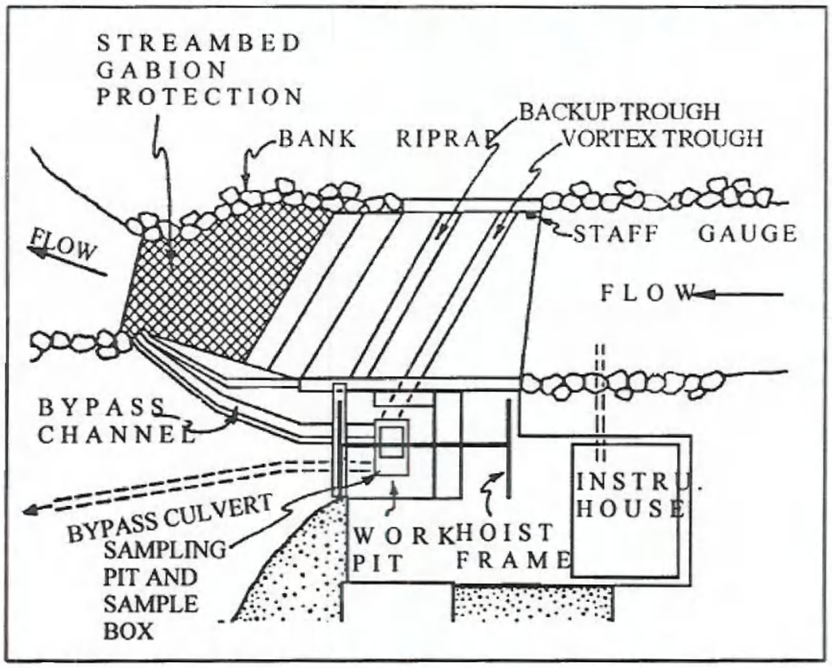
Total Station

Figure 5. Nikon 'Top Gun' Total Station A-014 surveying instrument mapping channel topography.

A relative basepoint for a Nikon Top Gun Total Station A-014 was established at the broad-crested weir, containing the vortex trough, at the downstream end of the study site. From this reference point (5000, 5000) a series of relative surveys of bed topography were conducted. Four detailed stream bed surveys averaging 275 points were conducted from January to May 1996.

Vortex Bedload Sampler

There is a vortex bedload sampler originally constructed in 1969 and modified in 1975 located at the downstream end of the study reach. The sampler is located within a broad-crested weir which approximates the stream dimensions at 3.6 meters wide and 0.9 meters high (Klingeman and Emmett, 1982). The sampler works by creating a vortex in one of two troughs placed at approximately 60 degrees to the direction of flow. The upstream trough captures all transported bedload and carries it into an offstream pit where samples can be collected or diverted with streamflow downstream. When the capacity of the first trough is reached the second trough is filled (Milhous, 1973) (Figure 6). Both troughs were emptied prior to installation of the particles so that during a storm event they could potentially capture all transported bedload.



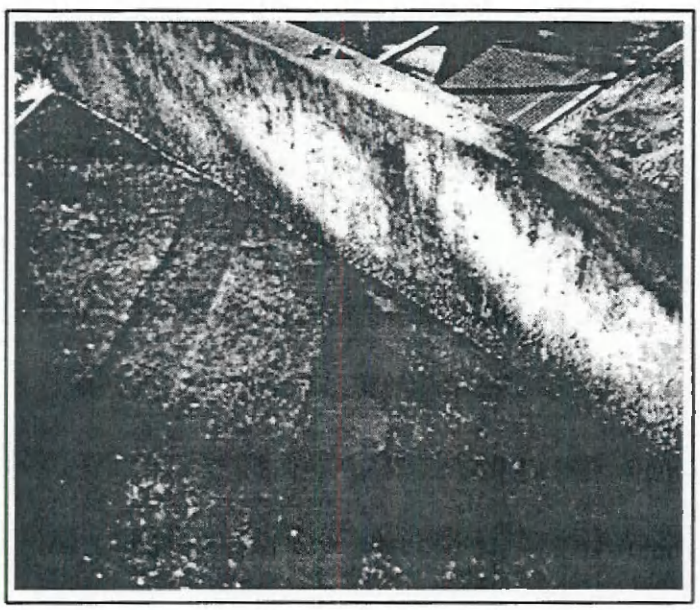


Figure 6. Schematic of the layout of the vortex bedload sampler at the downstream end of the Oak Creek study site (after Klingeman and Emmett, 1982) and a view of the two troughs and work pit within the broad crested weir.

Results

The implanted particles mass and b-axis ranged from 4.1 grams and 11.4 mm to 523.17 grams and 75.8 mm. The median of the b-axis was 24.7 mm (Table 2). The mean density of the implanted particles was 2.74 g/ml with a range of 2.3- 3.3 g/ml. These values are consistent with computed figures for dry weight basalt densities (Carmichael, 1989). The removal of a small amount of material to install the transponder did not significantly affect the density.

	Minimum	Maximum	Average	Median
Particle mass	4.1 g	523.2 g	91.4 g	42.2 g
B-axis	9.7 mm	75.8 mm	29.7 mm	24.7 mm

Table 2. Implanted particle characteristics (see Appendix for complete data).

November Installation

The 30 particles installed in November of 1995 were placed during the onset of turbid conditions in the creek and once placed and recorded they could not be visually identified during the event. Rain had begun approximately 24 hours previously when the creek was at approximately 6.32 cfs. At the time of particle emplacement and the continuation of precipitation the streamflow of the creek had risen to approximately 33.3 cfs by reading the staff gauge. The particles were installed along transects 4m, 7m, 10m, 13m, 21m, and 25m. Particles were not installed along transect 17m because of the presence of a large hole caused by woody debris.

Within an additional 24 hours after emplacement the flow had receded to approximately 11 cfs and the turbidity had decreased. Several days after the event three particles of the 30 placed could be seen in the reach. The identification of two of the particles is unknown other than that they could not have come from further upstream than the 25m transect. The third particle was found in the original location of emplacement. No implanted particles were discovered in several successive vortex bedload samples.

February Installation

A second installation was conducted over two days at the beginning of February 1996. During this time 38 implanted particles were installed in transects 17m, 31m, 35m, 42m, 45m, 49m, 52m, 55m and 5 particles were installed in the previously implanted transect 13m. A large storm system moved into the Willamette Valley immediately following the last of the implantations on February 4, 1996 with a precipitation total of 21.7 cm measured at the Hyslop Experiment Station (Taylor, 1996). The resultant streamflow began to rise from a steady 8 cfs to a peak flow of approximately 234.3 cfs (Figure 6) at 14 hundred hours on February 6, 1996 (Figure 7).

Upon return to low streamflow none of the second installation particles could be visually identified within the creek and no implanted particles were found in several successive vortex bedload samples. In later visual searches and through the completion of a bed topography survey 2 particles were located which had been transported from there original location.

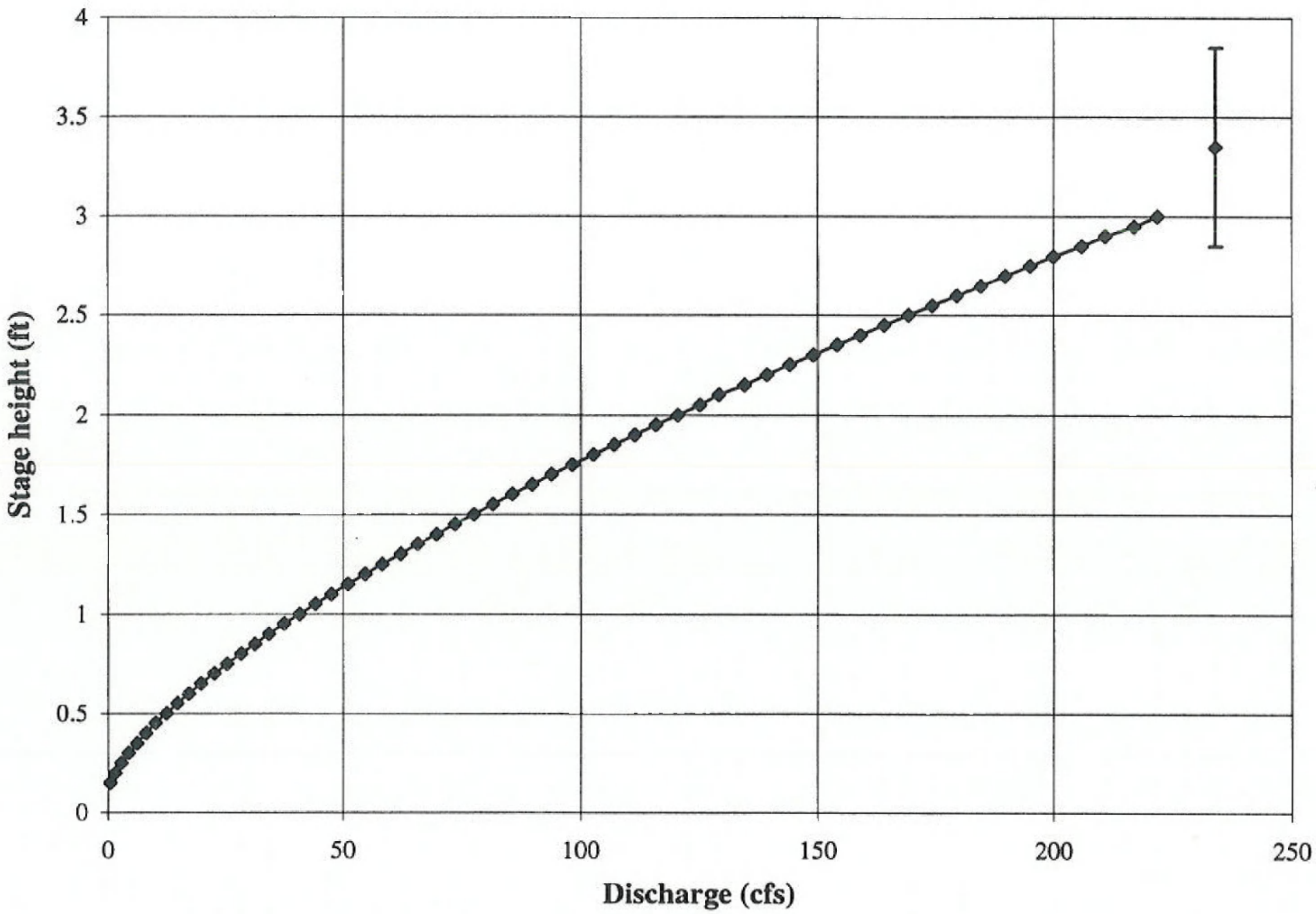


Figure 7. Oak Creek rating curve with vortex sampler closed and reading stilling well. Data for maximum stage extrapolated by regression (after Castro, 1994).

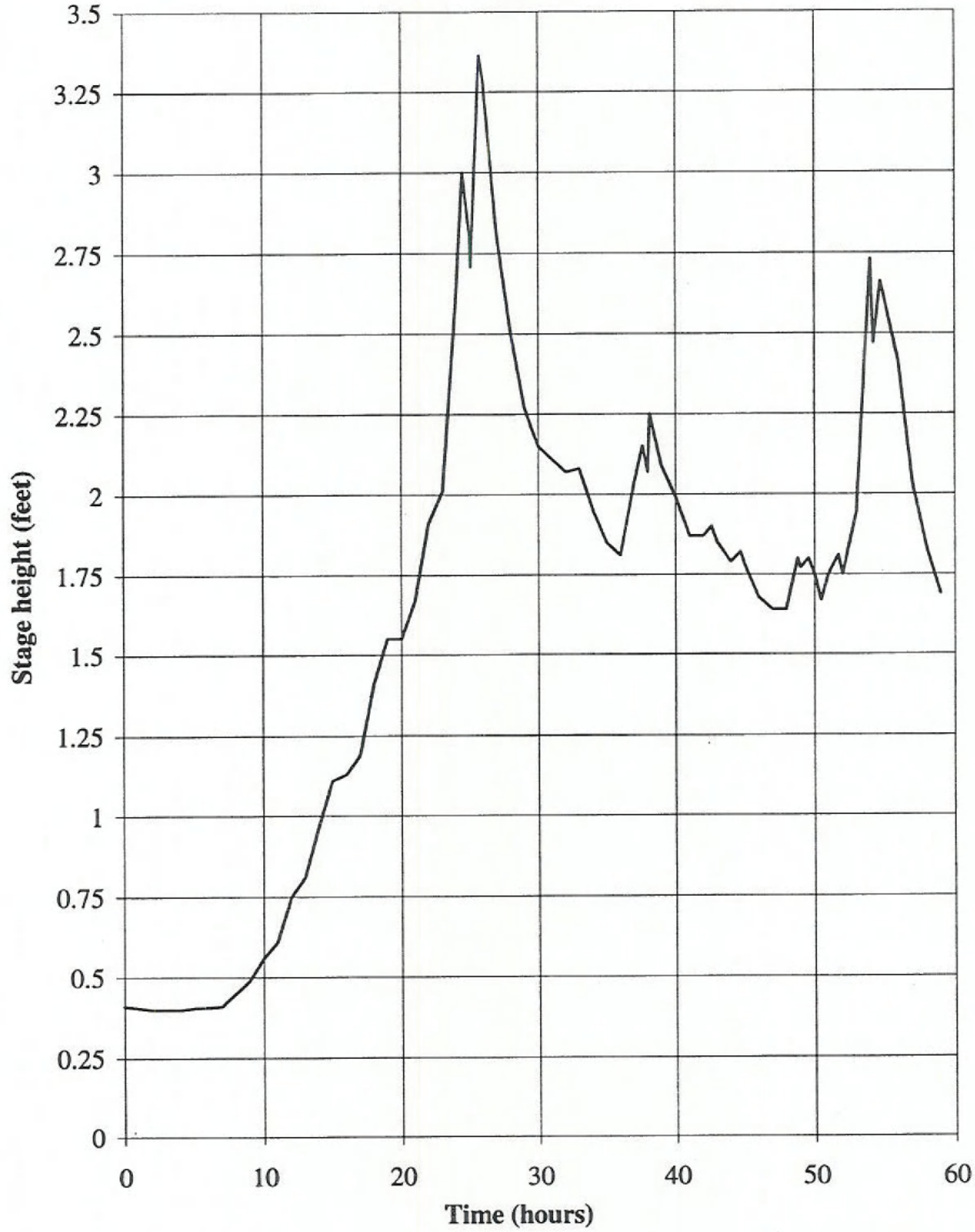


Figure 8. Hydrograph of storm event, O hundred hours 2/5/96 to 12 hundred hours 2/7/96 recorded at Oak Creek stilling well, vortex sampler closed.

The troughs were allowed to fill at the end of the storm and were not emptied until two weeks later after no additional significant streamflow events had passed. One particle that had earlier been recorded was found in the vortex trough when it was cleared. The particle had been transported from its original location along the upstream right bank at the 55m transect (Figure 9). This particle was also tracked once approximately 10 m downstream of its original location. The second particle came from the 52m transect. A third implanted particle was found on the surface of a gravel bar approximately 200 meters downstream. This particle was originally placed along the 17m transect within the study reach. The particle must have passed the vortex bedload sampler when its capacity was reached. When found the particle was cracked in half and 3/4 of the paint had been scoured.

The four channel bed topographic maps (January 3, February 3, February 17 and May 3) reveal some of the channel dynamics and change in morphology (Figures 10 and 11). The downstream reach remains fairly consistent during the four surveys with a scour hole developing at approximately 28 m beginning with the February 3 survey.

The January 3 bed is relatively planform with no major scour holes or bars present. The February 3 map shows the development of a significant scour hole at the approximately 40 m mark and a some scouring on the upstream left side of the channel. There is also the beginning of a scour hole at approximately the 28 m mark. The February 17 survey shows the infilling of the large scour hole at the 40 m mark and the continued development of the 28 m scour hole. The left side channel scour upstream of the 40 m mark is less continuous.

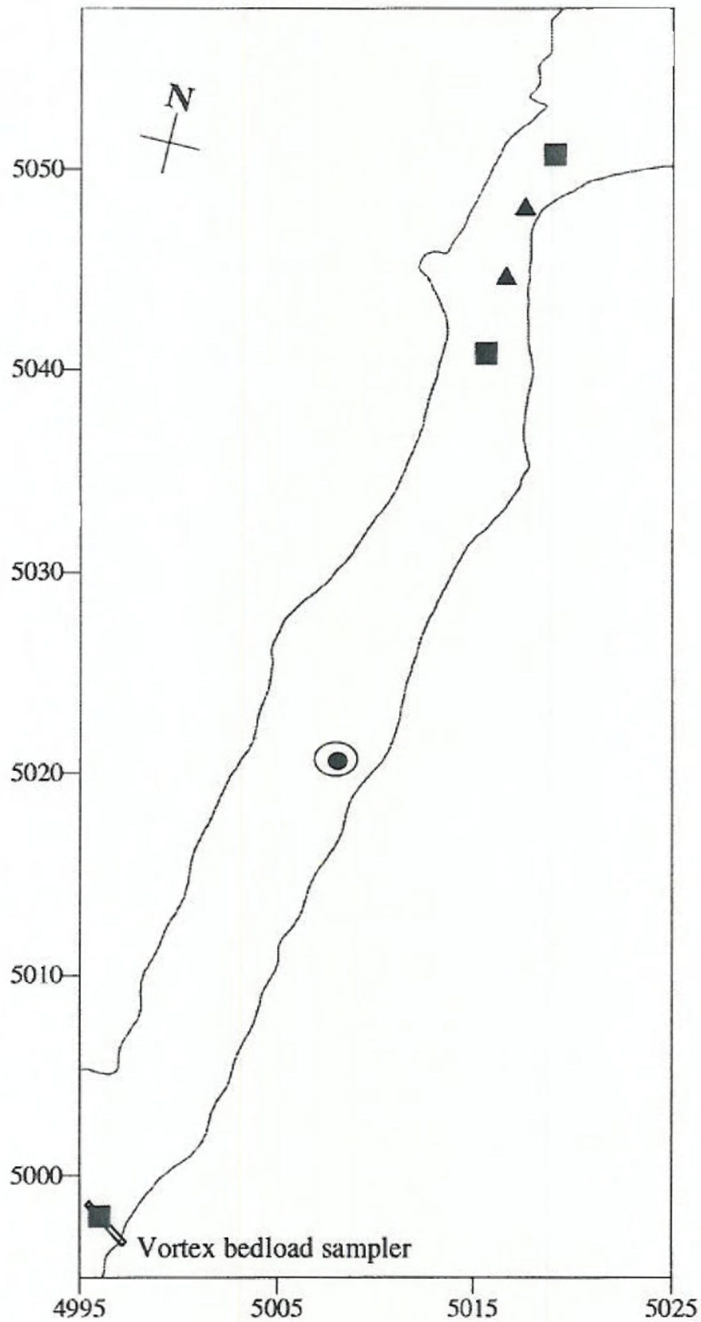


Figure 9. Diagram showing original and transported positions of three identified implanted particles. The square was originally placed on the 55 m transect and was located once approximately 10 meters downstream after the February storm event. This particle was also found in the vortex bedload sampler trough at a later date. The particle represented by the triangle was originally placed on the 52 meter transect and was located after the February storm event approximately 5 meters downstream. The circled dot represents the original location of a particle place on the 17 m transect, it was located approximately 200 meters downstream of the study reach.

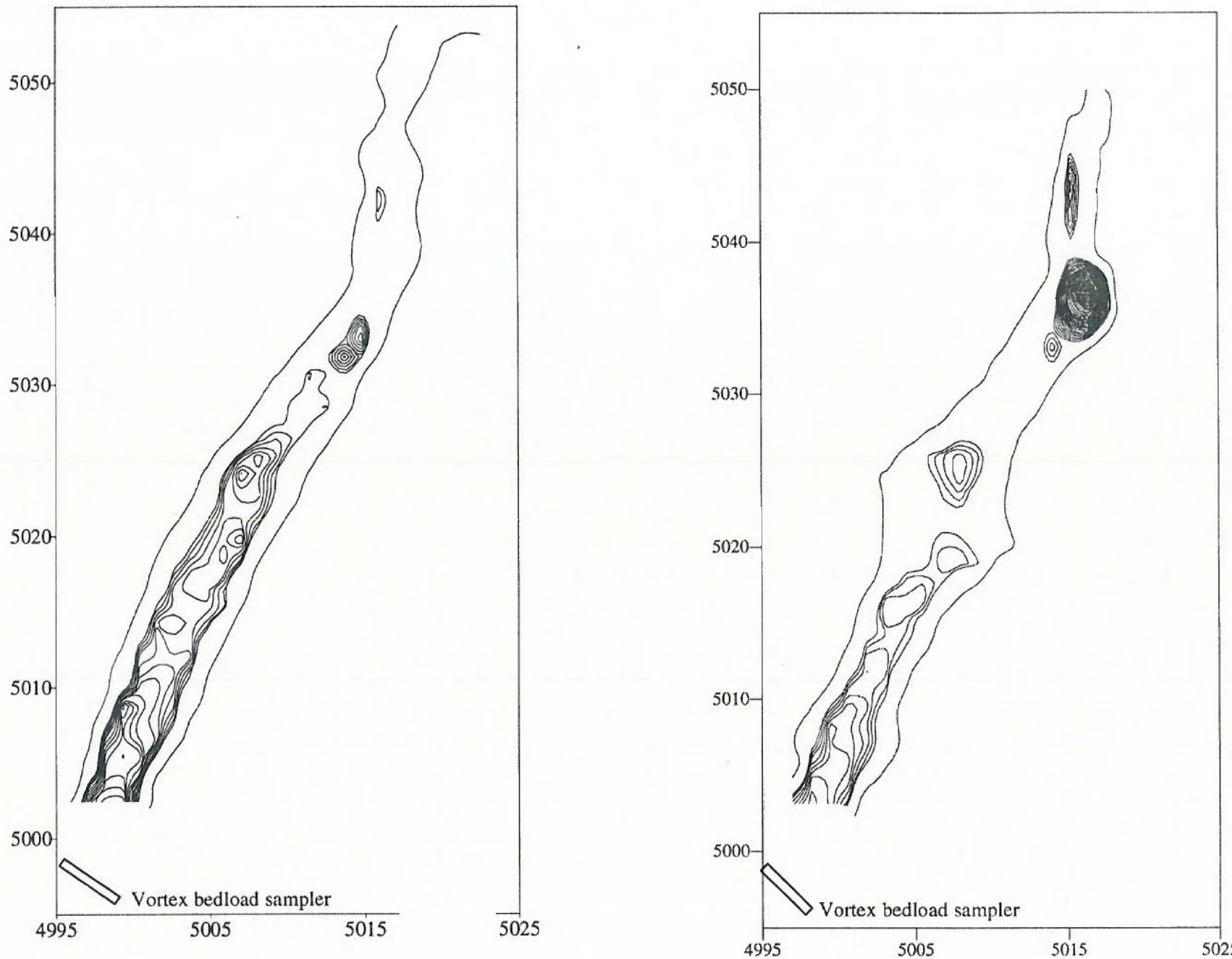


Figure 10. Bed topography of Oak Creek study site-January 3, 1996 and February 3, 1996.

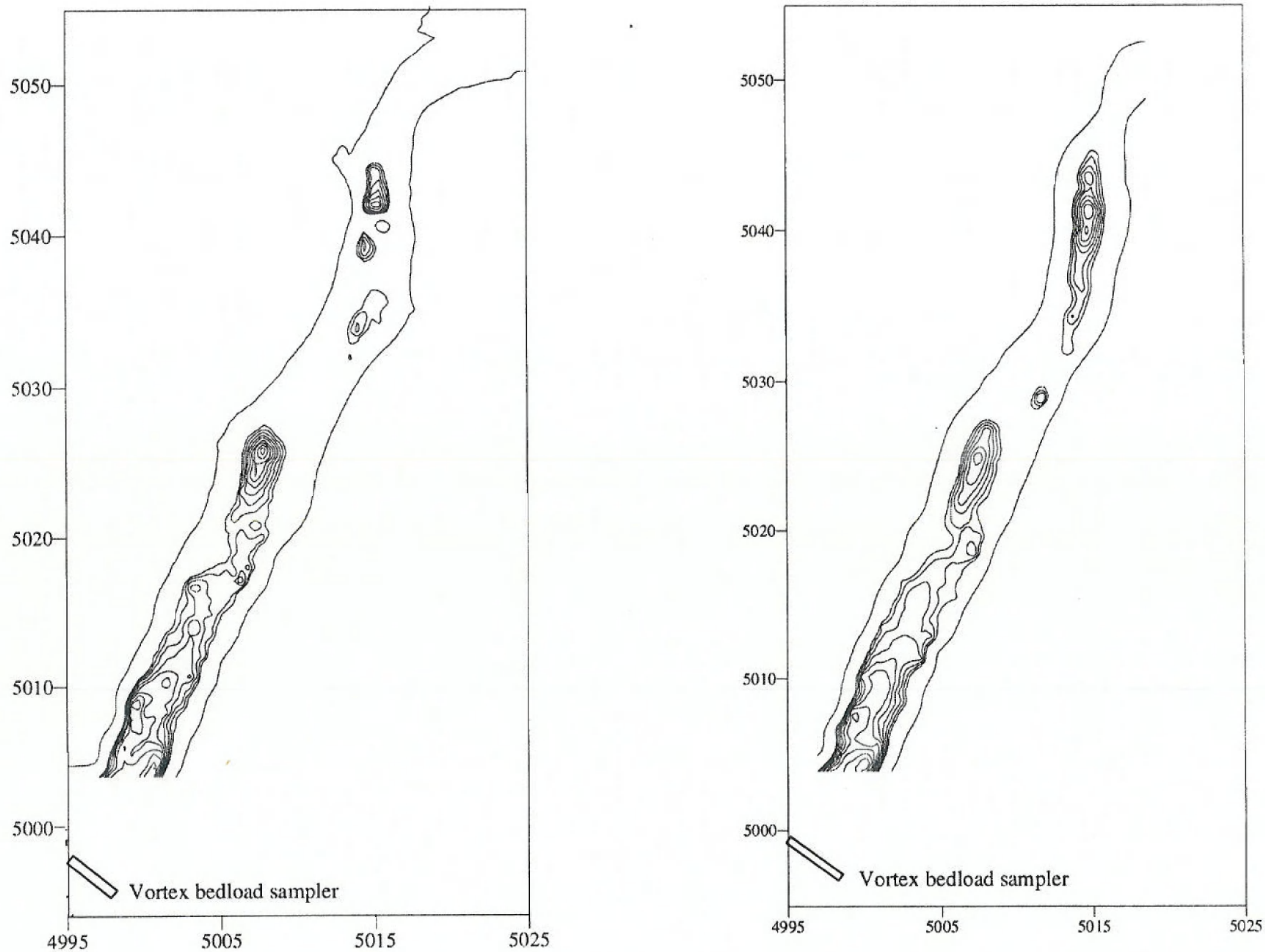


Figure 11. Bed topography of Oak Creek study site- February 17, 1996 and May 3, 1996.

The May 3 survey shows the continued development of left side channel scour upstream of the 40 m mark and a relatively stable condition of the 28 m scour. These surveys help to show changing bed morphology through time. A more in depth view of channel morphology changes can be provided by examining a transect profile. The 55 m transect shows a representative change in channel shape through time (Figure 11). The January 3 profile shows a relatively planar profile similar to the topographic map of the channel for that time. The February 3 profile show a change in thalweg location to concentrating on the left side of the channel. The February 17 profile shows the development of a large bar of gravel on the left bank and a change of active flow to the right side of the channel. Finally, the May 3 profile shows the winnowing of the large bar developed between February 3 and February 17 with a mid-channel thalweg.

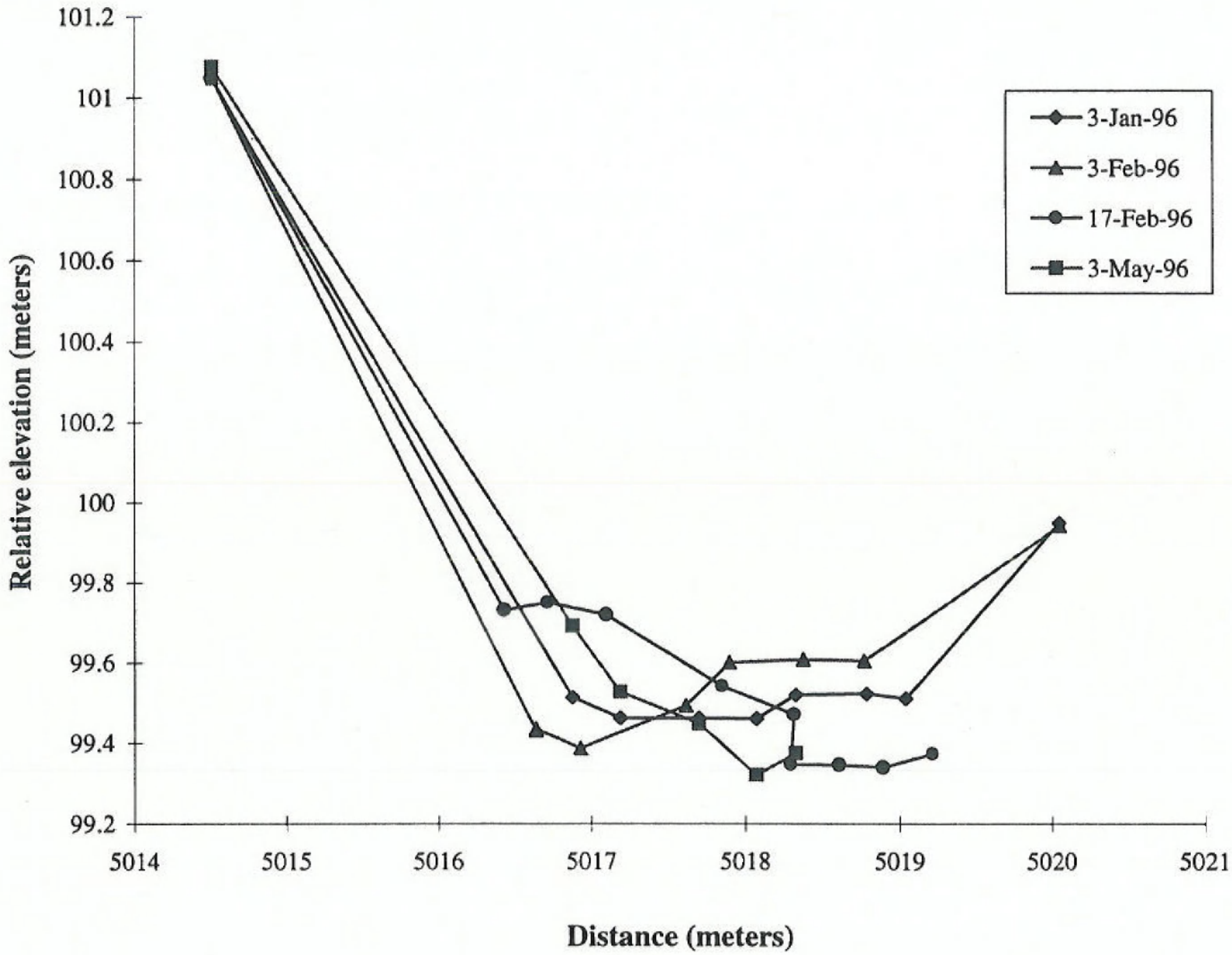


Figure 12. Profiles of transect 55 over four different measurements of the winter of 1996.

Discussion

Previous research indicates that critical tractive forces exist in Oak Creek when discharge is of 45 cfs and subjective observations indicate that particle motion exists at discharge in the order of 40 cfs (Milhous, 1973). This implies that the November event approached the limit necessary to move particles and the February event easily exceeded the limit. It is unknown what percentage of the particles that were not able to be located after the November and February events are still in the study reach. Previous research indicates an active turnover layer in the range of 30 centimeters (Rosenfeld, 1995). It is possible that a significant percentage of particles are buried in the active layer of the study reach.

The bed of Oak Creek has an armour layer as a result of the winnowing of fines in non-transport storm events. This armour layer may have been completely disrupted during the large flows of the February event. Data from Milhous (1973) reports the presence of a distinct armour layer. Previous research shows that bedload transport rates for rising and falling limbs of storm hydrographs may differ by an order of magnitude, with the falling limb being greater. This fact is attributed to that during rising limb discharges the mobility of individual particles is limited by the armour layer.

	July 1971	July 1971	February 1996	June 1996
Size	Average Armour (cm)	Average Bed (cm)	Storm Sample (cm)	Bed Grab Sample (cm)
D_{10}	3.2	0.16	0-0.095	0-0.095
D_{35}	5.2	0.86	0.08	0.15
D_{50}	6.0	2.0	1.5	2.13
D_{65}	6.8	3.3	2.35	2.68
D_{90}	8.6	6.5	4.70	4.34

Table 3. Relative compositions of Oak Creek channel bed. 1971 data (Milhous, 1973).

The design of the experiment was based on available data for active scour depth and armour layer mobility of Oak Creek. The size of the February 1996 storm event created scour beyond the instrumented capacity of the experimental design. In a grab sample from transect 55 m a single particle layer was found on the surface and the subsurface was of mixed composition to an unknown depth (Table 3).

The change in profile shape and location of thalweg from upstream left to upstream right during the large February storm event accounts for the transport of the implanted particles along the transect. The particle was implanted on a gravel bar at upstream right and was transported downstream approximately 10 m when located. The same event also deposited a large gravel bar at upstream right caused by the downing of a large dead tree. The upstream right side woody debris caused scour and the jag seen in the profile line (Figure 11). This same particle was captured in the vortex bedload sampler sometime after the event.

The particle originally planted on transect 17 m in February was among the top ten largest implanted particles. When located 200 m downstream the particle was cracked and the smooth surfaces were devoid of paint. It is unknown when the particle was deposited or cracked, but it is likely that the transport occurred during the February storm event. During the storm event bedload transport exceeded the capacity of both the vortex and secondary trough quickly and a significant amount of material bypassed the troughs. Due to the magnitude of flood discharge, the implanted particles were widely dispersed. The backup identification method of painting the clast was the only way it was located so far downstream of the study reach, as surface scanning at this distance was impractical with proto-type equipment.

Conclusion

The magnitude of the February 1996 storm event exceeded the experimental design of the field test. The field test of the implanted particles provided an approximate 4 percent return. The absence of a determinable scour depth by the February storm and the empirical evidence of locating one particle 200 m of the study reach suggests that the implanted particles could have been transported beyond or potentially buried within the study reach.

The located implanted particles were identified visually and then scanned to determine their identification code and starting position. A more powerful antennae and scanner could enable buried particles to be located.

The design of this field test readily utilized other transport monitoring techniques that were available including painted the particles and physically capturing bedload transport with a vortex bedload sampler. This study was greatly enhanced by combining available monitoring techniques.

There is no known limitation to the number of particles which can be identified by the scanner. Due to the low relative cost of the transponders a greater number of instrumented particles are capable of being monitored.

The dynamic quality of Oak Creek and its relatively quick response to storm events led to several bank-full events over the study period of the winter on 1995-1996. The storm season in the rain dominated Pacific Northwest lasts from approximately November-February. This seasonality enables the passive radio transponder scanning equipment to be utilized in other areas during the year. The system could potentially be employed in the snow-melt dominated system of Squaw Creek, Bozeman, Montana in the late spring and early summer. Cooperation in monitoring between Montana State University (Squaw Creek) and Oregon State University (Oak Creek) could lead to the development of a very useful empirical database.

Recommendations

This experiment tested the prototype of a new method of monitoring individual particle transport. The passive radio transponder technology is potentially capable of providing the most complete information on tracking individual particle movement. Continued research design and monitoring of particles installed during this field test at the Oak Creek study site is imperative to the continued improvements and most effective use of the technology. Potentially this technology could provide solid data to develop specific models for transport in a variety of environments. The use of the technology is not limited to fluvial environments, but could also be utilized to examine other geomorphic transport processes.

Several recommendations can be made based on the winter 1996 field test. The Oak Creek study reach should continue to be utilized to field test equipment modifications and potentially locate any implanted particles remaining in the study reach. Potential equipment modifications include the development of a weather-proof portable scanner and location could enable the technology to be utilized in uncontrolled reaches. At the Oak Creek study site a data logger attached to a scanning antennae in a fixed location, such as the vortex bedload trough, could provide the time and identity of particle transport without capture. Finally, the absolute depth to which the antennae can scan is currently unknown. The development of a stronger antennae to determine particle location which are not visible at the surface is necessary. These are very tangible goals that would involve minimal expense.

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Appendix - Installation positions and properties of implanted particles p.1 of 3								
November 1996 Installation								
Transect #	Position(L-R)	ID#	Mass(grams)	Density(g/ml)	A (mm)	B (mm)	C (mm)	Shape
4	A	7F7B112D69	10.11	2.66	17.6	12.9	12	D
4	B	7F7B113954	3.80	2.69	26.4	10.9	10.3	C
4	C	7F7B13086E	15.79	2.87	30.6	24.7	19	D
4	D	7F7B113F12	21.30	2.88	47.1	28.8	22.2	C
4	E	7F7B106E71	192.10	2.72	98	63	46	D
7	A	7F7D171000	4.80	2.64	23	19.4	13.3	F
7	B	7F7B124658	3.77	2.57	21.3	18.5	8.3	E
7	C	7F7B124719	19.85	2.8	41	32.8	21	D
7	D	7F7B105736	4.38	2.68	30.7	11.8	8.8	D
7	E	7F7B1B0B7D	162.30	2.92	73.5	75.8	35.6	E
10	A	7F7B13106E	47.50	2.84	40	39.8	35.4	E
10	B	7F7B180927	4.50	2.78	25.6	19.1	12.7	D
10	C	7F7B111D62	7.00	2.75	39.6	11	14.1	D
10	D	7F7B113E33	3.92	2.72	21.7	11.6	13.2	C
10	E	7F7B13113E	134.10	2.87	84.9	52.5	45.3	E
13	A	7F7B135955	3.90	2.77	28.6	14.6	5.6	E
13	B	7F7B1B2211	5.58	2.76	31.5	12.9	8.8	D
13	C	7F7B1B1C30	1.61	2.55	12.9	11.4	8.3	D
13	D	7F7B124C4D	4.13	2.75	25.2	14.5	9	D
13	E	7F7B11403F	4.30	2.7	23.4	14.1	13.3	C
21	A	7F7B135961	3.15	2.59	21.7	14.5	12.3	F
21	B	7F7B114948	66.30	2.83	73.8	56	18.4	E
21	C	7F7D4C263F	77.40	2.74	63.1	53.9	34	D
21	D	7F7B11130B	15.13	2.79	39.3	25.8	12.6	D
21	E	7F7B1B170D	4.39	2.48	18.6	15.8	10	D
25	A	7F7B1B6E42	4.05	2.74	31.3	10.4	5.4	E
25	B	7F7B1B6006	119.70	2.85	67.6	65	39.9	D
25	C	7F7B1A437D	23.80	2.79	59	23.4	21.8	C
25	D	7F7B113A53	3.29	2.73	26.7	14.3	4.3	D
25	E	7F7B180419	3.50	2.65	19.8	17.9	11.3	C

Appendix - Installation positions and properties of implanted particles p. 2 of 3								
February 1996 Installation								
13	A	7F7B17660D	13.95	2.72	36.9	27.6	21.4	C
13	B	7F7B196463	2.30	2.53	15.2	15	17.4	E
13	C	7F7B107102	47.40	2.84	53.6	47	26.8	D
13	D	7F7B122704	55.25	2.85	53.9	39.4	32.4	D
13	E	7F7D782B33	29.80	2.76	62.5	39.2	12.6	E
17	A	7F7B1B2045	2.44	2.67	19.6	14.3	7.8	D
17	B	7F7B106070	3.33	2.74	25.9	19	11.9	D
17	C	7F7B135C51	125.00	2.85	88.9	61.5	42.4	C
17	D	7F7B1A3D58	62.40	2.9	62.8	35.9	35.6	D
17	E	7F7B177425	54.90	2.87	50.6	38.2	37	D
31	A	7F7B195D76	12.30	2.8	33.6	28.2	18.1	C
31	B	7F7B111167	5.28	2.71	27.2	15.6	7	D
31	C	7F7B127478	42.00	2.83	68.8	36.9	17.4	D
31	D	7F7B1A5F35	85.50	2.9	77.3	60.7	26.8	D
31	E	7F7B1B1B50	108.40	2.89	71.4	68.9	32.4	D
35	A	7F7B196223	3.45	2.7	24.7	13.8	10.3	C
35	B	7F7B11356C	3.22	2.65	27	13.6	5.4	D
35	C	7F7B122B43	4.00	2.3				D
35	D	7F7B177B24	14.00	2.61	32.9	27.4	20.6	C
35	E	7F7B133F4B	2.00	2.49	16.6	12.4	4.5	C
42	A	7F7B1B6423	55.80	2.83	51.4	52.6	27.4	D
42	B	7F7B11752B	26.85	2.8	48	32.4	28.6	D
42	C	7F7B0F4777	4.55	2.64	33.5	9.7	7.3	
45	A	7F7B134430	22.45	3.3	44.8	32.7	29.4	D
45	B	7F7B105F27	3.90	2.59	21.4	18.4	7	
49	A	7F7B135733	16.70	2.82	45.8	31	18.8	D
49	B	7F7B124D51	48.40	2.83	54.5	44	36.6	D
49	C	7F7B1A5C1B	3.65	2.63	24.1	13.6	9.1	D
52	A	7F7B1A7F13	69.40	2.83	68.7	47	25.4	C
52	B	7F7B122538	3.45	2.72	25.6	15.5	8.2	D
52	C	7F7B1B0132	2.75	2.58	17.9	15.2	5.5	E

Appendix - Installation positions and properties of implanted particles p. 3 of 3								
52	D	7F7B1B2254	40.20	2.86	54.9	32.3	30.3	D
52	E	7F7B180A01	78.20	2.76	66.7	45.8	33.9	D
55	A	7F7B130B29	4.70	2.73	22.5	13.8	13.7	C
55	B	7F7B124671	38.50	2.84	49.9	34.7	29.6	D
55	C	7F7B177129	24.30	2.8	48.6	30.3	22.9	D
55	D	7F7B124262	4.03	2.73	25.6	16.9	8.1	D
55	E	7F7B0B2B1E	13.58	2.83	39.9	30.9	21.8	D
Not placed								
		7F7B1A5702	113.00	2.71	68.6	57	46	D
		7F7B113F3B	56.90	2.36	69.5	36	27.5	D

Original Placement of Particles- Nov 1995 and Feb 1996