A RADIO FREQUENCY IDENTIFICATION SYSTEM FOR MONITORING COARSE SEDIMENT PARTICLE DISPLACEMENT

M. H. Nichols

ABSTRACT. *A radio frequency identification system was implemented to monitor the displacement of coarse particles following runoff in two upland, ephemeral channels on the USDA−ARS Walnut Gulch Experimental Watershed in southeastern Arizona. Commercially available radio frequency identification components including transponders, an antenna, a reader, and software were used to develop a system for locating particles under field conditions. During the 2003 field season, 124 particles were located following four runoff events in two ephemeral channels. The locations of 340 particle positions were measured with a real−time kinematic geopositioning system after each particle was located with the radio frequency identification system. The overall recovery rate was 96%. The passive transponder system offers the advantages of low cost, consistent results under harsh environmental conditions, and no need for a power supply in the particle. The radio frequency identification system can be used to efficiently collect data for developing sediment transport equations and improving mathematical models for simulating sediment transport under natural runoff conditions.*

Keywords. *Radio frequency identification, Sediment transport, Displacement.*

Semiarid fluvial sediment transport processes, including entrainment, transport, and deposition associated with runoff in normally dry channels are generally poorly understood and difficult to quantify. The total sediment discharge during any flow is comprised of a range of particle sizes, which may travel in suspension or along the channel bed depending on flow conditions. In the southwestern United States, channel runoff associated with intense summer thunderstorm rainfall is highly variable, turbulent, and often short lived, making measurement and data collection difficult. In practice, sampling suspended sediment (Edwards and Glysson, 1999; Renard et al., 1976) is easier than measuring bedload, and tracking individual particles is especially difficult.

There is a need for field data coupling runoff measurements and sediment measurements to improve sediment transport prediction equations. Flume experiments have been the basis of research to understand particle displacement frequency and transport and to develop prediction equations (Wilcock, 1997a). Testing the results of laboratory experiments under field conditions requires experimental measurement methods and subsequent analysis of collected data. Tracers have been used in sediment research to study the sediment movement for at least a century (Foster, 2000), with varying degrees of success. Tracers, traditionally in the form of painted rocks (Leopold et al., 1966; Wilcock, 1997b), and more recently magnetic (Custer et al., 1987; Gintz et al., 1996) and "radio" rocks (Ergenzinger at al., 1989; Emmett et al., 1990; Rosenfeld et al., 1996), have been used to study the movement of individual particles.

Continually evolving electronic technologies offer new opportunities for field experiments and hypothesis testing. The objective of this research project is to improve the understanding of sediment transport dynamics in alluvial channels. A radio frequency identification (RFID) system was developed to monitor the displacement of individual coarse, synthetic, sediment particles on the USDA−ARS Walnut Gulch Experimental Watershed as part of a long−term sediment transport experiment. This article describes the RFID system for monitoring individual coarse−grained particles and summarizes particle recovery rates.

MATERIALS AND METHODS

RADIO FREQUENCY IDENTIFICATION SYSTEM

Radio frequency identification (RFID) is a wireless, automatic identification system. RFID systems are employed in diverse applications from supply chain operations and inventory tracking in industrial settings, to toll road access and automatic gasoline payments in consumer settings. RFID technology and applications are evolving rapidly. Because a primary benefit of RFID is the ability to uniquely identify individual items, research was undertaken to evaluate the technology for monitoring coarse particle movement in alluvial channel systems.

RFID systems consist of three parts: a transponder (derived from transmitter/responder), a reader, and an antenna. RFID transponders may be active or passive. Active transponders rely on an internal battery for power. Passive transponders rely on an external power source, usually delivered by the reader through an antenna. Passive transponders have a shorter read range, but are less expensive and are not susceptible to battery failure. Components purchased from Texas Instruments were used to develop the system for monitoring particles. A summary of system parts and costs is

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The author is **Mary Hennessey Nichols,** Research Hydraulic Engineer, USDA−ARS Southwest Watershed Research Center, 2000 E. Allen Rd., Tucson, AZ 85719; phone: 520−670−6481 ext. 161; fax: 520−670−5550; e−mail: mnichols@tucson.ars.ag.gov.

Table 1. Summary of RFID system parts and costs (January 2004).

Part	Part Number	Cost (US$)
Series 2000 High Performance Remote Antenna RFM	RI−RFM−008B−00	235.01
Series 2000 Control Module with RS232 Interface	RI−CTL−MB2A−02	235.01
Series 2000 Gate Antenna Small	RI−ANT−GO2E	139.05
32−mm Glass Transponder R/W	RI−TRP−WR2B	3.59
Cables		50.00
Palmtop computer		249.00
Batteries		20.00
Total (with one transponder)		931.66

shown in table 1. Texas Instruments (Dallas, Tex.) has been developing RFID systems since 1991 under the business name TIRIS (Texas Instruments Registration and Identification System, http://www.ti.com/tiris).

Transponders are available in a variety of physical shapes, with varying programming options, read ranges, and costs. The TIRIS RI−TRP−WR2B transponder was chosen for this application. These 32−mm long, 3.2−mm diameter, cylindrical transponders are encased in a waterproof glass capsule and will operate reliably under harsh environmental conditions. Each transponder has a resonant circuit that is energized by an electromagnetic field radiated from an antenna. This circuit further charges a capacitor, which supplies power to the transmitter within the transponder that sends the return signal. The operating frequency of the transponder is 134.2 kHz. The transponders can be programmed by the user with an alphanumeric string up to 128 characters long that may be used to uniquely identify the transponder.

The particle tracking system (reader and antenna) is implemented in a manner similar to that of a metal detector. Particles are found by walking the channel and sweeping the antenna over the channel bed. The sweeper is powered by a battery pack made up of three 6V rechargeable batteries and consists of a gate antenna attached to one end of a pole and the reader mounted on the other end (fig. 1). A cable attaches the antenna to the reader, and a serial cable attaches the reader to a portable computer. When a transponder is detected the computer displays the alphanumeric string stored within the transponder that indicates which particle was found.

The reader consists of electronics that send and receive signals that contain encoded data to and from the transponder. The size (approximately 10 × 10 × 8 cm) of the reader makes it suitable for field application. Under ideal conditions with a large, efficient antenna and a strong charging signal, the read range of the transponders used in this application can reach 100 cm. In practice, read range is determined by a variety of factors. The key factors are antenna shape and size, ambient electromagnetic interference, the spatial orientation of the antenna to the transponder, and proximity to metal objects. The antenna chosen for this application was a 20.3− × 20.3−cm gate antenna manufactured by Texas Instruments. This high efficiency antenna was chosen for its compact size and compatibility with the reader. Although metal obstacles and surrounding interference are a serious concern in industrial settings, they are of minor concern for this field experiment, which was conducted in a remote, outdoor setting.

FIELD EXPERIMENT

The USDA−ARS Walnut Gulch Experimental Watershed (Renard et al., 1993) is located in southeastern Arizona (fig. 2). The watershed is located in the semiarid transition zone between the Sonoran and Chihuahuan deserts. Walnut Gulch is the main channel on the watershed and is a tributary to the San Pedro River. Walnut Gulch and its tributaries are dry most of the time. Flow events in response to thunderstorm rainfall dominate the surface runoff regime.

Runoff is monitored at several locations within the watershed. The channels between flumes 102 and 104 and between flumes 106 and 104 within the Lucky Hills Subwatersheds (fig. 3) were selected to test the RFID system. Santa Rita Critical Depth Flumes (Smith et al., 1982) at the outlets of watersheds 102 and 104 (1.46 and 4.4 ha), provide event runoff discharge data. Depth integrated traversing slot sediment samplers collect sediment that passes through the Santa Rita Flumes (Renard et al., 1976). Additionally, watershed 106 (0.36 ha) is instrumented with an H flume at the subwatershed outlet (Brakensiek et al., 1979). Computed mean annual runoff values at watersheds 102, 104, and 106 are 23.8, 17.0, and 23.2 mm, respectively (standard deviation are 17.2, 14.2, and 19.4 mm, respectively). Two−year peak runoff rates are 40.0, 32.5, and 45.8 mm/h for watersheds 102, 104, and 106, respectively.

Figure 1. RFID sweeper and portable computer.

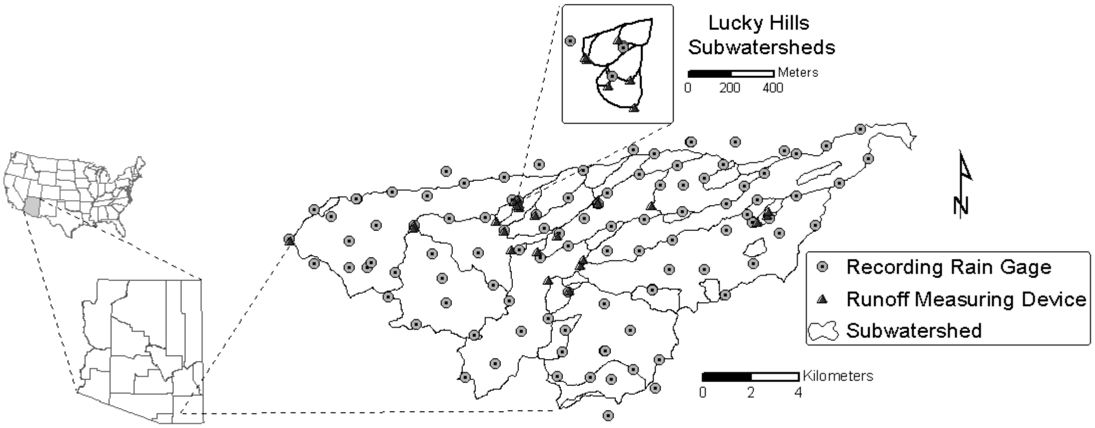

Figure 2. USDA−ARS Walnut Gulch Experimental Watershed location map.

In early July 2002, the channel morphology, including profile, cross−section geometry, and bed material characteristics of channels 102−104 and 106−104, was measured. Channel 102−104 is 114.3 m long with an average slope of 2.9% and channel 106−104 is 161.3 m long with an average slope of 3.6%. Natural rocks sampled from a channel within the Lucky Hills Subwatersheds ranged in size from 32 to 130 cm^3 with an average density of 2.3 g/cm^3 (standard deviation = 0.2 g/cm^3). Concrete spheres with a 5.72−cm diameter (95 cm^3), representing very coarse gravel, were cast from concrete with aggregate added to adjust the density (fig. 4). Transponders were placed into wet concrete during casting. The average density of cast spheres was 2.2 g/cm^3 (standard deviation = 0.1 g/cm^3), which was in close agreement with the natural rocks. In addition, synthetic cubes (98 cm^3) were cast.

A total of 124 transponder laden concrete particles were set on channels 102−104 and 106−104 within the Lucky Hills Subwatersheds. A natural particle was removed from the channel for each particle added and the location of each particle was measured using a surveyor’s total station. Particles were located after each of seven flow events in 2002 by sweeping the channel with the antenna and locations were measured with the total station.

During the 2002 field season, difficulties associated with implementing the system in the field were identified and the system was refined. A buzzer was added to the reader, providing an audio signal when a transponder is sensed and the laptop computer was replaced with a palmtop computer running a terminal emulation program to interpret return signals and display identification information. Because the strength of the antenna signal decreases inversely in proportion to the square of the distance from the transponder, and the orientation of the antenna to the transponder affects the signal pickup, the sweeping procedures were modified to maximize the likelihood of finding the particles. Within each particle, the orientation of the transponder is unknown, so sweeping the channel requires moving the antenna both across the surface of the channel and through planes oblique to the channel.

During the 2003 field season, particles were located after four flow events. Locations were measured using a survey grade real−time kinematic geopositioning system. In addition to the quantified particle location, each particle was qualitatively characterized as buried, half buried, less than half buried, more than half buried, missing, or passed though the flume. A trap located below the overfall of flume 104 limited the travel distance for those particles traveling

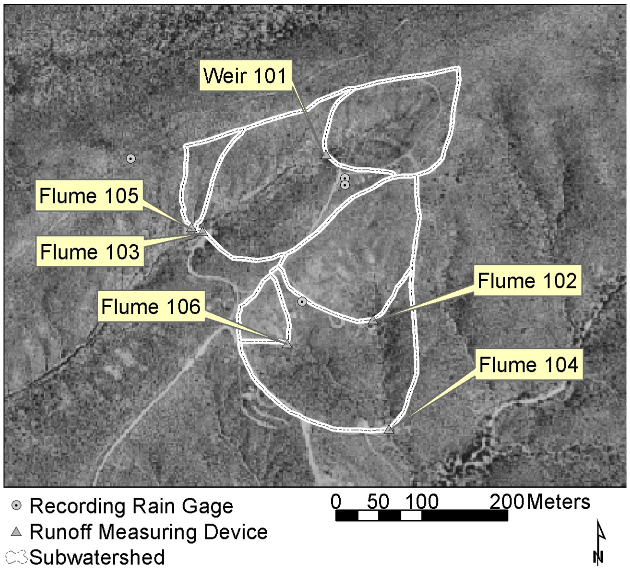

Figure 3. Lucky Hills subwatersheds and monitoring sites.

Figure 4. Synthetic particles and transponder.

through the flume. Particles recovered from the trap were not found using the RFID system, nor were they missing, thus they were not included in the recovery rate assessment. Particle recovery rates and experimental results are presented for the 2003 season, representing the current implementation of the system in the field.

RESULTS

The RFID system was used to locate 96% of the particles searched for following four runoff events during the 2003 “monsoon” season. Without the RFID system, recovery of uniquely identifiable particles would have been limited to 70% of the particles in the 102−104 channel and 63% of the particles in the 106−104 channel (table 2).

The field experiment is being conducted to monitor particle displacement following each flow event during several runoff seasons. Identifying buried particles is critical to maintaining continuity of particle travel data through successive flows. Given the high bed mobility and depth of alluvium in channels on the watershed, the state of burial of an individual particle is highly variable in response to runoff. Recovery of buried particles, and identifying the particles in situ has been a shortcoming of the use of painted rocks, or even magnetically tagged particles. The depth of alluvium in the 102−104 channels is variable ranging from zero (exposed hardpan) to approximately one meter in the fluvial deposit at the flume intake. During initial testing, several buried particles were dug up to verify their detection (fig. 5). With the RFID system, buried particles can be located and uniquely identified without disturbing the particle or the channel. However, a modified antenna configuration would be required if the system were used in a channel with deeper alluvium.

Although particles that were not classified as buried could be detected visually, particle detection was much more efficient with the RFID system. Often, particles were partially buried, obstructed by vegetation, or intermixed with particles of like color and size (fig. 6). Detecting the particles, particularly those particles under bank vegetation, was relatively easy by systematically sweeping the antenna below the vegetation. In addition, the synthetic particles employed in this experiment were intentionally of like shape and the RFID system was critical for uniquely identifying particles. When particles deposited in groups, additional care was taken when sweeping the antenna to ensure that the signal from any particular transponder did not dominate both the returned signal and the displayed identification string.

Table 2. 2003 particle recovery characteristics.

Channel No.	Particle Position	No. of Particles
102−104	Buried	28
	Half buried	24
	Less than half buried	21
	More than half buried	25
	Surface	44
	Missing	3
	Total number of positions	145
	Recovery rate	0.98
	Maximum recovery rate without RFID system	0.79
106−104	Buried	60
	Half buried	15
	Less than half buried	32
	More than half buried	34
	Surface	42
	Missing	12
	Total number of positions	195
	Recovery rate	0.94
	Maximum recovery rate without RFID system	0.63

Figure 5. Buried particle exposed for demonstration after detection with RFID system.

CONCLUSION

The radio frequency identification system provides reliable identification of tagged particles in a field setting. The tracking system consists of transponders, an antenna, a reader, and software. The passive transponder system offers the advantages of low cost, consistent results under harsh environmental conditions, and no need for a power supply in

Figure 6. Two buried particles indicated with flags and one exposed particle in the foreground.

the particle. In addition, line of site is not required for locating particles.

The system was implemented and tested under natural runoff conditions. The RFID system was successful in locating 96% of the particles searched for following four runoff events. As RFID technology evolves, longer read ranges and lower costs will advance the feasibility of conducting field experiments based on radio frequency tracking. The radio frequency identification system is being used to efficiently collect data for developing sediment transport equations and improving mathematical models for simulating sediment transport under natural runoff conditions.

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