Measuring Water and Sediment Discharge From a Road Plot With a Settling Basin and Tipping Bucket

Thomas A. Black and Charles H. Luce

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Abstract

A simple empirical method quantifies water and sediment production from a forest road surface, and is well suited for calibration and validation of road sediment models. To apply this quantitative method, the hydrologic technician installs bordered plots on existing typical road segments and measures coarse sediment production in a settling tank. When a tipping bucket gauge and a flow splitting device are added to the installation, both coarse and fine sediment can be collected along with a continuous discharge record. Included in this report is the design of a simple and inexpensive tipping bucket system and the procedures for measuring plot discharge up to 60 gal (227 L) per minute.

Keywords: fine sediment monitoring, sediment budget, road sediment, road runoff, road discharge, non-point source sediment, effectiveness monitoring, sediment trap, tipping bucket

The Authors

Thomas A. Black is a Hydrologist with the USDA Forest Service, Rocky Mountain Research Station in Boise, Idaho. He completed a B.A. degree in Geography from the University of California and an M.A. degree in Geography from the University of Colorado.

Charles H. Luce is a Research Hydrologist with the USDA Forest Service, Rocky Mountain Research Station in Boise, Idaho. He completed a B.S. degree in Forest Management at the University of Washington, an M.S. degree in Forest Hydrology at the University of Washington, and a Ph.D. in Civil Engineering at Utah State University.

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Introduction

Forest road runoff and fine sediment delivery are widely acknowledged to have serious impacts on aquatic ecosystems (Cederholm and other 1981; Platts and other 1989; Thurow and Burns 1992; Lee and others 1997; Luce and Wemple 2001). Roads influence a variety of watershed processes, including sediment production (Megahan and Kidd 1972; Reid and Dunne 1984; Bilby and others 1989; Luce and Black 1999, 2001a; MacDonald and others 2001), hydrologic event timing (Wemple and others 1996; Jones and Grant 1996), and slope stability (Sessions and others 1987; Montgomery 1994). As a consequence, water quality regulations and cumulative effects modeling of forest management have frequently focused on forest roads.

Land managers and watershed specialists use models to predict sediment delivery from forest roads. Several empirical models are used to evaluate road sediment risks, but are limited by a lack of calibration data. For example, the R1-R4 model (Cline and others 1984) predicts sediment production in western cordilleran watersheds; however, its derivatives rely on a data set measured in the 1960s and 1970s in the Idaho Batholith. Developments since then have used results from other studies to parameterize the effects of various road treatments (Washington Forest Practices Board 1993; NCASI 2003), but interpolating the data results to new and unique geology, precipitation, and design standards still often relies on professional judgment.

Physically based erosion models predict the amount of water discharge and road sediment transport using physical equations and a particular configuration of input variables. WEPP (Elliot and others 1999) and DHSVM (Wigmosta and others 2001, 2002; Doten and others 2006) are two examples of the physically based erosion models. One of the theoretical promises of physically based models in contrast to empirical models is being able to define significant variables or parameters that can work across many different precipitation regimes and soils. There are many parameters in physically based models such as hydraulic conductivity and soil erodibility, many of which cannot be measured directly but are derived from observations of outputs under varying inputs. While tools like rainfall simulation may be helpful for smaller scales or components of a road system (e.g. Luce and Cundy 1994), finding the effective parameters for a whole road segment with all of its spatial variability and multiple water pathways (Luce 2002) requires observations of erosion under real precipitation and snowmelt events. Put succinctly, these parameters need calibration at the scale of the typical road segment (sidebar 1).

Outside of the context of modeling road impacts, land managers, engineers, and regulators want better information about how new designs, materials, or methods might help prevent erosion or delivery of sediment. While a general understanding of erosion and transport process can guide the design and estimated effectiveness of new approaches, observations of how treatments affect erosion (e.g. with a before-after control-impact design) are the most objective ways to assess treatment effectiveness. While adaptive management is an expressed ideal for both managers and regulators, high quality observations are required, and costs for acquiring data can be a barrier to rigorous learning.

While the value of data on road erosion and runoff is clear for model calibration and adaptive design, relatively inexpensive yet reliable methods for systematically collecting road erosion data have not been described with much detail. A literature search on road erosion provides a variety of useful methods for quantifying surface erosion. (Megahan and Kidd 1972; Reid and Dunne 1984; Ice 1986; Bilby and others 1989; Kahklen 2001; Foltz and Trube 1995; Luce and Black 1999; MacDonald and others 2001, 2004). The methods require a range of effort and expense and vary substantially in accuracy. The processes described in this manual are derived from 17 years of experience using sediment trap based systems (Luce and Black 1999, 2001a, 2001b, 2001c; Sugden and Woods 2007) and specify methods for collecting high-quality road erosion data. Alternatives are offered depending on the degree of precision needed in observations; a simple retention trap may be used for rough estimates, while greater accuracy can be obtained with a combination of concentration and flow measurement for some additional expense. This report provides detailed designs, material lists, and costs for the construction of plots, sediment traps, tipping bucket devices, and the associated suspended sediment samplers, as well as information on measurement and maintenance after installation.

This document provides a simple approach for documenting the sediment production rate from forest roads. This method will be of interest to the watershed professional or engineer involved in making decisions about road restoration, decommissioning, or maintenance practices. This information will be useful to scientists and students planning to gather data on road sediment production, road hydrology, or those attempting to calibrate or validate a model.

Sidebar 1: Why Measurements are Important for Models: An example with WEPP

The idea of a physically based model, like WEPP, is to be able to estimate parameter values based on a series of experiments across a range of soils or treatments. Conceptually, these parameters are properties of the soil or treatment, and work with any precipitation or snowmelt input to estimate runoff, detachment, and transport of sediment. The most important parameters for WEPP are the hydraulic conductivity and erodibility parameters (Tiscareno-Lopez and others 1993). Substantial work has been done with rainfall simulators and complex data analysis to find hydraulic conductivity for roads across a number of different soil textures (Luce and Cundy 1994), and earlier work was done to identify erodibility parameters for WEPP for a range of soil textures (Elliot and others 1989).

The expectation for a physically based model is that parameters identified in this way could be applied over a range of climates and soils to predict erosion. Figure 1 shows the results of applying WEPP using soil texture and observed precipitation across a range of sites with measured soil erosion (Dubé and others 2011). While there is a general correspondence between prediction and observation, the slope of the predicted erosion versus observed is flatter than the 1:1 line, and there is a slight tendency to over predict. The Nash-Sutcliffe value (Nash and Sutcliffe 1970) is a measure of how well a model matches observations. The Nash-Sutcliffe value calculated using the WEPP sediment production predictions is 0.20 with normal axes and -0.09 in log-transformed axes (this transformation is used if one is just considering "order of magnitude" effects).

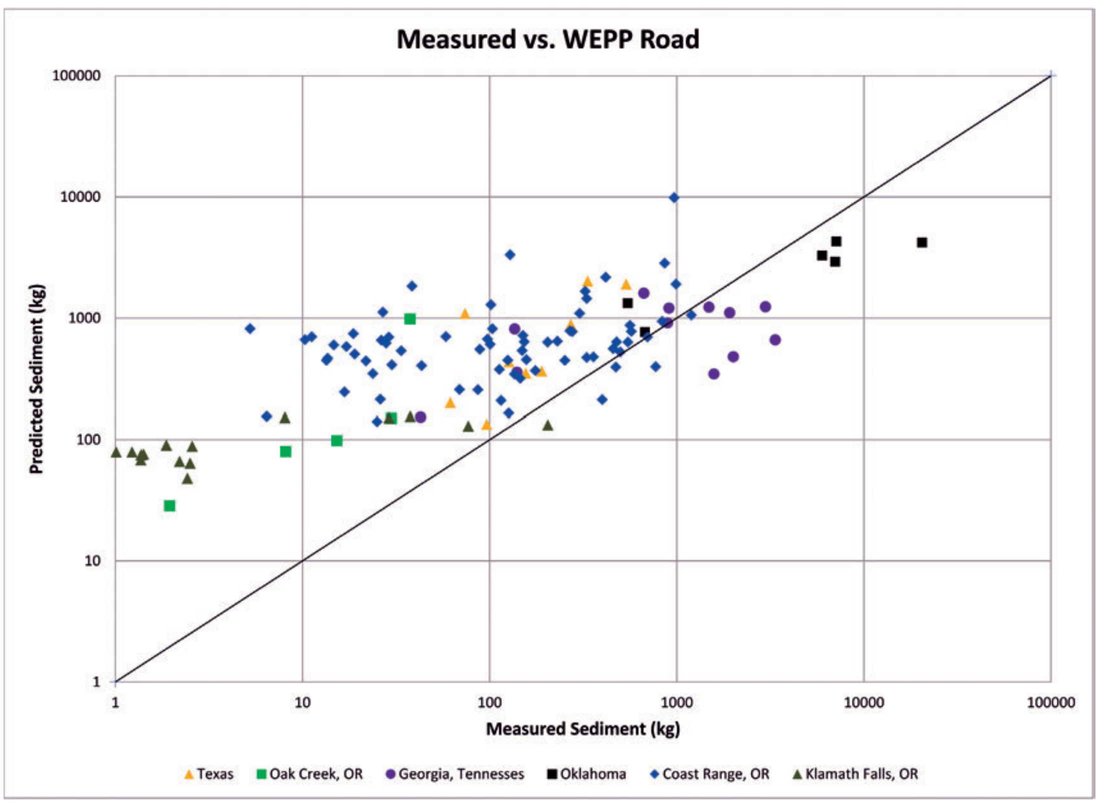

Figure 1—WEPP-predicted versus observed surface erosion from six different road erosion experiments from Dubé and others (2011). The Nash-Sutcliffe value of the log-transformed results is -0.09.

Sidebar 1: Continued

Such results indicate that the mean observed erosion may serve better than the model to estimate erosion across this range of sites. Given that the range of erosion values spans 5 ½ orders of magnitude, that is not a particularly compelling case for using un-calibrated model predictions based on soil texture and precipitation.

By calibrating the WEPP model results to better approximate the means for each group of sites, substantial improvements can be made to the fit (fig. 2). The Nash-Sutcliffe coefficient is 0.73 for untransformed and 0.61 for log-transformed data, which would rate the model as substantially useful with this mild degree of calibration.

One likely reason for this result is that the hydrology of forest roads varies across sites based on the interactions of soils and climate (Luce 2002). In some places, particularly with low conductivity soils and high precipitation intensity, Hortonian overland flow (the hydrologic process modeled by WEPP) is common on roads (Ziegler and others 2000), whereas in places with high conductivity soils (such as forests) and lower precipitation intensities or snowmelt dominated environments, a greater proportion (up to 95%) of road runoff is derived from cutslope interception (Burroughs and others 1972; Megahan and Kidd 1972; Wemple and Jones, 2003). While the underlying hydrologic model in WEPP does not reflect the range of active hydrologic processes in the field, it would appear that local calibration can reduce the bias caused by the differences.

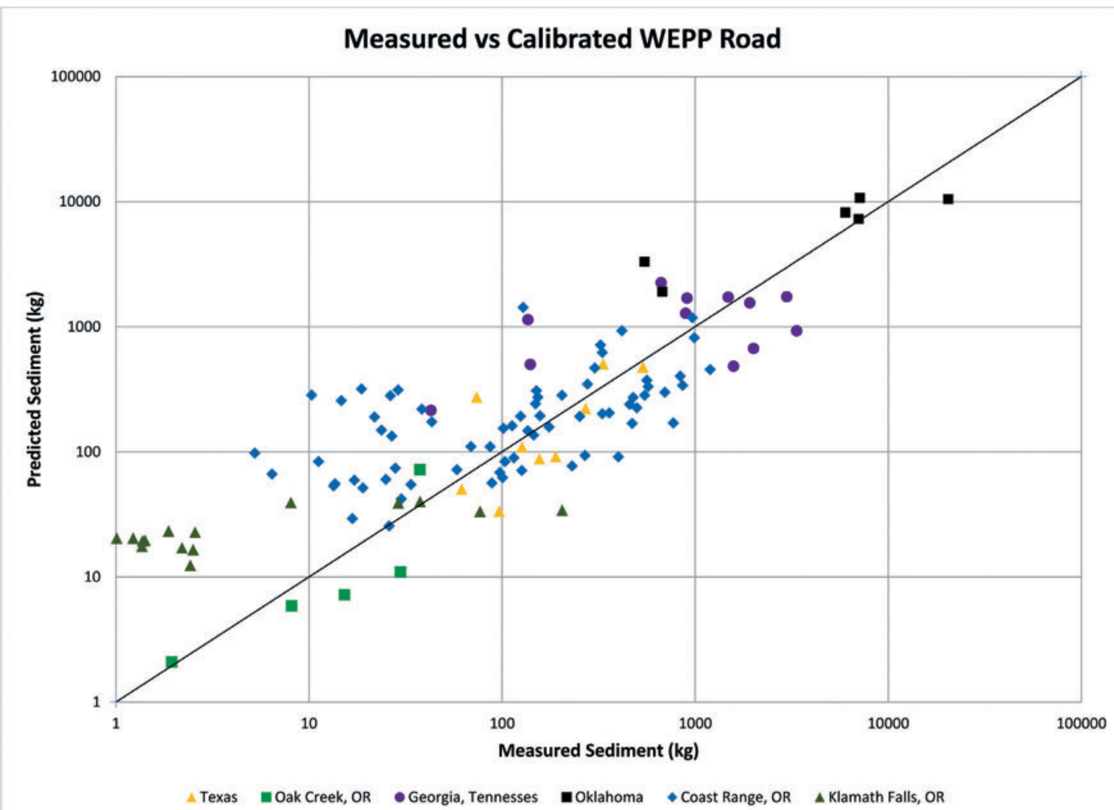

Figure 2—WEPP-predicted versus observed surface erosion from six different road erosion experiments from Dubé and others (2011) after calibrating WEPP to the mean erosion for each experimental group. The Nash-Sutcliffe value of the log-transformed results is 0.61.

Previously Used Data Collection Methods

Sediment Production

The quantification of sediment production from forest roads in the Rocky Mountain region has evolved considerably through the years, but generally began with the work of Megahan and Kidd (1972). In the Zena Creek Study in the 1960s, sediment data was collected below newly constructed roads using settling ponds built into the stream channel. A large rain-on-snow event in April 1964 produced a sizeable road-fill failure, generating the majority of the sediment collected during the study period. Megahan and Kidd concluded that 30 percent of the 6,030 ft^3 (171 m^3) of sediment measured in one watershed was due to road-related surface erosion and that overall erosion increased 770 times as compared to a reference watershed. The Zena Creek Study provides the baseline for data used in the R1-R4 model (Cline 1984).

Several paired basin studies compared small watersheds with various timber harvest treatments to undisturbed reference watersheds. Studies found substantial treatment effects (Fredricksen 1970; Beschta 1978; Ketcheson and others 1999) by measuring sediment accumulation in settling ponds that followed road construction and logging. Unfortunately, the signal from roads was not always easily resolved from the background rate and only coarse sediment could be captured by the in-stream settling basins. One limitation of the settling pond approach was resolved by moving the settling basin close to the road using a water tank (Ice 1986), allowing only road sediment and runoff to collect. Fine sediment sampling was also made possible with fractional flow splitting devices, such as the Coshocton wheel (Coote and Zwertman 1972), and automated pump samplers, such as the ISCO. Fractional flow splitting systems have the advantage of collecting a representative sample of all of the sediment in transport, but require an accurate flow record to calculate the total mass of sediment.

Reid and Dunne (1984) used manual flow and sediment concentration measurements below culverts, paired with precipitation measurements, to construct unit hydrographs and sedigraphs for road segments. This technique yielded valuable data on the impact of heavy-vehicle traffic, but required a substantial investment in field labor during peak flows to calibrate the sedigraph for the expected range of discharge. This technique records short-term transient impacts, such as traffic loading, but requires a significant number of sediment concentration measurements to produce hydrographs and sedigraphs that can be correlated with precipitation measurements to predict sediment production.

Several investigators have monitored sediment concentrations in channels above and below contributing road segments as a way of indirectly measuring road sediment inputs (Bilby 1985; Sullivan 1985; Anderson and Potts 1987; Bilby and others 1989). Bilby's Johnson Creek study in southern Washington used pump samplers installed above and below a road crossing to monitor suspended sediment and turbidity. Samples were collected four times daily and composited from sample sites located 100 meters apart and near the channel bottom. Riffle crest gravels were sampled above and below the sediment delivery location using a freeze-coring device to determine if sediment was being stored or mobilized. Although the road contributed 20.4 tons of fine sediment to the reach annually, no significant change in fine sediment storage was detected in this 2% gradient channel.

In addition, Sullivan (1985) documented 9 years of sediment concentration and turbidity measurements on the Middle Fork of the Santiam River in the Oregon Cascades in an 8000-ha watershed. Suspended sediment was sampled every 6 hours from the fifth-order channel above and below an area of active road building and timber harvesting. Discharge was measured at a USGS gauging station below the study reach and flow measurements were estimated at the upper station by correlating mean daily discharge. No significant differences in fine-sediment yields were detected at the two sample locations.

Finally, other researchers have mapped sediment trapped behind filter fabric dams and obstructions to estimate sediment transport below road drainage locations and fillslopes (Brake and others 1997; Megahan and Ketcheson 1997; Robichaud and Brown 2002; Ramos-Scharrón and MacDonald 2005; Coe 2006). A concern with filter fabric measurements is the unknown amount of material that passes once the filters are clogged with fine sediment. The volume of water stored in this situation makes settling of sediment less likely once the filtering capacity of the fabric has been filled. Trap efficiency is an issue with other techniques as well, and a combination of discharge and sediment concentration measurements can reduce uncertainty.

Measurements of Discharge

Once roads were found to play a pivotal role in generating fine sediment, the next logical step was to examine the hydrology of the road system. Measuring road hydrology is vital to understanding the sediment transport along roads and sediment delivery from roads to streams as well as the timing and amount of water that is intercepted and routed by roads. Knowledge of runoff from forest roads is derived from methods that were developed to measure open-channel flow. Early road plot studies relied on manual flow and sediment measurements collected at road drainage points (Reid and Dunne 1984). Other investigators have used weirs and flumes to measure discharge through a known cross section so that a stage-to-discharge relationship could be established and recorded by mechanical or electronic means (Ackers and others 1978; Brakensiek and others 1979; Replogle and Clemmens 1981; Bilby and others 1989; Kahklen 2001; Gilbert 2002).

To establish a stage-to-discharge relationship, stage is measured with a pressure transducer, magnetostrictive rod, or float and pulley system and recorded with a data logger. Stage-based systems are often paired with continuous samplers to collect suspended sediment and develop a relationship between discharge and the suspended sediment. Where appreciable quantities of coarse sediment are in transport in traction or as bed load, a settling basin or pit trap may be used upstream of the sampling location (Ice 1986; MacDonald and others 2001). Measuring flows with appreciable coarse sediment load with a weir may be difficult due to sediment and debris deposition, unsteady calibration, and plugging of the inlet to the stilling well or weir (Grant 1988). Ultimately, the cost of stage recorders and flume equipment, limited power availability, and the availability of trained personal may limit the widespread deployment of such systems.

Site Selection

A road has several important physical attributes that influence erosion and runoff. When selecting locations for plots to quantify local rates of sediment production, it is often best to select road segments that are typical of the local road system and landscape where the results are to be applied by inference or model. Plots should represent local geology, slope, construction, and maintenance practices as well as road surface and ditch vegetation. The slope should remain consistent down the plot so that sediment deposition does not occur in unexpected locations.

Road plots are also used to isolate and study the influence of a particular environmental or engineering variable as it influences sediment production. When one road variable is under investigation, all the other variables must be controlled to the degree possible, either by careful site selection or by treating the sites to reach a standard state. Road plot length, vegetation, grading practices, and surfacing may be standardized by manipulating the site. Other fundamental attributes of the road, such as gradient, cutslope height, and geology, must be selected in the field. Several important factors influence road sediment production rates:

- Road surfacing material
- Traffic level
- Road slope
- Flow-path length
- Rainfall intensity
- Soil erodibility
- Geology
- Ground water interception
- Road design
- Road grading

How Many Plots?

As with any study, it is vital to have replication of observations in order to have confidence that the results are not anomalous. One common objective of road sediment plot investigations is to obtain a general base erosion rate for the roads from an area that has similar geology and climate such as a U.S. Forest Service or Bureau of Land Management district. There are often little existing data on local road erosion rates on which to base calculations for the ideal number of plots, although inference can be drawn from studies done in similar environments (Megahan and Kidd 1972; Reid and Dunne 1984; Ice 1986; Bilby and others 1989; Kahklen 2001; Foltz and Trube 1995; Luce and Black 1999; MacDonald and others 2001, 2004; Coe 2006; Sugden and Woods 2007; Dubé and others 2011). Previous studies have used between one and five replicates for each treatment. The decision about how many plot replicates are required depends on the goal of the study and is an optimization to reduce the uncertainty in the erosion number while working within the available budget.

The desired length of record is another important factor to consider in the planning of a road sediment investigation. The goal of many road investigations is to quantify annual average erosion rates that occur with typical weather events. An approximation can be easily achieved with a few years of observations (fig. 3), but much of the sediment transport on roads occurs during a few infrequent storm events that generate runoff at high rates. These events are often associated with summer thunderstorms, rain on snow events, or hurricanes. It is necessary to maintain the study plots for as long as practical to increase the likelihood of recording these large events.

The long-term data that could be used to characterize the magnitude-frequency relationship for surface erosion from forest roads is not available. Observations of fluvial sediment transport (Wolman and Miller 1960) indicate that common runoff events occurring with a return interval of once or twice per year carry the majority of the sediment over the period of record. Forest roads that receive traffic have fine sediment that is readily available for transport under most runoff conditions. It is plausible that the magnitude-frequency relationships observed in small channels will apply to fine sediment transport from road surfaces; in which case, the bias from a short record may be less than expected. However, the impact of large storm events on road related landsliding, gully formation, and stream crossing diversions has been demonstrated to be profound (Wemple and others 2001). Collecting local precipitation data at the study site or co-locating sites near existing weather stations will allow for the assessment of precipitation effects.

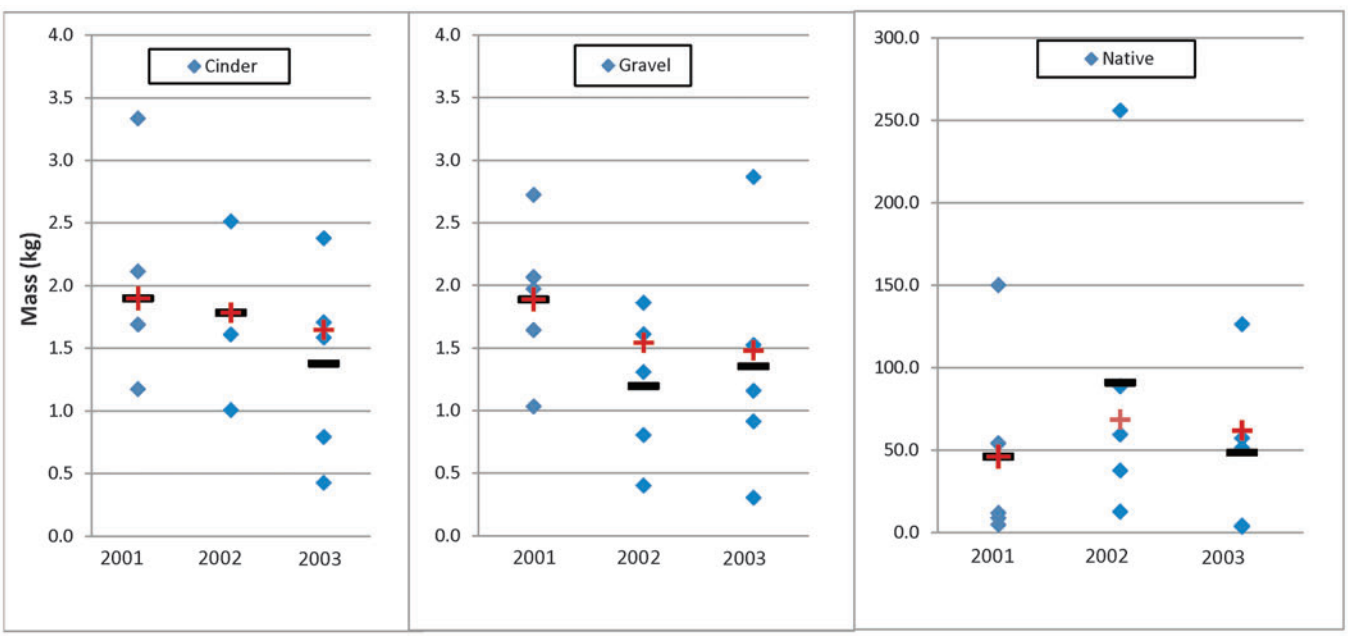

Figure 3—Sediment plot data from three groups of five plots in the Spencer Creek watershed in southern Oregon. Plots were similar in length and slope but had different surfacing material. Starting from the left panel, the road tread was surfaced with volcanic cinder (left), crushed basalt (center), and native material (right). The blue diamonds show the data, the black line the annual mean, and the red star indicates the cumulative mean.

The remainder of this report describes a simple and low-cost system for quantifying road sediment and water discharge that a field crew can install in a few days. The system consists of a bordered road plot, ditch inlet, and steel settling tank to capture sediment. A tipping bucket and a fractional sampler will quantify any runoff and fine sediment exiting the settling tank. Forest roads in the central Oregon Coast Range were selected to calibrate the instruments used to determine the total discharge of water and sediment from the road cut-slope, road running surface, and ditch. Although these plots are designed to be low cost and low maintenance, they will require periodic inspection, occasional maintenance, and data retrieval. The cost of the installation is approximately $1,800 for the coarse sediment settling tank plot and an additional $750 to capture the finest sediment and flow (see table 1 for details).

Table 1—Cost of five road sediment plots.

Materials	Units	Quantity	Cost per ($)	Extended cost ($)
Sediment tank, 330 gal galvanized steel [a]	piece	5	500.0	2,500
Pipe, 6 in plastic N12 pipe, each plot 90 ft	feet	450	2.0	900
Waterbars, conveyor belt [b,c]	piece	10	110.0	1,100
Waterbars, hardware		250	0.5	125
Waterbars, 2 by 6 in lumber	feet	400	1.1	440
Ditch inlet structure, section of 24 in plastic	feet	5	20.0	100
Load cell scale		1	200.0	200
Construction Equipment Rental				
Mini excavator	days	1	225.0	225
Riding trencher	days	2	250.0	500
Gravel packer	days	2	100.0	200
Labor				
Construction 3 person days per plot (@$18/hr)	days	15	144.0	2,160
Periodic plot maintenance (1 year)	days	3	144.0	432
Sediment tank weighing	days	1.5	144.0	216
Sub-total				**9,098**
Additions for tipping bucket system				
Tipping bucket and sediment collector [d]	5		300.0	1,500
Data loggers [e]	5		95.0	475
Reed switches [f]	5		30.0	150
Magnets [g]	5		7.0	35
Dry box enclosure	5		18.0	90
Labor ($18/hr)	days	2	144.0	288
Operational costs				
Downloading flow data device and maintenance (1 year)	days	8	144.0	1,152
Total (2013 U.S. dollars)				**12,788**

Vendor	Email	Address	Phone
[a] Pacific Corrugated Pipe	www.pcpipe.com	89822 Highway 99 North, Eugene, OR 97402	(541) 461-0990
[b] Motion Industries	www.motionIndustries.com	696 West Amity Road, Boise, ID 83702	(208) 377-4334
[c] Goodyear Rubber and Supply	www.goodyear-rubber.com	765 Conger Street, Eugene, OR 97402	(541) 686-9554
[d] Smitty-Bilt Industrial Fans, Inc.		32060 Herman Road, Eugene, OR 97408	(541) 343-7584
[e] Onset Computer Corporation	www.onsetcomp.com	P.O. Box 3450 Pocasset, MA 02559	(508) 759-9500
[f] Hermetic Switch Inc.	www.hermeticswitch.com	P.O. Box 2220 Chickasha, OK 73023	(405) 224-4040
[g] Texas Electronics Inc.	www.texaselectronics.com	P.O. Box 7225, Dallas, TX 75209	(214) 631-2490

Sediment Plot Construction Details

Sediment plots were sized to represent the characteristic flow path lengths for gravel-surfaced roads in the Oregon Coast Range (Luce and Black 1999). A detailed road inventory was collected on roads in Lake Creek watershed using the Geomorphic Roads Analysis and Inventory Package (GRAIP) (Black and others 2012; Cissel and others 2012) to document the structure of the forest road system and where it is hydrologically connected to the channel network. Based on the observed drainage spacing and the uniformity of road variables such as road slope and cutslope height, an 80-m plot length was selected as a typical unit for measurement.

Existing forest roads have variable cross sectional profiles and widths. The variability in width and drainage can alter the effective contributing area of the road. Insloping the road surface or applying a lateral berm made of gravel ensures that the entire road contributing area is captured at the lower boundary of the plot and by the inboard ditch. Considerations for selecting the capacity of the settling tanks and tipping buckets (Luce and Black 2001b) include rainfall intensity, groundwater interception, road construction variables, and road surfacing. The sediment plots described here produced flows in the range of 0-35 gal (132 L) per minute (figs. 4, 5). If plot runoff rates are expected to exceed this range, the design presented here can be scaled up or the length of the plot can be shortened.

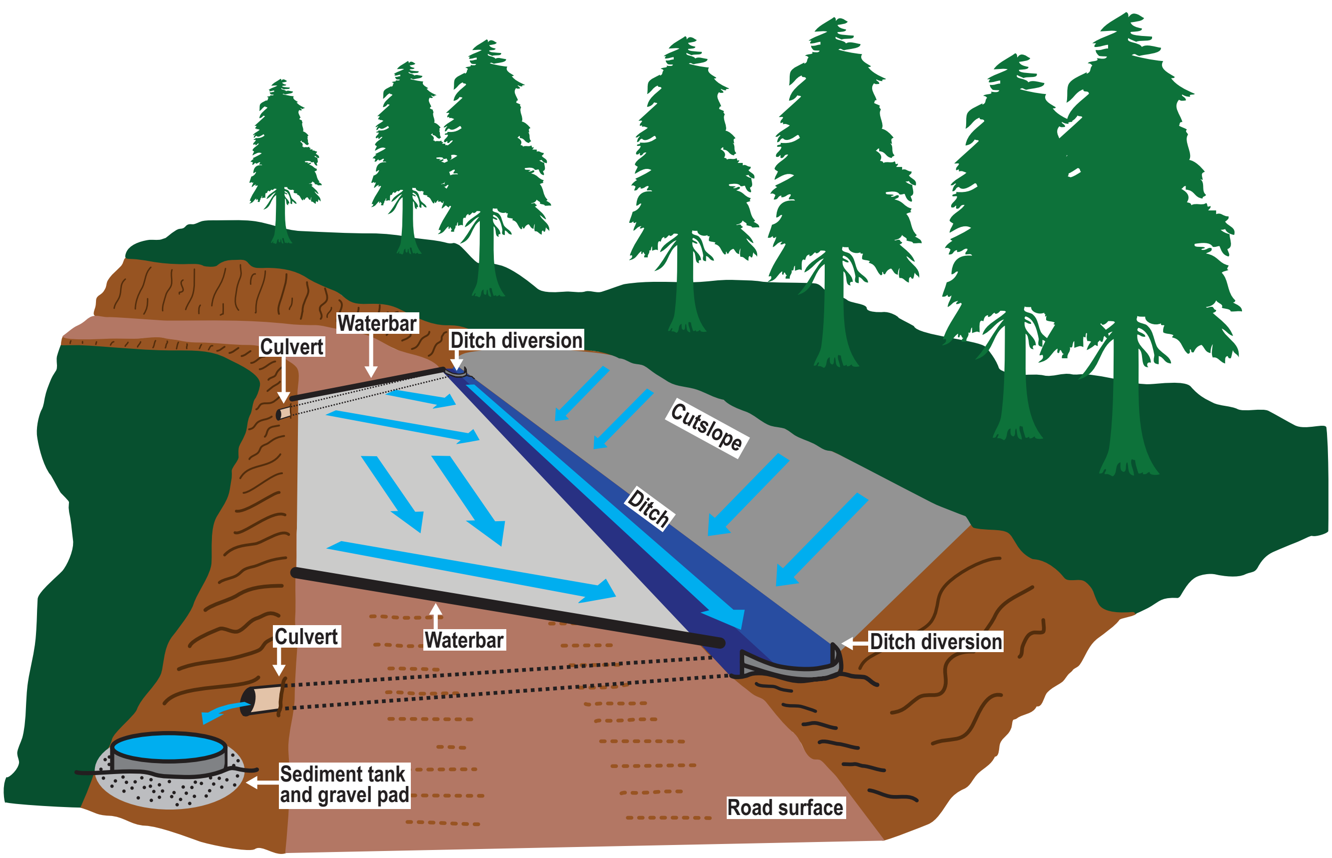

Figure 4—A runoff plot schematic showing flow directions, plot boundaries, and sediment tank.

Figure 5—A road runoff plot with ditch diversion inlet (in foreground) for the collection of runoff into the pipe.

Water bars were installed to divert flow coming down the road surface towards the ditch. The water bars were constructed of a 9.25 in (23.5 cm) wide by 0.38 in (1 cm) thick segment of fabric-reinforced conveyor belt bolted between two pressure-treated 2 in (5.1 cm) by 6 in (15.2 cm) boards (fig. 6). The five-ply conveyor belt material (two fabric layers between three rubber layers) should extend about four inches above the top edge of the wood. Each was installed at a 35-degree angle to the roadway in a narrow trench cut into the roadway with the aid of a mechanical trenching tool.

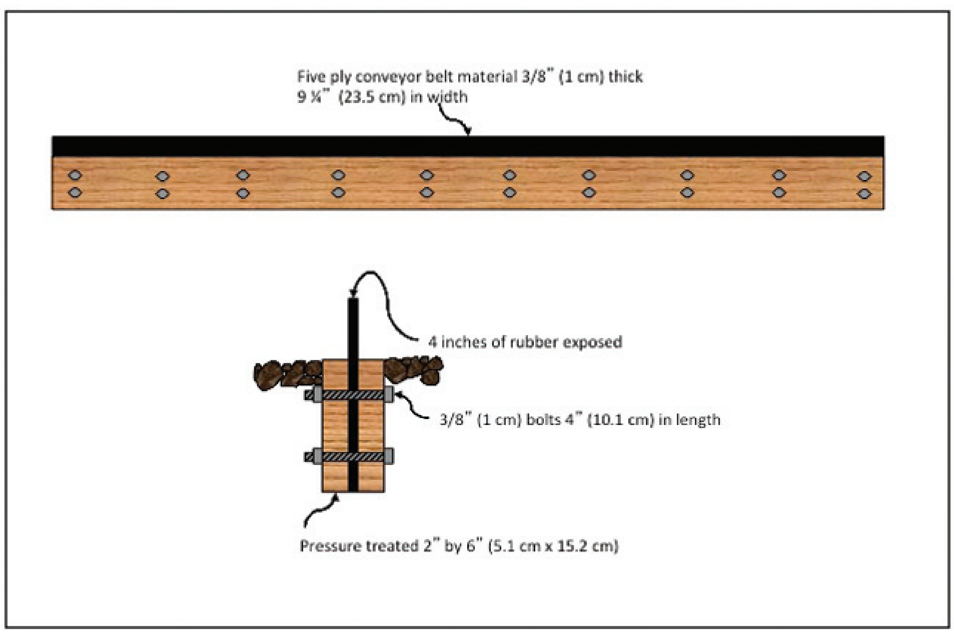

Figure 6—Detail of a waterbar fabricated from conveyor belt material and lumber.

The waterbar was installed with the top of the wood positioned at grade level, backfilled with gravel, and mechanically compacted in place, allowing traffic to move across the plots unimpeded at normal forest road speed. A similar waterbar was installed at the upslope end of the plot to divert flow off of the road segment. The ditch at the top of the plot was dammed then diverted to the fillslope through a 6 in (15 cm) inside diameter pipe with a smooth interior. Flow accumulating in the ditch at the lower end of the plot was diverted into a similar pipe using a corrugated steel or plastic half-round inlet structure with a concrete footing (fig. 4); the concrete footing may be replaced by well compacted fill material. The pipe was placed beneath the road with the aid of a riding trencher and exited the road on the fillslope, entering a 307 gal (1.16 m^3) steel settling tank (figs. 7 through 9).

The tank was placed in an excavated alcove cut into the fillslope of the road. For wet environments, the alcove may be floored with compacted gravel or concrete to allow for winter access. Adequate drainage is necessary around the tank location to prevent ponding of water. During precipitation events, runoff and sediment entered the open system settling basin where the coarse sediment settles from suspension. The tank continuously filled and overflowed through the outlet that routed the flow to the optional tipping bucket.

In arid landscapes the sediment tank will present an appealing water source for animals. This may result in some unexpected animal mortality as the water level drops below the edge of the tank, unless an escape ramp is provided. Various designs have been tested but a simple 6-foot t-post wrapped in hardware cloth was usable by most rodents and birds. Table 1 provides a list of the equipment and hardware that is required to install 5 typical road sediment plots and the cost in 2013 dollars.

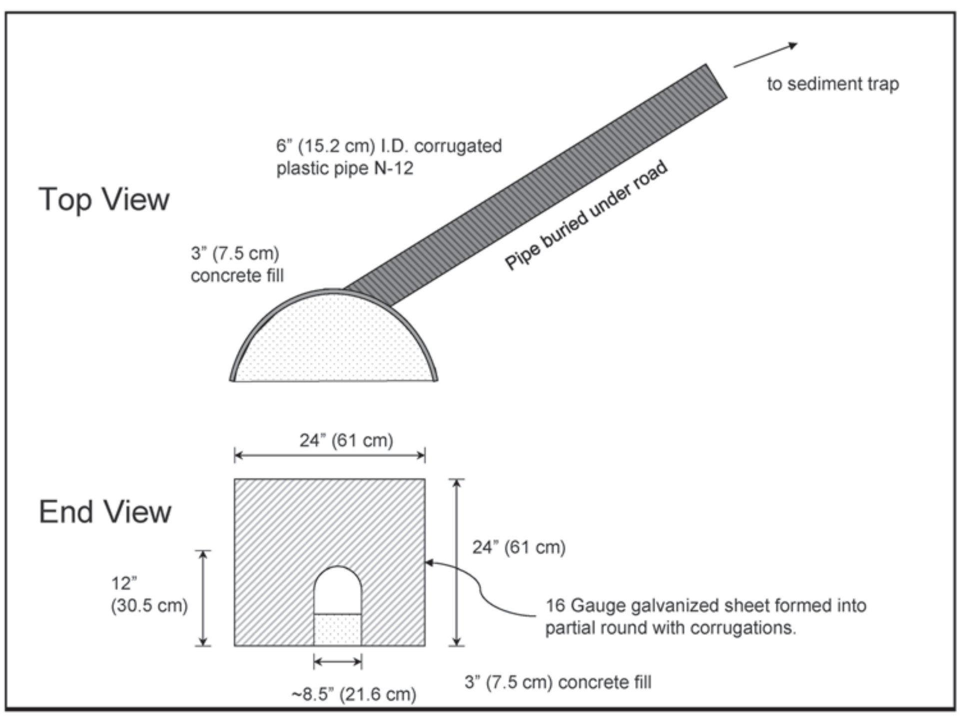

Figure 7—The ditch inlet structure collects water and diverts it to the settling basin.

Figure 8—The upper sediment tank is located on a gravel pod. The lower settling tank is located on a concrete pod behind a steel retaining wall.

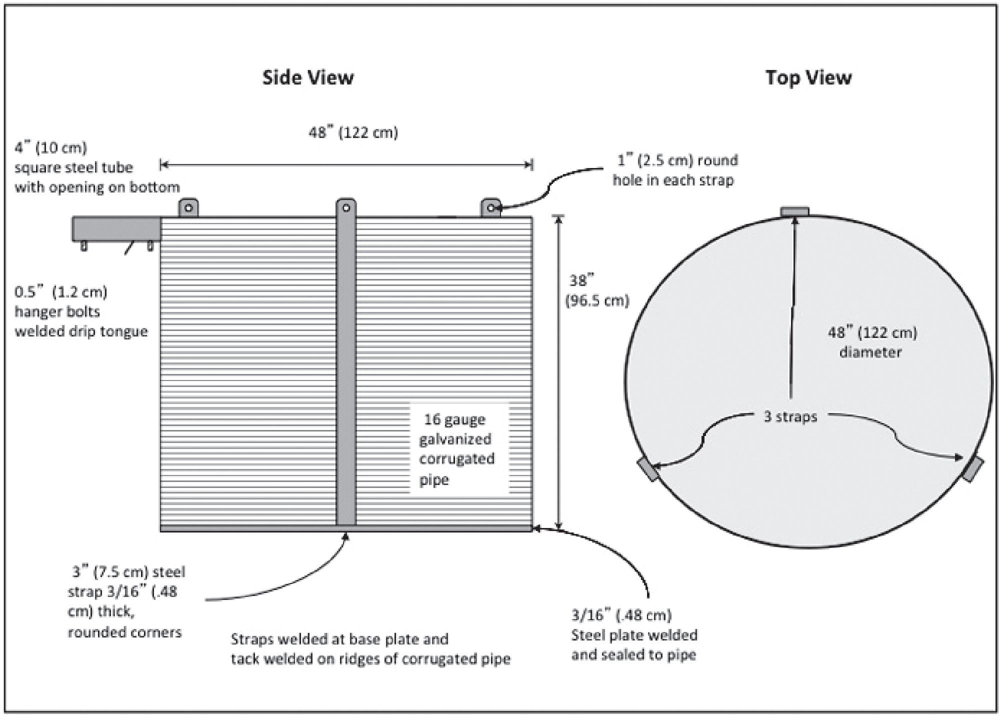

Figure 9—Detail of a 307 gal (1.16 m^3) steel sediment-settling tank with an outlet to measure discharge and lifting points for crane rigging.

Plot Maintenance

Properly installed sediment measurement plots will perform as designed for many years with periodic maintenance. Be aware that heavy traffic and large runoff events may cause road surface rutting, generating coarse sediment accumulation at the waterbars and ditch inlet where the flow velocity is reduced. The conveyor belt material used in the waterbars performs well for up to 5 years depending on the traffic loading. Where heavy truck traffic occurs, waterbars will need to be replaced or refurbished periodically.

The sediment settling efficiency of the tank will decline as it fills with sediment, causing unequal sediment collection in subsequent events. To prevent this from happening, inspect the plots on a monthly schedule throughout the runoff season and after large events to ensure that flow does not escape the plot boundaries and the settling tanks do not fill with sediment beyond half their designed capacity.

Methods of Sediment Measurement

Tripod Method

The sediment that accumulates in the settling tanks may be measured using several options. A robust and cost effective method was developed to weigh the accumulated sediment at the site for use at locations with less than 200 lb (90 kg) of sediment. Previous studies have attempted to collect the entire volume of sediment in sealed containers and transport it to a facility where it can be oven dried and weighed (Foltz and Truebe 1995). In other settling basin-based studies, volumes have been estimated using surveying techniques and using a density conversion factor (Megahan and Kidd 1972) to convert to a mass. When the sediment mass is large and plots are numerous, the sediment becomes quite cumbersome to handle and transport. A method was developed that uses the difference between the wet sediment and container mass and the mass of the container full of water, adjusted by the particle density, to yield a measure of the dry mass of sediment.

When the expected sediment sample size is less than 200 lb (90 kg) and there are fewer than 12 samples (replicates), the most efficient means to determine the sample mass is to use a portable scale system. The portable scale system uses a battery-powered load cell suspended from a surveying tripod to measure the sediment. This system is not only inexpensive to operate, but it does not require transporting the accumulated sediment to a lab facility for oven drying. Table 2 provides a general equipment list for the tripod weighing procedure. The recommended measuring interval is twice a year, at a minimum. During the site visits, record the observations of the site condition, any maintenance needs, and the sediment weights on the field form in Appendix A.

Measuring Sediment Accumulation—When measuring the sediment, carefully siphon or pump the excess water from the sediment tanks close to the level of the sediment surface. A 1-1/2-inch diameter siphon hose with a foot or check valve will drain the 307 gallon tank in less than 10 minutes. Avoid disturbing the sediment by keeping the siphon hose off of the bottom of the tank. Measure the average depth and texture of the sediment before removing it from the tank. Collect a representative sample of the sediment for particle density analysis.

Enter the tank wearing rubber boots and shovel the material from the tank into plastic buckets. Scrape the sides and bottom with a plastic scraper or brush to remove any material adhering to the tank. Collect all the material in the tank by tipping it on its edge and using water to flush the corners where sediment may be trapped. Transfer the plastic buckets filled with sediment to the road to measure with the tripod scale.

Fit the scale to a heavy-duty survey style tripod with a hook made from threaded rod. Hang a 100 lb (45 kg) capacity digital load cell from the hook. (The authors used an Intercomp CS 200 scale with a reported accuracy of 0.1 percent of full-scale range.)

Table 2—Tripod weighing equipment list.

Equipment	Equipment
Battery operated load cell 100 lb (45 kg) capacity, and spare	Pump, portable gasoline powered
Load cell battery and spare	Hoses for pump, suction and discharge
Survey tripod	Hose for water supply container
Load cell hanger hook	Pump fuel container
Steel leveling bucket	Tool box
Plastic buckets 3 gal (11 L) and 5 gal (19 L) sizes	Tape measure
Plastic scoops, two large	Digital camera
Plastic cup	Field book with data sheets
Squirt bottle	Sample bags, plastic 1 gal (4 L) size
Plastic scraper	Sharpies
Shovel, short handle flat blade	Pencils
Brush to clean inside of tank	Eye protection
Water supply (55 gal (208 L) drum or other)	Gloves
	Rubber Boots

Set the tripod up on the road above the tank. Turn on the load cell and let it stabilize for 10 minutes. When stabilized, hang the weighing bucket from the tripod using the central support ring attached to the load cell and turnbuckles. Adjust the tripod so that the weighing bucket clears the ground when suspended from the scale (fig. 10).

The weighing bucket can be precisely leveled using the three turnbuckles shown in figure 11. First, fill the bucket with water and measure the weight of water and the container (M_2). Then, level the bucket by filling it to the spill point and adjusting the turnbuckles so that water spills out in equal volumes from each of the three sections defined by the attachment points. When close to level, a half turn adjustment of the turnbuckle is sufficient to make an appreciable difference in height. The authors found it generally easier to raise the lowest of the three sides (the one with the most flow) rather than lowering the two that have the least flow.

Check the level of the water surface by slowly pouring a small volume of water from a cup into the bucket. When water spills evenly from each of the three sections, the bucket is level. Once the bucket is level, carefully add a small volume of water to the bucket, and record this measurement after 5 seconds settling time. We have found this to be a measurement reproducible to within 0.1 lb when repeated measurements were made at a site. This measurement is the M_2 value that represents the mass of water and bucket. You will take this measurement at the start of each sampling day to check the portable scale and the precision of the system. The M_2 value should not vary significantly over the course of a day.

Figure 10—Measure the sediment using a fiberglass survey tripod fitted with 100 lb (45 kg) capacity load cell.

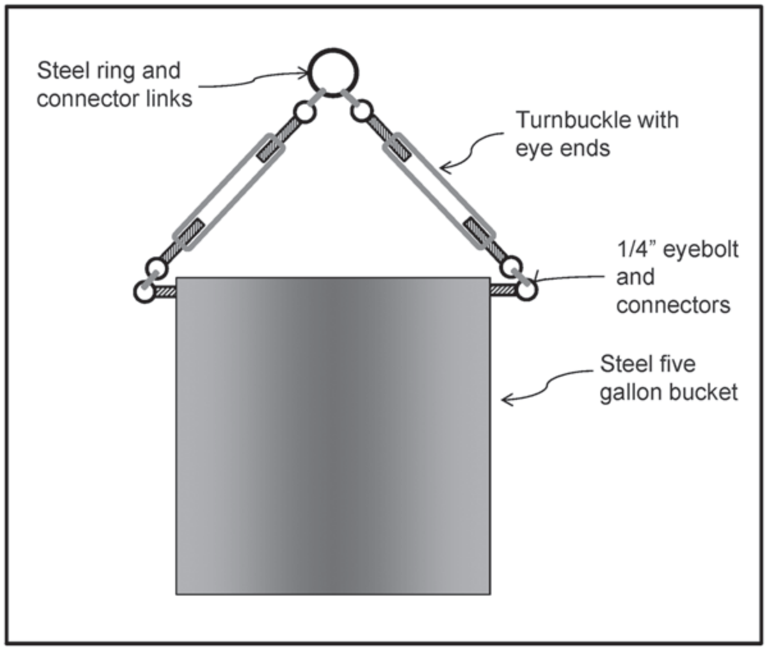

Figure 11—Fabricate a sediment weighing container from a steel 5-gal (22 L) bucket with three evenly spaced lifting points located equidistantly around the upper rim. The three turnbuckles are used to level the top edge of the bucket.

To measure the sediment, use the same process as with the water except fill the weighing bucket with the excavated sediment to a level close to full. Add clean water to reach the full level (as defined above) and top it off with a small volume of water until it spills evenly. Once level, wait 5 seconds for the scale to stabilize before recording the reading as M_1. Repeat the process until the entire sample is measured. Clean the weighing bucket thoroughly between measurements to prevent sediment carryover.

Calculate the mass of the sediment using the difference of M_2 from M_1 as shown in equation 13. Collect a 1 lb (0.5 kg) representative sub-sample of the sediment, label it and dry it for later use. The samples will be used in the lab to determine the sediment particle density ρs using a picnometer (Blake and Hartage 1986). The particle density is used in the conversion from wet to dry sediment mass and is a function of the mineralogy of the sediment and will vary with the geology.

Using the portable scale system to weigh sediment from a tank has proven to be repeatable and sufficiently accurate when tested in the field. To verify the precision of the full water tank measurement M_2, the authors made seven measurements of the mass of water under the same conditions. The average of the repeated observations with the tripod system was 47.15 lbs (21.4 kg) and the values varied over a range of 0.35 lb (0.16 kg).

Crane Method

If the sediment mass is expected to exceed 200 lb (90 kg) per sample, or if a large number of sites are being monitored, a more efficient means of moving and measuring the sample is required. A truck-mounted crane proved suitable for lifting, moving, and weighing sediment tanks up to 5,000 lb (2,268 kg).

Sidebar 2: Equations that are used to calculate the mass of the sediment.

Mt = mass of the sediment tank, kg

Mw = mass of the water, kg

Ms = mass of the sediment, kg

ρs = particle density of sediment in kg/m^3

ρw = density of water at the observed temperature, kg/m^3

$M1$ = observed mass of the tank, water, and sediment, kg

$M2$ = observed mass of the tank and water, kg

Vw = volume of water, m^3

Vs = volume of sediment in, m^3

Note that $M1$—the **observed mass of the full tank of sediment**—is comprised of the mass of the tank, sediment, and water, or

$$M1 = Mt+Mw+Ms \quad (1)$$

The **observed mass of the tank full of water** is comprised of the mass of the tank and the mass of the water, or

$$M2 = Mt+Mw+Ms \quad (2)$$

The masses of the sediment and water are the product of the **densities** and **volumes**.

$$Mw = \rho wVw \quad (3)$$

$$Ms = \rho sVs \quad (4)$$

The **mass of the total system** can be written using equations 1, 3 and 4.

$$M_1 = Mt + \rho wVw + \rho sVs \quad (5)$$

The **mass of the tank with water** can be written using equations 2 and 3.

$$M_2 = Mt + \rho wVt \quad (6)$$

The **volume of the tank** can be described in terms of the sediment and water.

$$Vt + Vw + Vs \quad (7)$$

Substituting equation 7 into equation 6 yields:

$$M_2 = Mt + \rho w(Vw + Vs) \quad (8)$$

Taking the difference between equation 8 and 5 eliminates the tank and water mass terms.

$$M_1 - M_2 = \rho wVw + \rho sVs - \rho w(Vw + Vs) \quad (9)$$

$$M1 - M2 = \rho wVw + \rho sVs - \rho wVw - \rho wVs \quad (10)$$

$$M_1 - M_2 = Vs\,(\rho s - \rho w) \quad (11)$$

Expressed in terms of the volume of sediment:

$$Vs = \frac{M_1 - M_2}{(\rho s - \rho w)} \quad (12)$$

Substituting equation 4 to rewrite in terms of the **mass of sediment**.

$$Ms = \rho s\frac{M_1 - M_2}{(\rho s - \rho w)} \quad (13)$$

The mass of sediment is determined using equation 13 for both the crane and the tripod method.

The crane-based system was used on disturbed road plots that produce as much as 2 tons per plot year. For the disturbed road plots, a 10,000 lb (5,000 kg) capacity battery powered S-beam load cell (Dillon model ED 2000) was used, with a reported accuracy of 0.1 percent of full-scale range. A 12 ton truck-mounted crane was used to lift, manipulate, and empty the sediment tanks (figs. 12, 14).

Tanks were lifted from their top edge using three welded lifting points shown in figure 14. The load hook on the crane cable connected an alloy ring to the load cell via a shackle. Attached below the load cell were a roller-bearing swivel, spreader bars between the 3 chain legs, and a turnbuckle in line with each chain leg (figures 13 and 14). Similar to the portable scale system, the turnbuckles allowed the tank to be precisely leveled under load. To ensure the accuracy of the weighing process, the system was calibrated using a 1,000 lb (453.6 kg) steel test weight at the start and end of each day's sampling.

Figure 12—A crane and load cell system is used to weigh large sediment samples. Note the water supply tank mounted on the bed of the crane.

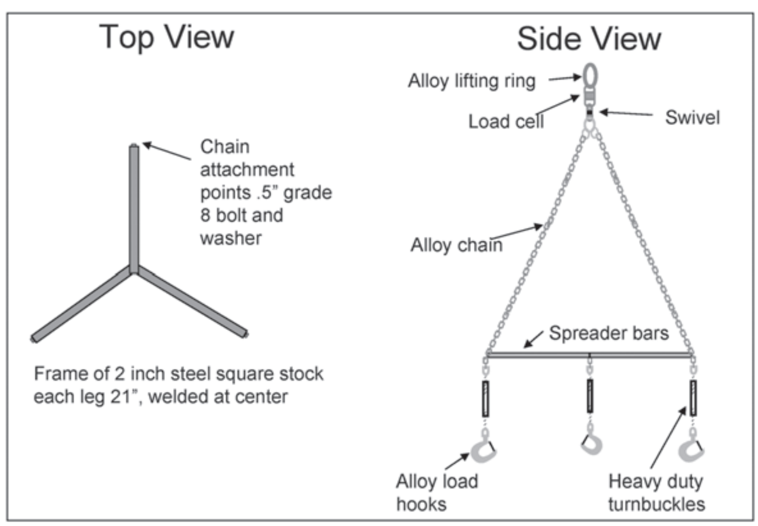

Figure 13—Top-view and side-view details of tank lifting, leveling, and weighing apparatus used with the crane.

Figure 14—A sediment collection tank is suspended from a crane by a radio-linked load cell. Notice the load distribution frame, turnbuckles used to level the water surface, and steel tipping bars below the tank.

A large supply of water was required to fill and clean the tanks, so an 800 gal (3,028 L) water tank was mounted on the bed of the crane truck and a portable gas powered pump transferred water to and from the settling basins. (See table 3 for a general equipment list for the crane weighing procedure.)

After the crane was moved as close to the collector as possible, but in a safe location on the road surface avoiding areas of soft fills, it was leveled and stabilized. Railroad ties were used to build solid footings and a level platform on which to spread the load from the hydraulic outriggers. The bed of the crane was leveled to within 1 percent in all directions, as recommended by the manufacturer. The tank lifting assembly was attached to the crane hook, and the weighing system and lifting mechanism was set to zero. For safety purposes, a signal person stood nearby to help the crane operator direct the lifting of the sediment-laden tanks from the retaining wall enclosure to the roadway where the measurements were made.

Table 3—Crane weighing equipment list.

Equipment	Equipment
Radio linked load cell 10,000 lb (5000 kg) capacity	Pump fuel container
Spare batteries for load cell and receiver	Tipper bars
Rigging and spreader bars for crane	Railroad ties, 16
Plastic buckets, 5 gal (19 L)	Tool box
Plastic scoops, two large	Tape measure
Shovels, long and short handled with flat blade and spade	Field book with data sheets
Pulaski	Sample bags, plastic 1 gal (4 L) size
Brush to clean inside of tank	Sharpies
Water tank	Pencils
Pump, portable gasoline powered	Leather and rubber gloves
Hoses for pump, suction and discharge	Hard hats
Hose for water supply container	Rubber Boots
	Eye protection
	Digital camera

The tank containing the sediment was topped off with clean water and leveled using the turnbuckles (this procedure is described in the section on the tripod method). The mass of the tank, water, and sediment were recorded from the calibrated load cell. The temperature of the water is recorded to correct for the density difference in water that can influence the large volume in the tank. If the difference between the temperature of the M_1 and M_2 sample is less than 5 °C the density effect is expected to be less than 1 kilogram (see Appendix B).

The tank was lowered onto a pair of heavy gauge steel C-channel brackets that were used to support the tank while it was being tipped over to empty the water and sediment. The sediment tank tipping supports are composed of two pieces of 3 in (7.6 cm) C-channel welded into an L shape with heavy duty lifting eye bolts attached to each of the horizontal legs of the L as shown in figure 15. These eye bolts were attached to the

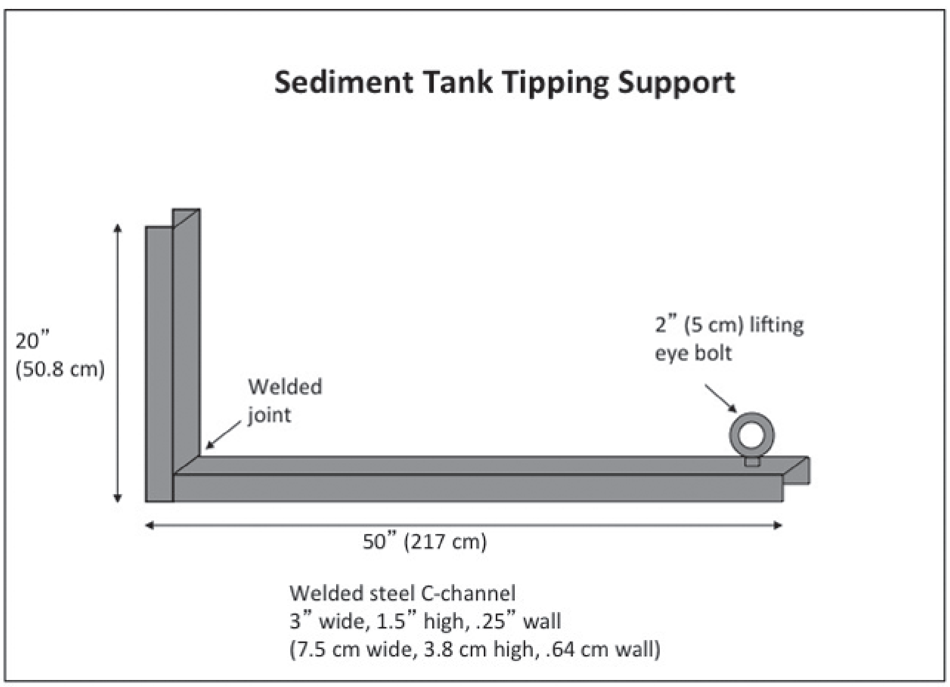

Figure 15—Detail of the steel bars installed beneath the sediment tank as tipping support.

crane using the hooks on the spreader frame and the tank was slowly lifted on one side. The vertical side of the L supports the tank as it rotates and gently spills the water and sediment out of the tank onto the road shoulder vegetation (fig. 16). The hooks must have safety retainers that close under spring tension so that they do not slip from the lifting eye bolts as the load shifts.

To determine the sediment particle density, and therefore, the true dry mass of the sample, a composite sample of the sediment was collected from various depths in the homogenized mass at the bottom of collector. The tank was cleaned with a shovel and a fire hose driven by a small gasoline powered impeller pump (avoid emptying the tanks near stream channels). Blocks and railroad ties prevented the tank from rolling during the cleaning process.

To verify the system's ability to measure the mass of a known amount of sediment *Ms*, the authors tested the system using 300 lb (136.1 kg) of clean graded-quartz sand with a particle density of 2.65 g/cm^3. The initial mass of tank plus water and sand was 2,987 lb (1,354.9 kg). The mass of the tank and water was 2,804.9 lb (1,272.3 kg). In this test, the calculated mass of the quartz sand was 300.5 lb (136.3 kg), resulting in a

Figure 16—A sediment tank is tipped over for sediment sampling. Note the L-shaped bars that support the tank during the sampling.

0.5 lb (0.2 kg) error. The error likely includes the uncertainty from the load cell, meter, and imperfect tank leveling.

With the cleaned tank in the upright position, it was refilled by gravity flow from the water reservoir on the crane bed. The filled tank was leveled and a second reading was recorded from the load cell meter for the mass of the tank and water M_2 and water temperature

Field crews found an efficient way to recycle the water at the end of the weighing process by lifting the tank above the crane and siphoning the 307 gal (1,162 L) of water back into the reservoir using a large-diameter rubber suction hose. The empty tank was then placed in an upright position on the pad for the next sample.

Sidebar 3: Working with heavy tanks.

When lifting, moving and emptying the tanks, it is necessary to exercise caution as they are extremely heavy and can easily injure a person in their path. The authors recommend obtaining the proper training before operating heavy equipment and using the recommended safety equipment.

In an inelastic collision, momentum is conserved; so

$$M_2V_i = (M_2 + M_p)V_f$$

Where M_2 is as defined earlier, V_i is the initial velocity of the swinging tank, M_p is the mass of a person attempting to slow the tank, and V_f is the final velocity of the tank-person system. The final velocity is

$$V_f = V_i\, M_2/(M_2+M_p)$$

If the mass of the person were about 1/10 that of the tank, the final velocity would be about 91% of the initial velocity.

Tipping Bucket System for Flow and Fine Sediment Measurement

The trap efficiency of the settling basin system alone may be sensitive to several factors including the particle size distribution of the sediment supply and the flow rate through the tank. The particle sizes available for transport may be the most easily measured variable; in particular, clay size particles have a very slow settling velocity once suspended and will produce low trap efficiencies in a small settling tank system. Similarly, when there is minimal ground disturbance on a plot, production of coarse sediment will be low, and trap efficiency may be low simply because all particles are fine.

Sediment trap efficiency is defined as the retained mass of sediment in a sampler divided by the known true mass delivered to the sampler. The effects of trap efficiency on experimental outcomes can be illustrated by considering a simple experiment comparing trap efficiency under various intensities of road traffic and grading under natural rainfall on a silty clay-loam soil. Ditch grading mobilized a substantial supply of sand-sized aggregated soil particles that were readily trapped in the settling basin. Heavy truck traffic, on the other hand, produced finer sediment sizes that passed through the settling basin but were observed in the suspended sediment splitter. The range of sediment tank trap efficiencies for 307 gal (1162 L) tanks on silty-clay loam soils from the traffic experiments showed a low of 21 percent of total sediment retained for light traffic treatments with no grading. The trap efficiency for light traffic with ditch grading was 68 percent. If traffic is an important contributor to sediment (e.g. because of wet weather haul), addition of fine sediment measurement capacity may be important. The settling tank system addresses the immediate need to quantify the sediment (approximately greater than 0.1 mm) generation from a typical forest road system. However, with a small additional investment, a great deal more hydrologic and fine sediment information may be gathered.

To understand the fine sediment budget of plots, and the timing of that sediment generation, the sediment trap system can be modified to include the measurement of flow and suspended sediment concentration. The minor increase in cost greatly increased the utility of the system to cover a broad range of problems and environments. This is especially true when soil textures are predominantly fine and the plot receives little disturbance that would generate coarse material. Fine sediment has been repeatedly found to be elevated during periods of heavy truck traffic (Reid and Dunne 1984; Coker and other 1993; Foltz and Truebe 1995; Black and Luce 1999). When an appreciable portion of the sediment transport is finer than fine sand, others have also noted the need to add a system for measuring flow (Edwards and others 1974; Hollis and Ovendon 1987; Kahn and Ong 1997) and fine sediment concentration to the basic settling basin road plot.

Design Overview

The tipping bucket uses a container divided into two equal volumes that are balanced about an axle. Incoming water enters one side of the container or bucket at a time, and as the bucket fills, the system becomes unbalanced and the heavier side tips and empties as shown in figures 17-19. As the bucket rotates to empty, a magnetically actuated reed switch records the passage of a magnet that is attached to the side of the container. Once the device has rotated, the opposing side is now in position to collect incoming flow and the process repeats itself.

A data-logging device in a waterproof case was connected to the reed switch; in this case, an Onset Hobo Event or Pendant data logger was used. Each time the magnet passed the reed switch, a circuit closed causing the data logger to collect a time stamp. The device was calibrated to determine the relationship between discharge and switch closures because the relationship is somewhat dependent on the setup and leveling of the device. The calibration was then applied to the record and a high resolution continuous hydrograph was created.

Figure 17—A 20 gpm (76 lpm) tipping bucket and flow splitter in operation.

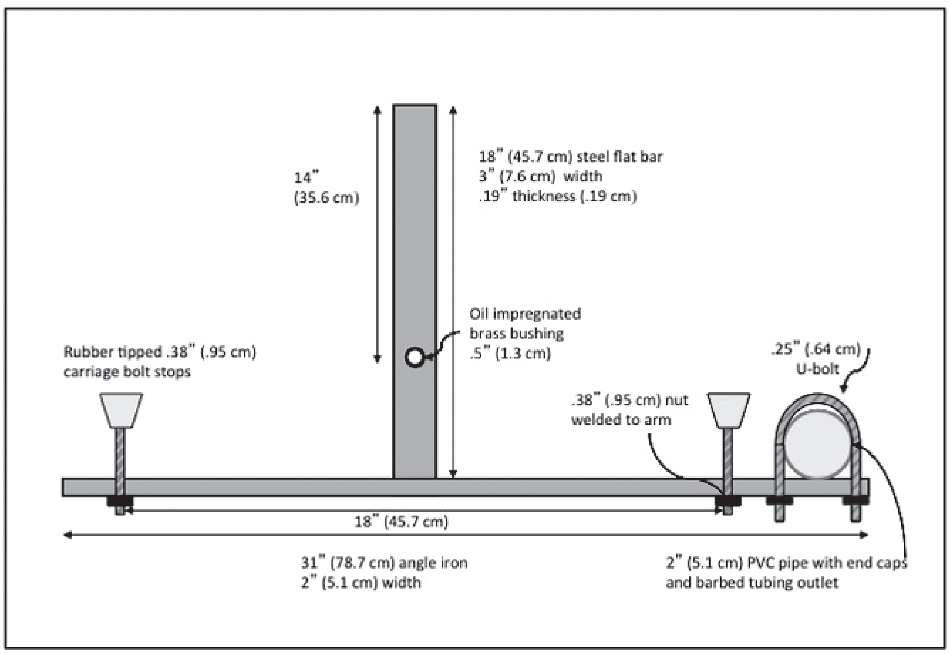

Figure 18—Detail of a hanger assembly and sediment splitter for a tipping bucket.

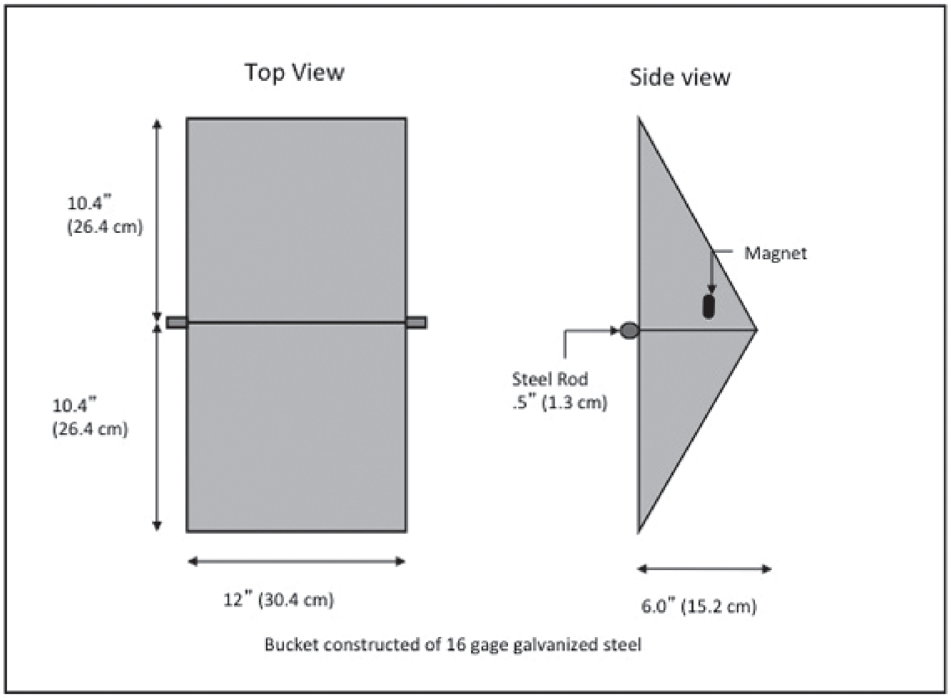

Figure 19—Top view and side view details for a small tipping bucket for measuring flows less than 20 gpm (76 lpm).

One side of the tipping bucket was arranged to spill over the top of a piece of pipe with one or more slots cut into it with a fine saw blade (figs. 20, 21). This effectively subsamples a few drops of water from each cycle of the tipping bucket. The subsampled water was routed to a collection bucket. The sediment concentration of the water in this bucket was measured, providing an estimate of the average sediment concentration of the flow exiting the tank.

Designs and Costs

Tipping buckets are designed to be durable and sufficiently adjustable to accommodate a variety of field installations, while minimizing complexity and cost. Tipping buckets such as those described here are generally not commercially available so it may be necessary to have them fabricated. Both the small (figs. 17-19) and medium-sized buckets (figs. 20-22) are suspended from the tank outlet. The small bucket size can be used to measure discharge of up to 20 gpm (76 liters) and the medium size is suitable for flows up to 35 gpm (133 lpm). Fabrication costs were in the range of less than $200 for the small bucket, and approximately $300 for the medium size (figs. 19, 20. The large free-standing model supported flow rates as high as 60 gpm (227 lpm) and was more durable, and fabrication costs were about $600.

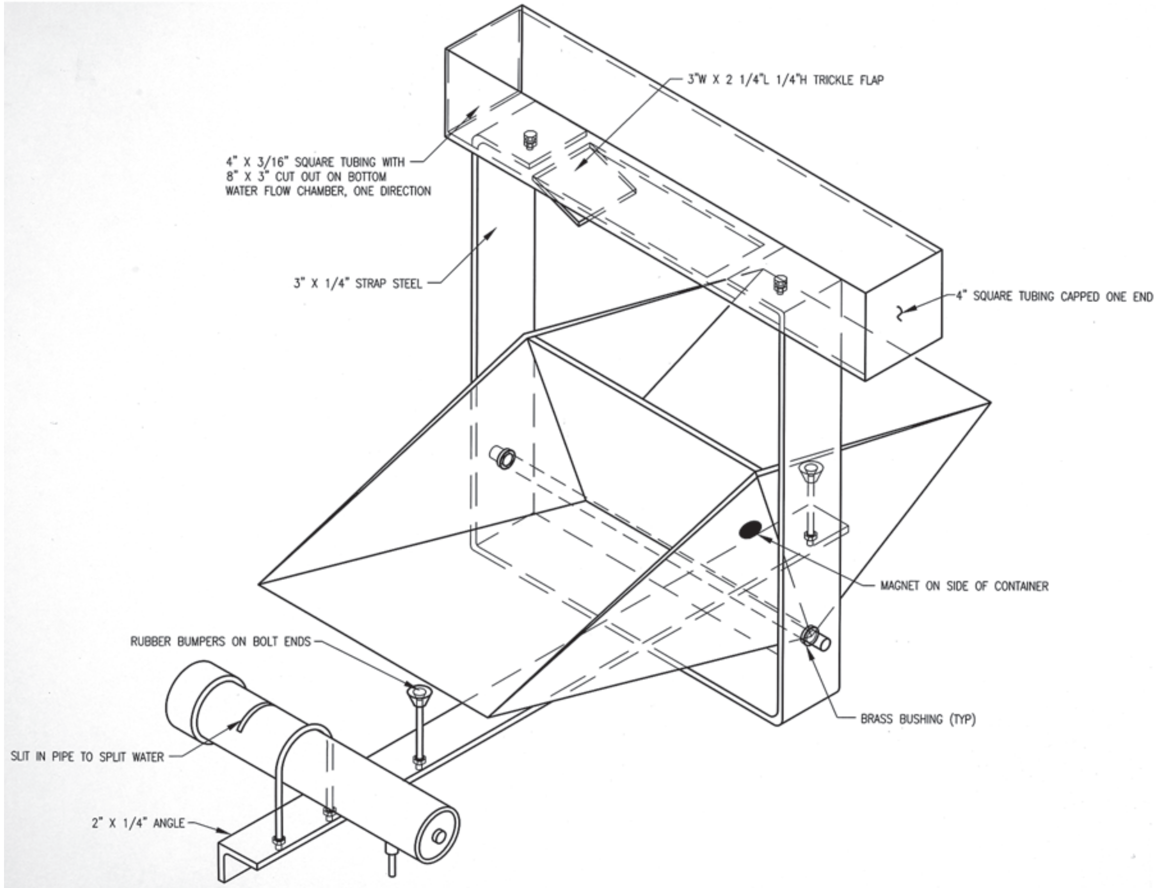

Figure 20—An isometric view of the medium-size tipping bucket and attachment to tank outlet.

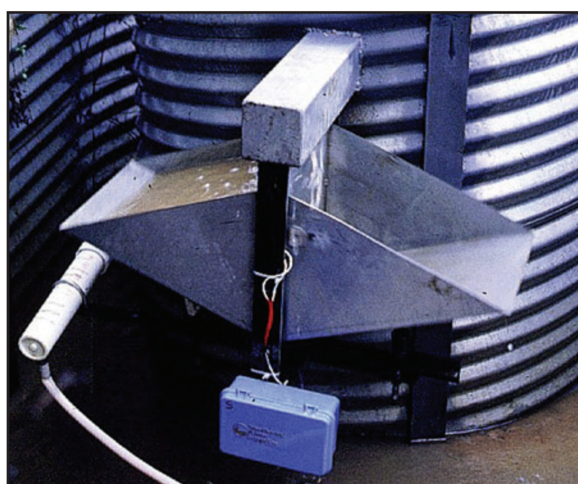

Figure 21—A medium-capacity tipping bucket and flow splitter in mid-cycle.

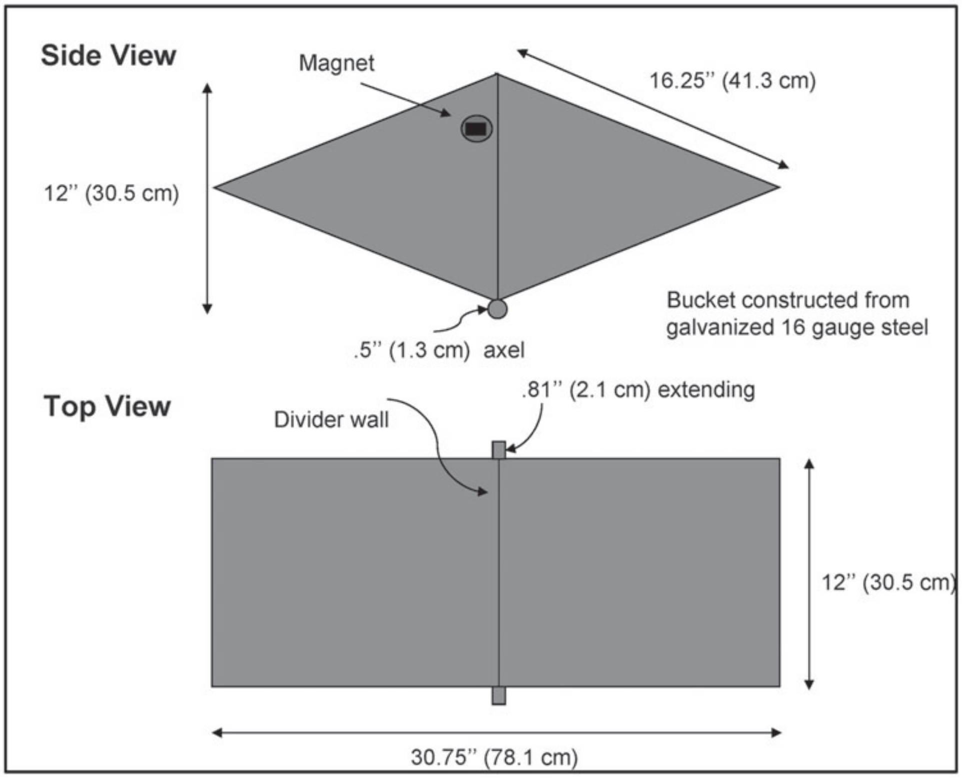

Figure 22—Side view and top view of specifications for a medium-capacity bucket.

The support frame, constructed from steel flat bar, hung from the tank outlet and was suspended from two 0.5 in- (1.2-cm) bolts from which the small and medium buckets were suspended. Each bucket was constructed of welded 16-gauge galvanized sheet metal sealed at the seams. The pan was welded to a half-inch (1.3 cm) rod that acts as an axle. The buckets were connected to the frame by inserting the rod through a brass bushing in the frame before the frame assembly was hung from the bolts on the outlet of the tank. Adjustable rubber stops on the frame were used to set the travel of the tipping bucket pan. The stops were constructed from carriage bolts with a rubber crutch tip glued to the round head of the bolt. They attached to a transverse arm on the frame by a nut welded in place, and secured by a second nut.

A variety of data loggers are available on the market, with new models appearing each year. At the time of this tipping bucket design, the authors selected the Hobo Event logger[1] for its ease of use, durability, and value. To select the appropriate-size data logger, consider the number of tip records that will be produced by dividing the expected plot discharge by the effective tipping bucket volume.

[1] The Hobo Event logger has a memory capacity of up to 8,000 switch closure events or roughly 6,000 gal (26,430 L) of discharge with the small-size bucket at 0.75 gal (2.8 L) per tip. The medium size device holds 1.1 gal (4.2 L) per tip or 8,800 gal (33,312 L). The largest size device holds 3 gal (11.4 L) per tip and will record 24,000 gal (90,720 L) of discharge. The Hobo Event has been replaced by the Hobo Pendant logger, which has a similar event storage capability.

The ideal size bucket can be determined for the desired application based on the three existing designed sizes. It is conservative to select a larger volume bucket to ensure that peak flows are within the recordable range. Low flow resolution may be compromised if the bucket size is excessively large.

The reed switch is a critical component of the system that registers the motion of the bucket. A high quality reed switch is available from Texas Electronics (S1-128), (see table 1). This device is less prone to errors associated with the passage of the magnet. Inexpensive but low quality reed switches were found to be prone to switch flutter, which resulted in rapid multiple closures from a single magnet pass. This situation can occur with any reed switch depending on the proximity of the magnet, but can be rectified by setting a tolerance in the data logger. A filter setting that ignored signals closer together than 2 seconds was used. The switch and wiring assembly is epoxied to the inside of the frame and the magnet is epoxied to the side of the bucket in such a way that it passes directly across the switch (within a millimeter) when the bucket spills.

The data logger is connected to the leads of the reed switch and sealed into a watertight container. A waterproof container purchased from a white-water outfitter was used with a watertight cable entry. A desiccant package and humidity indicator were used in the dry box to keep the electronics dry. The enclosure assembly is attached with Velcro to the front of the tipping bucket frame (fig. 21).

Installation

The bucket and the frame that make up the tipping bucket device are assembled in the field. Insert the axle of the pan assembly into the brass bushings with the proper number of spacer washers to position the magnet and the reed switch within 1 millimeter of each other. Use thin brass spacer washers to fine tune the switch to magnet location. The fine tuning is accomplished by trial and error. Verify the magnet to switch location by attaching a voltmeter to the plug for the data logger and checking for a single signal with each pass of the magnet. Once installed, test the device with the data logger in place to verify that a single time stamp is generated from each pass of the magnet.

Adjust the level of the device across the two sides of the bucket by using the adjustable bumpers so that each side holds approximately the same volume of water. Level the bucket in the opposite direction by placing spacer washers on the hanger bolts. When the lock nuts are tightened onto the hanger bolts, the bucket should operate freely without contacting the frame.

Tipping buckets have been used with success in areas that receive moderate snow accumulation, but this requires additional protection for the device. The challenge is to ensure that the device is not frozen when snowmelt begins. Building a small peaked roof enclosure over the device and the settling basin will limit the problems encountered with ice and snow interfering with the free flow of water and the movement of the tipping bucket.

Calibration

As each field installation is unique and the leveling of the device influences the capacity of the bucket, calibrate each device in place. Create a dynamic calibration curve for each tipping bucket gauge (Kahn and Ong 1997) by running a known discharge through the system and recording the observed number of cycles of the bucket. Verify manual observations of tips against the data logger record. A fire truck may provide a convenient water source and an industrial water meter can be used to measure the volume of water. A brass positive displacement type water meter with a measurement increment of gallons can be obtained from a plumbing supplier for about one hundred dollars. Use a stopwatch to measure the time. Create the calibration curve from at least three discharge measurements within the range of expected flows for the site. It was noted that for the smaller capacity tipping buckets, flows above 20 gpm (76 lpm) sometimes caused erratic behavior of the bucket due to the force of the falling water. The devices were calibrated at the beginning and end of the measurement period. This calibration is recommended to account for any changes in the adjustment of the system and variation in the friction on the axle.

Maintenance and Data Collection

Download the data logger frequently so that the memory does not fill during storm events. In order to ensure data integrity, the data were collected twice monthly and after large events and maintenance was performed at the same interval. The data were downloaded to a Hobo Shuttle logger in the field or directly to a laptop. Change desiccant packages at each visit and check the operation of the tipping bucket mechanism for freedom of motion. Use a dry lubricant such as graphite on the bushing as necessary.

During the 2 years of data collection, the system operated well but a few problems were encountered. Initially, moisture was encountered in some data logger enclosures despite the double gasket sealed enclosures. A 50 gram charge of desiccant was kept in the dry box enclosure and a charge sized to fit inside the case of the data logger itself was used. Frequent desiccant changes and the use of an umbrella when opening the enclosure in the rain reduced the humidity related problems. Humidity indicator paper was kept in the enclosure.

Several of the medium-size tipping buckets were damaged during a high intensity runoff event. Initially, 0.38 inch (1 cm) diameter bolts were used to secure the frame but they did not provide enough resistance to support the device in place when the flow reached high rates. When the hanger bolt size was upgraded to 0.5 inch (1.3 cm) and secured by nylon lock nuts the problem did not reoccur. The free standing design was created to eliminate the instability encountered at high flows and to reduce the potential for calibration drift (figures 23 and 24). This design improvement is worthy of consideration for designs of all sizes.

Figure 23—A large free-standing tipping bucket with a pipe directing the flow to inlet.

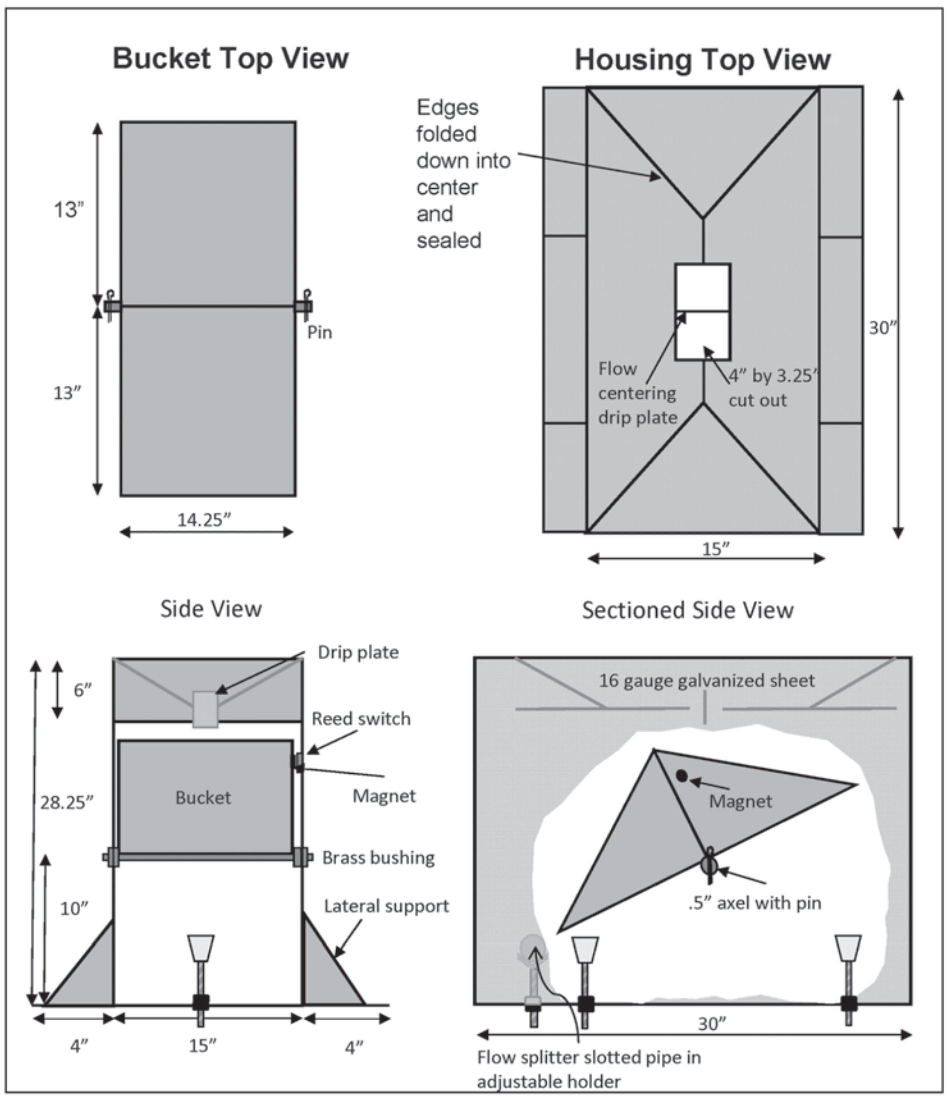

Figure 24—Multiple views of specifications for a large-size free-standing tipping bucket.

Fine Sediment Collection

A flow splitter was used to quantify the sediment that was exiting the settling basin at high flow. A sub-sample of the discharge from one side of the tipping bucket was collected using a 1.5 inch (3.75 cm) diameter segment of PVC pipe attached to the cross arm of the tipping bucket frame below the lower edge of the bucket (see figs. 20 and 21). The ends of the pipe were capped and a plastic barbed hose fitting was epoxied to the lowest point. A single narrow slit was cut in the pipe with a hacksaw blade so that when the bucket discharged water across the pipe, a 5 ml sample of water and suspended sediment was collected. This sample was routed through the inclined pipe and into a piece of rubber tubing and collected in a sealed 5 gal (19 L) bucket with an air vent made from a small 90 degree plastic barbed fitting.

The sub-sample water reservoir was examined each time the discharge data were collected (fig. 17). A sub-sample was taken and the reservoir cleaned if more than a gallon of water had accumulated. The fine sediment in the water reservoir was homogenized with an impeller driven by a portable drill for a period of 3 minutes. A 0.3 gal (1 L) sample was immediately taken from near the bottom of the bucket, using a wide mouth container. The sediment concentration of these samples was determined by filtration through a Buchner funnel apparatus (Eaton and others 1995). The sediment concentration may also be determined by oven drying the sample at 105 °C when dissolved solids do not constitute an appreciable portion of the mass in transport (Eaton and others 1995).

Summary

Information regarding sediment production from road surfaces and ditchlines can be important for management of sediment from a forest road network, particularly where aquatic values are high. Sediment measurements provide information for calibration of models and are necessary for adaptive management addressing new sediment reduction methods and designs. Estimates of sediment production from roads in many places have generally been based on samples from just a few experimental sites. This document details the construction of a customizable system for measuring sediment from forest roads. Using a system such as this can provide information on real values of sediment production for local soils, weather, designs, and road management methods.

Settling basins provide a simple and reliable system for monitoring road derived sediment production. The installation, maintenance and measurement of five plots can be accomplished by a technician in less than a month. Settling basins alone provide a reasonable measurement of sediment leaving the road on newly constructed roads and on coarse textured soils.

Adding a tipping bucket system to measure discharge and fine sediment can improve precision of sediment measurements in places where sediment production is small or where most of the disturbance to roads comes from traffic. They may be helpful in areas with fine grained soils as well. The tipping bucket discharge and fine sediment system is simple, flexible, and inexpensive compared to other instrumentation choices. The tipping bucket devices described herein provide a detailed and reliable record of discharge up to 60 gallons per minute (227 liters per minute) when properly calibrated and maintained. The system provides a complete sediment and discharge record when used with a settling basin and a flow splitter to measure the coarse and fine sediment budget for a bordered road plot.

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Appendix A: Road Sediment Plot Field Sheet

Field area:
Plot ID:
Crew:
Date:
Depth of sediment (in):
Texture of sediment:
Tare of bucket + water (lbs):
Tare water temp. (°F):
Sample water temp. (°F)

Sample	**Sediment + bucket + water (lbs)**	**Sample**	**Sediment + bucket + water (lbs)**
1		9	
2		10	
3		11	
4		12	
5		13	
6		14	
7		15	
8		16	

Sub-sample taken:

Plot condition:

Vegetation cover road:

Vegetation cover in ditch:

Remarks:

Appendix B: Density of Pure Water at 101,325 Pascal;

Data From Lide (2001)

Degrees Celsius (C)	kg/m³	Degrees C	kg/m³
1	999.902	16	998.945
2	999.943	17	998.777
3	999.967	18	998.598
4	999.975	19	998.407
5	999.967	20	998.206
6	999.943	21	997.995
7	999.904	22	997.773
8	999.851	23	997.541
9	999.783	24	997.299
10	999.702	25	997.048
11	999.607	26	996.787
12	999.500	27	996.517
13	999.379	28	996.237
14	999.246	29	995.949
15	999.102	30	995.651

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(970) 498-1100

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