Geomorphic Road Analysis and Inventory Package (GRAIP) Field Collection Activities: Quality Assurance Project Plan (QAPP)

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Prepared for
U.S. Forest Service and Environmental Protection Agency
Interagency Agreement
(DW-12-92273301-1)

Prepared by
US Forest Service
Rocky Mountain Research Station
and
US EPA Region 10 and Headquarters
Clean Water Act Section 303(d) Program Offices

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A1 Title and Approval Sheet

Geomorphic Road Analysis and Inventory Package (GRAIP) Field Collection Activities: Quality Assurance Project Plan (QAPP)

Approvals:

Signature indicates that this QAPP is approved and will be implemented in conducting this project.

______________________________	__________
USEPA Project Manager	Date
______________________________	__________
USEPA Project Quality Assurance Officer	Date
______________________________	__________
USFS Project Manager	Date
______________________________	__________
USFS Project Quality Assurance Officer	Date

NOTE: All concurrences for the QAPP are on file with the USEPA Interagency Agreement Manager in email format.

A2 Table of Contents

A3 Distribution List

This QAPP and associated manuals or guidelines will be distributed to the following U.S. Forest Service (USFS), EPA, and other project staff participating in the GRAIP field collection activities. Project staff for each of these roles are identified in the **Appendix**.

- USFS Project Manager
- USFS Project Quality Assurance Officer
- USEPA Project Manager
- USEPA Project Quality Assurance Officer
- USEPA Interagency Agreement Manager

A4 Project/Task Organization

The major areas of activity and responsibilities for GRAIP field collection activities are discussed below and illustrated in the **Figure**. The name and phone number of the individual assigned to each role are provided in the **Appendix**.

USEPA EPA Project Manager
Coordinates with the USEPA project quality assurance (QA) officer and USEPA interagency agreement (IA) Manager to ensure task is being conducted according to the IAG task descriptions, detailed work plan, and approved QAPP for GRAIP field activities.

USEPA Project QA Officer
The USEPA Project QA Officer reviews and approves the GRAIP field activities QAPP developed for the project. Responsibilities also include, as needed, providing QA/QC technical assistance to the USEPA Project Manager. USEPA's Project QA Officer will be independent of task staff generating information.

USEPA Interagency Agreement (IA) Manager
The USEPA IA Manager ensures task activities are performed in accordance with IA conditions and task descriptions.

USFS Project Manager
The USFS Project Manager provides overall coordination of the project and makes decisions regarding the proper functioning of all aspects of the task, including GRAIP training, field collection activities, and adherence to the approved QAPP for field activities. Responsibilities also include coordinating with the USEPA Project Manager, as needed, to resolve QA/QC issues that may occur during field collection activities.

Data/GIS Processor
The Data/GIS Processor accepts data and information collected by the field crews and performs the following data management activities before the GRAIP model is run: differential correction of GPS data, field data error checking, and advanced data checking and preprocessing. The Data/GIS Processor generates an error report used to determine whether the field crews need to collect additional information to correct the error(s).

USFS Project QA Officer
The USFS Project QA Officer reviews and approves the GRAIP field activities QAPP developed for the task. Responsibilities also include, as needed, providing QA/QC technical assistance to the USFS Project Manager and conducting external performance audits of field activities. USFS's Project QA Officer will be independent of task staff generating information.

Field Crew
The USFS Project Manager will be supported by staff performing GRAIP field activities. Field staff will attend GRAIP training and conduct field activities in accordance with the approved QAPP. Field crew members are typically hired college students.

Field Crew Leader
The Field Crew Leader will provide day-to-day oversight of field crews assigned to each project and communicate directly with the USFS Project Manager on progress of field activities and resolution of

issues to meet the project data quality objectives. To the extent feasible, field crew leaders will have prior experience with GRAIP road inventory procedures.

<u>Field Crew "Experts"</u>
Field crew "experts" will conduct field audits of hired field crews and perform road inventory replicates. Field crew "experts" will have extensive knowledge (conceptual and practical application) of the GRAIP process and communicate directly with the FS Project Manager.

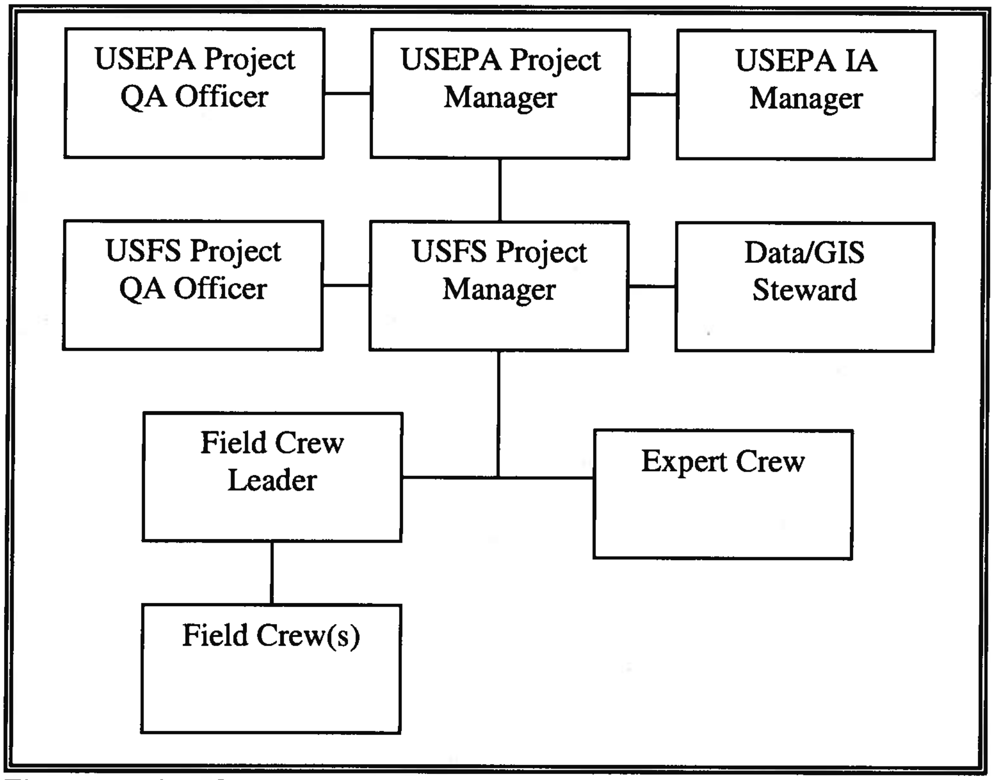

Figure. Project Organization

A5 Problem Definition/Background

Under Section 303(d) of the Clean Water Act (CWA), states, territories, and authorized tribes (hereafter referred to as "jurisdictions") are required to develop lists of impaired waters every two years (i.e., Section 303(d) list). Impaired waters are those that do not meet applicable water quality standards (WQS). The CWA further requires jurisdictions to establish a priority ranking for waters on the Section 303(d) list and develop Total Maximum Daily Loads (TMDL) for them. A TMDL is the maximum amount of a pollutant that a waterbody can receive and still meet applicable WQS with a margin of safety, and an allocation of that amount to the pollutant's point and nonpoint sources. USEPA regulations also recognize that alternative pollution control requirements may obviate the need for a TMDL. Specifically, waterbody segments are not required to be included on the Section 303(d) list if jurisdictions demonstrate that "[o]ther pollution control requirements (e.g., best management practices) required by local, State, or Federal authority" (see 40 CFR 130.7(b)(1)) are stringent enough to achieve applicable state WQS within a reasonable period of time. These alternatives to TMDLs are commonly reported to EPA as Category 4b waters as described in EPA's Integrated Reporting Guidance (IRG) for Sections 303(d), 305(b), and 314 of the CWA.

In many environments, forest roads are the leading source of fine sediment delivery to waterbodies, which can cause water quality impairments. Assessing the amount of sediment delivery from forest roads within the upstream watershed of an impaired waterbody can assist with TMDL development and implementation, as well as, development of Category 4b rationales.

The Geomorphic Road Analysis and Inventory Package (GRAIP) process (Black and Luce 2007a) can be used to inventory and model the risk profile of roads within a watershed. The GRAIP process consists of a detailed road inventory combined with a GIS model. The road inventory is used to systematically describe the hydrology and condition of a road system using GPS and automated data forms. This GIS model analyzes mass wasting potential with and without road drainage, fine sediment production and delivery, hydrologic connectivity, and stream crossing failure potential. Detailed information about the performance and condition of the road drainage infrastructure is also supplied.

The purpose of this document is to establish a quality assurance project plan (QAPP) for application of the GRAIP process in the project area(s) to ensure collection of well-documented data and information of known quality. Under USEPA Order 5360.1 A2, all organizations conducting environmental programs funded by USEPA are required to establish and implement a quality system. Additionally, EPA requires that all data used for purposes of environmental decision making must be supported by an approved QAPP. This QAPP intends to satisfy these requirements, and has been prepared according to USEPA's *Requirements for Quality Assurance Project Plans* (USEPA 2001) and *Guidance for Quality Assurance Project Plans* (USEPA 2002).

A6 Project/Task Description

The purpose of this project is to apply the GRAIP process in the project area(s). The GRAIP process is organized into five major activities, including:

- Road inventory
- Data preparation
    - data transfer
    - differential correction
    - GRAIP preprocessor
- Stream network delineation (TauDEM)
- Stream crossing filtering
- GRAIP Analysis
    - Road erosion, drainpoint accumulation, and stream sediment inputs
    - Terrain stability analysis
    - Drain point erosion sensitivity
    - Fish habitat segmentation

Additional details about each of the five activities are provided in Black et al. (2009) (see **Attachment A**). Note that the road inventory portion of the GRAIP process includes the collection/generation of new geospatial data – point and line features associated with the road network in the project area.

To complete the GRAIP process, predictions of road sediment production are made for each road segment based on either (1) values from comparable regions available in the literature, or (2) locally collected road sediment/erosion plot data for "typical/average" road segments Black and Luce (2007) (see **Attachment B**).

This QAPP addresses the road inventory and data preparation activities of the GRAIP process. This QAPP also addresses, when applicable to the project, locally collected road sediment/erosion plot data for typical road segments in the project area Black and Luce (2007). GPS specification and settings for collection of geospatial data are described in Black et al. (2009).

This QAPP is designed to be used in concert with the compendium QAPP developed for the remaining GRAIP process activities, including stream network delineation, stream crossing filtering, and GRAIP analysis.

Additional project-specific information for performing the GRAIP process is provided in the **Appendix**.

A7 Quality Objectives and Criteria

The primary objective is to produce well-documented data of known quality of the GRAIP process to assess the condition of ALL roads in the project area that could potentially contribute sediment directly/indirectly to streams in the project area.

The data quality objectives (DQO) for the first two activities of the GRAIP process (road inventory and data preparation) are presented below. As appropriate, DQOs for locally collected road sediment/erosion plot data for "typical/average" road segments are also presented.

Note that the GRAIP road inventory does not include collection of environmental samples for laboratory analysis. The sediment/erosion plot process does include collection of sediment for analysis of particle density in the laboratory.

A7.1 Precision, Bias, and Accuracy

Precision and bias are estimates of random and systematic error in a measurement process. Collectively, precision and bias provide an estimate of the total error or uncertainty associated with an individual measurement or set of measurements.

GRAIP Road Inventory and Data Preparation

For this project, precision and bias will be assessed for GRAIP modeled outputs (i.e., sediment production and sediment delivery). Note that assessment of precision and bias for just the road inventory could yield diagnostic information about the quality of the data generated from that portion (i.e., field data collection) of the GRAIP process. However, the road inventory generates a description of each road segment rather than a single value/score that can easily be compared. The road inventory descriptions are then incorporated into the GRAIP model that generates a values/score (e.g., tons of sediment produced and delivered) that can be easily compared. Hence, using sediment production and delivery results for assessing precision and bias is both practical and an appropriate means to assess precision and bias of the entire GRAIP process.

Precision will be estimated from GRAIP modeled outputs (i.e., sediment production and delivery) of replicates of the same road segments by the different field crews. For field determinations (e.g., the road inventory), bias cannot be determined directly, since the "true" values at any particular road segment are not known. However, bias can be determined indirectly by comparing the results of the GRAIP modelied output (i.e., sediment production and deliver) of an experienced/"expert" crew at selected road segments to that of the other field crews for the same road segments.

For measurement variables (e.g., sediment production and sediment delivery) with large ranges of expected values, performance objectives for precision and bias are established in both absolute and relative terms. At lower values, objectives are specified in absolute terms. At higher values, objectives are stated in relative terms (Hunt and Wilson, 1986). The "transition value" is that value where the absolute and relative objectives are equal. At sediment production and delivery values less than or equal to the transition value, the absolute objective is used (it is larger than the relative objective). At sediment production and delivery values greater than the transition value, the relative objective is used (it is larger than the absolute objective).

Precision in absolute terms is estimated as the sample standard deviation when the number of measurements is greater than two:

$$s = \sqrt{\frac{\sum_{i-1}^{n}\left(x_i - \overline{X}\right)}{(n-1)}}$$

where,
x_i = individual estimate of sediment production or delivery (replicate)
$\overline{X}$ = mean of all replicates, including estimates derived from measurements by expert crew
N = number of replicates

Relative precision for such measurements is estimated as the relative standard deviation (RSD, or coefficient of variation, [CV]):

$$RSD = \frac{s}{\overline{X}}$$

where,
s = sample standard deviation
$\overline{X}$ = mean of all replicates, including those produced from expert crew measurements

Net bias (B) will be estimated in absolute terms as:

$$B = \overline{X} - T$$

where,
T = estimated sediment production or delivery based on measurements obtained by expert crew
$\overline{X}$ = mean of all replicates, not including results of expert crew

Bias in relative terms is calculated as:

$$\%B = \left(\frac{B}{T}\right) \times 100$$

where,
T = sediment production or delivery estimate obtained by expert crew
B = Net bias

The following absolute and relative objectives were derived from historic replicate GRAIP process results. Specifically, absolute objectives were derived from the standard deviation observed for replicates performed on low sediment production and delivery roads. Relative objectives were derived from the relative percent difference observed for replicates performed on high sediment production and delivery roads.

GRAIP Process Output	**Objectives**			
	Precision		**Bias**	
	Absolute	Relative	Absolute	Relative
Sediment production	2 T/Km	20%	2 T/Km	20%
Sediment delivery	1 T/Km	20%	1 T/Km	20%

Based on these absolute and relative objectives, the "transition values" are presented below.

GRAIP Process Output	**Transition Values**	
	Precision	**Bias**
Sediment production	10 T/Km	10 T/Km
Sediment delivery	5 T/Km	5 T/Km

For the project(s), replicates will be performed at a rate of once per month (after initial training) during the field season. The expert crew will establish, to the extent feasible, the replicates along the following road types:

- Low sediment production and delivery
- High sediment production and delivery

To identify these road types in the field, road slope and road surfacing will be used to stratify for sediment production potential. Proximity between road and stream channel will be used to stratify for sediment delivery. In general, low sediment production and delivery potential roads will be low gradient ridgetop roads with gravel surfacing. High sediment production and delivery potential roads will be steeper and possibly unsurfaced lower midslope roads with frequent hydrologic connectivity.
The road(s) used for replicates will be two to three miles in length. Each hired field crews (typically three per watershed) will perform a replicate within one month after the expert crew completes the original inventory. To the extent feasible, the location of the replicates will be "blind" to the hired field crews.

Accuracy and bias will be assessed at the end of the field season after all project work is completed. However, to the extent feasible, accuracy and bias will also be assessed at the end of each monthly replicate to determine the appropriateness of the absolute and relative objectives provided above and to identify and address potential problems with the individual field crews before they complete additional road inventories. The monthly evaluations are NOT intended as QC checks that would necessitate reassessment of previously inventoried road segments if the precision and bias objectives above are not met.

Note that the absolute and relative objectives in the table above may be revised during the project as additional replicates are performed on roads with low and high sediment production and delivery. Also, if problems are identified with the field crews, appropriate supplemental training will be provided before additional roads in the project area are inventoried.

Sediment/Erosion Plots

Field and laboratory precision and bias will not be assessed for sediment/erosion plots established in the project area for the following reasons:

Field data collection

- Sediment/erosion plots will be installed and maintained by individuals experienced in field and laboratory procedures
- Replicates of stationary settling tanks (for up to three years) on designated road segments are not practicable or feasible.

Laboratory Analysis

- Particle density will be assessed in the lab for homogenized samples from each settling tank. Each sample will be homogenized in the field for three minutes. Based on prior experience with the GRAIP process and knowledge of geology in the project area(s), the USFS Project Manager believes 3 minutes is more than adequate to homogenize sediment collected in the settling tanks. Hence, assessing the quality (e.g., precision) of the homogenization procedure (via assessment of particle density of split samples of the homogenized sample) is not warranted. Particle density will be assessed using the Blake and Hartage (1986) picnometer method from Methods of Soil Analysis (see **Attachment C**).

A7.2 Representativeness

Representativeness is the extent to which the measurements actually represent the true environmental conditions.

GRAIP Road Inventory and Data Preparation

The GRAIP process is intended to be a comprehensive (100%) inventory of ALL roads in the project area that could potentially contribute sediment directly/indirectly to streams in the project area. Hence, the process is intended to be unbiased (unlike targeted sampling) and without statistical inference (unlike probability-based sampling). Representativeness will also be achieved for each road segment inventoried through adherence to the inventory protocols and this QAPP.

Sediment/Erosion Plots

Sediment/erosion plots will be established for road segments that are "typical/average" road types in the project area. "Typical/average" road types in the project area are initially identified based on a desk-top review of what roads need to be inventoried (*see completeness discussion below*) in the watershed, as well as available data and information (e.g., topographic and geologic maps) for the project area. "Typical/average" road types are selected according to the following elements:

- Length
- Slope
- Surfacing (e.g., gravel is typically the most common road surface)

- Elevation (e.g., typically at mid elevation in the project area to account for average snow pack in the project area)
- Underlying geology

A field recon is also performed to confirm the representativeness of the selected road segments.

Five sediment/erosion plots will be established in the project area and maintained for three years. The mass of sediment generated in each plot will be measured once per year – typically in the Fall. The results of such measurements collected over the three year period will be averaged for incorporation into the GRAIP process model. The USFS will also calculate the 90% confidence interval from the measurements and run the GRIAP process model using the lower and upper bounds of the interval.

Ideally, up to three years of data will be collected from the sediment/erosion plots in order to capture variation in natural conditions, namely precipitation patterns. Predictions of sediment production from one year of sediment/erosion plot data may be incorporated into the GRAIP model. However, the predictions of sediment production in the project area become more representative as additional years of sediment/erosion plot data are collected and available for incorporation into the GRAIP model.

As discussed below (see completeness discussion), roads not identified prior to the inventory may be encountered in the field. Based on USFS's prior experience, such roads may include unauthorized ATV trails and old logging roads that are no longer maintained and are revegetating (i.e., do not resemble roads selected as "typical/average"). Based on the extent of "atypical" roads encountered during the inventory, the USFS Project Manager will assess the extent to which additional sediment/erosion plots are needed on such roads to develop a representative estimate of sediment production and delivery in the project area.

A7.3 Completeness

Completeness is the comparison between the amounts of data that were planned to be collected versus how much usable data was collected, expressed as a percentage.

GRAIP Road Inventory and Data Preparation

Completeness objectives are established and will be evaluated from two perspectives. First, at the project level, the objective is to complete the GRAIP road inventory on 100% of ALL roads in the project area that could potentially contribute sediment directly/indirectly to streams in the project area. Second, at the inventory level, the objective is to obtain a 100% complete data set for each road segment inventoried.

To promote achievement of the project-level completeness objective, several activities are performed prior to and during the inventory. Prior to the inventory, the USFS uses the most recent existing road GIS data in conjunction with the most recent remote sensing imagery to make an estimate of road mileage in the project area. This estimate is then used for budgetary purposes and estimating the amount of time needed to inventory 100% of the anticipated roads.

During the inventory, road data and information will be collected in a systematic manner, typically beginning in the lower region of a subwatershed and progressing upstream. As roads are constructed in branching networks, all of the branches of a main road network will be inventoried before a new main road system is inventoried. As newly identified roads are encountered (i.e., roads not identified prior to the inventory), they will be sampled within a reasonable time. This will ensure that all types of roads will be sampled before a subwatershed inventory is considered complete.

A road (officially or user created) shall be defined to be any structure that was created for the purpose of conducting motorized vehicles. For the purposes of road geomorphology, once constructed a road remains a road as long as it has the capacity to intercept water and concentrate it at discharge points or if engineered road drainage features (such as culverts and stream crossings) exist. A feature will no longer be considered a road when it does not move water along the surface, no longer has stream crossings and is not located in a position where it can interact with the stream channel.

If conditions do not allow for a 100% inventory of ALL roads in the project area, the USFS Project Manager will evaluate and document the appropriateness of the following options:

- Perform GRAIP modeling for completed inventoried subwatersheds
- Extrapolate completed inventoried subwatershed results to uninventoried subwatersheds
- Inventory uninventoried subwatersheds at a later date.

Sediment/Erosion Plots

The completeness objective is to establish and maintain five sediment/erosion plots on "typical/average" road types in the project area for three years. If conditions do not allow for meeting the completeness objective, the USFS project manager will evaluate and document the appropriateness of incorporating predictions of sediment production based on the sediment/erosion plots that could be established and maintained.

A7.4 Comparability

Comparability is defined as the confidence with which one data set can be compared to another. Comparability is addressed in this project by the use of standardized GRAIP process and sediment/erosion plot procedures by all project field crews and project participants. This project does not involve comparison of new data and information to previously collected data and information.

A7.5 Pre-Inventory Training

Prior to performing the road inventory, field crews will receive training on the GRAIP road inventory procedures. Training will be conducted by the USFS Project Manager or designee who is considered an expert in the GRAIP process. Training generally occurs over the course of a week and includes in-classroom instruction as well as field application. A sample syllabus is provided in **Attachment D**.

For the inventory, each field crew will consist of two individuals – typically hired college students. To the extent feasible, an experienced crew member (i.e., has been trained and performed the road inventory on previous GRAIP projects) will be paired with a newly trained crew member. For each project, all field crews will be supervised in the field by a designated field crew leader. To the extent feasible, the field crew leader will have been trained and performed the road inventory on previous projects.

A7.6 Documents and Records

Hard copies or electronic copies of the most current GRAIP inventory procedures and QAPP will be distributed to the individuals identified in the distribution list (above) prior to GRAIP field activities.

It is anticipated that the following documents will be generated by the USFS as part of the GRAIP process for this project.

- Signed "Review and Distribution Acknowledgement" QAPP forms
- Field notebooks and related forms
- Field audits report(s)
- Data preparation audit report(s)
- Data evaluation report that documents quantity, quality, and usability of the field data for the GRAIP model
- Project report describing GRAIP process results/output for the project area and assessment of quality/usability of data based on results of data quality objectives
- Records of relevant communication between project team members and the Agencies

In addition to hardcopy/paper documents, computer files will be generated during the course of the project. The USFS Project Manager will maintain these files during the course of the project. The USFS Project Manager will also maintain copies of all project documents on a regular basis for incorporation into a central project file.

At the end of the project, the USFS Project Manager will provide the USEPA Project Manager and USEPA IA Manager copies (hardcopy or electronic) of all documents generated during the project. For USEPA, final deliverables and reports from contracts, cooperative agreements, IAGs, or from in-house are governed by EPA Records Schedule 258 (*epa.gov/records/policy/schedule/*).

SECTION B DATA GENERATION AND ACQUISITION

B1 Sampling Process Design (Experimental Design)

GRAIP Road Inventory and Data Preparation

The GRAIP road inventory is intended to be a comprehensive (i.e., 100%) inventory of ALL roads that could potentially contribute sediment directly/indirectly to streams in the project area. Hence, the sampling design is unbiased (unlike targeted sampling) and without statistical inference (unlike probability-based sampling).

Sediment/Erosion Plots

A biased/targeted sampling design is employed to select roads to establish sediment/erosion plots in the project area. Factors considered in selecting areas for sediment/erosion plots in the project area are discussed in Section A7.2 above.

B2 Sampling Methods

GRAIP Road Inventory and Data Preparation

The GRAIP road inventory and data preparation will be performed according to the procedures in Black and Luce (2009) and Prasad (2007).

Sediment/Erosion Plots

When included in the detailed scope of work for the project, local road sediment/erosion plot data for "typical"/"average" road segments in the project area will be collected according to the procedures in Black et al. (2009). The procedures involve the collection and measurement of sediment in settling tanks installed along roads in the project area.

B3 Sample Handling and Custody

GRAIP Road Inventory and Data Preparation

Field measurements for the GRAIP road inventory are recorded electronically by the field crews for each road segment using a resource grade GPS system (Trible Pro XRS or comparable receiver) and customized data acquisition system (TerraSyncTM) loaded on a laptop. At least weekly this data is transferred to the data manager's computer via a thumb drive or memory card. Two copies of the raw TerraSync data files will be maintained after the data is transferred to the data manager. The data managers will process field data and transfer it to the GIS processor retaining an archive copy on the office computer. The GIS processor will edit data files, after creating an archival copy of the individual shape files. In addition, the data on the GIS processors computer will be backed up systematically on a daily basis. A master data log will be maintained by the GIS Processor to track all of the files from the field through the final processing and modeling.

Sediment/Erosion Plots

Sediment collected from sediment/erosion plots for particle density analysis (see analytical methods below) will be placed into storage containers in the field and packaged appropriately to avoid damage. Note that the particle density method does not require a special packaging, holding times, or holding temperatures. Chain-of-custody forms will be completed in the field as each sample is collected, and will be kept with the samples at all times. Whenever samples are transferred, the "relinquished by" portion of the chain-of-custody form will be completed.

B4 Analytical Methods

GRAIP Road Inventory and Data Preparation

There are no samples collected for laboratory analysis as part of the GRAIP road inventory..

Sediment/Erosion Plots
Sediment collected from sediment/erosion plots for particle density analysis eill be measured using the Blake and Hartage (1986) picnometer method from Methods of Soil Analysis (see **Attachment C**).

B5 Quality Control

Quality control (QC) consists of checks to ensure that QA objectives are met. These checks are also intended to identify any need for corrective action. QC checks apply to individual field measurement devices as well as the overall field measurement and observation procedures. QC checks and corrective actions are discussed below.

B5.1 Field Measurement Devices

GRAIP Road Inventory and Data Preparation

Field measurement devices include a GPS unit (Trible Pro XRS or comparable receiver), Stadia or Philadelphia rod, and Stadia level. QC checks will not be performed for the rod and level measurements. GPS units used for the project(s) are designed to provide at least ±2 meter accuracy. Such accuracy is adequate for the project(s) given that data is collected on the centerline of roads, which are typically 12 feet wide. The accuracy of the GPS units is checked at the beginning of the field season against a known surveyed benchmark at a USFS facility. GPS units that do not record locations within 2 meters of the known benchmark are not used. .

Sediment/Erosion Plots

The field measurement device used for the sediment/erosion plots is an electronic scale. The accuracy of the electronic scale will be checked at the beginning and end of each day that sediment collected in the settling tanks is weighed in the field.

B5.2 Field Measurement and Observation Procedures

QC checks and corrective actions for the field measurement and observation procedures for the GRAIP process and sediment/erosion plots are described in Section A7 (Quality Objectives and Criteria).

B6 Instrument/Equipment Testing, Inspection, and Maintenance

All field measurement devices and sampling equipment will be maintained in proper working order, with regular maintenance being performed according to manufacturer specifications. Prior to mobilization to the field, personnel will inspect the equipment to make sure it is in proper working order. Maintenance notes will be entered into the field logbook(s).

B7 Instrument/Equipment Calibration and Frequency

Field instrument calibration will be performed according to manufacturer specifications. More frequent calibration will be performed at the discretion of field personnel, and may be warranted by weather conditions or if problems with the instruments are suspected. Calibration notes will be entered into the field logbook.

B8 Inspection/Acceptance for Supplies and Consumables

All field supplies will be inspected by field crews to ensure they are in proper condition and working order prior to mobilization in the field. Any problems as well as application of maintenance requirements will be documented in the field notes. As needed, extra supplies will be brought to the field in the event that damage occurs.

B9 Data Acquisition (Non-direct Measurements)

Non-direct measurements are data and information collected using professional judgment and observation. The GRAIP road inventory includes a number of non-direct measurements, including the following:

- Culvert condition – evaluated as percent occluded (0-20%, 20-80%, or 80-100%
- Road surface cover – evaluated as percent cover (0%, >10%, >25%, >50%, or >75%)

To ensure the quality of non-direct measurements, most of the field attributes are assessed by field crews using a menu-driven data dictionary. The data dictionary supplies a limited set of choices and the field crews must pick the one the best describes the situation for the road segment being inventoried. The following activities also maintain the quality of non-direct measurements: training of field crews on GRAIP field procedures, adherence of field crews to the GRAIP field procedures, assessment of field replicates (and supplemental training, if needed), and evaluation of field audits (and supplemental training, if needed). Additional information about the field audits is provided in Section C1.

B10 Data Management

GRAIP Road Inventory and Data Preparation

Electronic data management procedures for the GRAIP road inventory and data preparation procedures are described in Section B3. The USFS Project Manager, or designee, will prepare a data evaluation report that documents the quantity, quality, and usability of the field data for the GRAIP model. Field notes maintained by the field crews will also be turned over to the USFS Project Manager at the end of the project.

Sediment/Erosion Plots

Field data and information collected during establishment and maintenance of sediment/erosion plots will be maintained in field notes and turned over to the USFS Project Manager at the end of each year (after the mass of sediment generated is measured in the Fall). Analytical data (particle density) will be submitted by the laboratory to the USFS Project Manager in both hard copy and electronic formats, as appropriate.

SECTION C ASSESSMENT AND OVERSIGHT

The primary mechanism through which project DQOs will be met is prevention. Specifically, planning and design of the project, documented instructions and procedures, and use of trained field personnel as outlined in the QAPP are expected to prevent most problems associated with data quality and quantity.

An assessment program will be used to identify any problems with the project data and trigger response actions to bring the data back in line with the project DQOs. The assessment will include routine evaluation of the data with respect to DQOs such as precision, bias, and completeness, as discussed in Section A. The assessment will also include a structured data validation process, as discussed in Section D. Assessment will also include high-level monitoring of certain project activities (field audits), as discussed below.

In the event that the assessment program identifies problems with project data and information, response actions will be triggered. That nature of these actions will depend upon the severity and types of problems encountered, and will begin with a review of the project procedures related to the identified problem(s).

Note that additional costs to the project could incur if response actions are triggered. The USEPA Project Manager and USEPA IA Manager must first approve (via memo or email) any response actions that would incur additional costs to USEPA.

C1 Assessments and Response Actions

Field audits and data preparation audits that will be performed for the GRAIP road inventory and data preparation activities are described below.

Field Audits

Field audits will be conducted for each field crew performing the GRAIP road inventory and corrective actions will be conducted in real time. These audits provide a basis for the uniform evaluation of data collection techniques, and an opportunity to conduct procedural reviews as required to minimize data loss due to improper technique or interpretation of field procedures. Through uniform training of field crews and field audits conducted early in the data collection process, sampling variability associated with specific implementation or interpretation of the protocols will be significantly reduced.

The field audits will be performed by personnel experienced in the GRAIP process (i.e., same "expert" crew members performing replicates), and include the following activities:

- The Evaluator(s) will view the performance of a field crew through one complete road line segment inventory.
- If the field crew misses or incorrectly performs a procedure, the Evaluator will note this and *immediately point this out so the mistake can be corrected on the spot.* The role of the Evaluator is to provide additional training and guidance so that the procedures are being performed consistent with inventory protocols and this QAPP.
- When the road line segment inventory has been completed, the Evaluator will review the results of the evaluation with the field crew before leaving the site (if practicable), noting positive practices and problems (i.e., weaknesses [might affect data quality], deficiencies [would adversely affect data quality]). The Evaluator will ensure that the field crew understands the findings and will be able to perform the procedures properly in the future.
- The Evaluator will record responses or concerns, if any.
- If the Evaluator's findings indicate that the field crew is not performing the procedures correctly, safely, or thoroughly, the Evaluator will continue working with this field crew until certain of the crew's ability to conduct the inventory procedures properly so that data quality is not adversely affected.
- If the Evaluator finds major deficiencies in the field crew's operations the Evaluator will contact the Forest Service QA officer and EPA task manager. And, data records from roads previously inventoried by this field crew will be evaluated to determine whether any roads must be re-inventoried.

Field audits will occur at a rate of once per month for each field crew. The audits will generally occur between the monthly replicates performed to assess DQOs for precision and bias.

Data Preparation Audits

During the data preparation step, the GIS/Data Processor will audit the data and information collected by the field crews on a weekly basis. Such audits promote achievement of the completeness objectives and include the following elements:

- Verify that all road segments have drain locations associated.
- Check that all drain points have ID valued filled in.
- Sort the data to check for completeness of data entry in all attributes.
- If a road segment has 2 Time stamp values for two flow paths then it should have all the data from both flow paths.
- If there is a ditch described at the base of the cutslope, there must also be cutslope data.
- There should be no missing values in the table as it is reviewed.
- The road segments should form a continuous network without major gaps
- Notes are made on values that are missing, gaps in the network, or places where the data is suspect. Field crews are sent back to the questionable locations to clarify the uncertainty and collect any additional data and information.

C2 Reports to Management

The USFS Project Manager will communicate regularly with the USEPA Project Manager and USFS Project QA Officer on the status of the project. In particular, the USFS Project Manager will immediately inform the USEPA Project Manager and USFS QA Officer of any unmet DQOs and associated response actions. As discussed above, the USEPA Project Manager and USEPA IA Manager must first approve any response actions (via memo or email) that would incur additional costs to USEPA.

SECTION D DATA VALIDATION AND USIBILITY

This section presents procedures for data review, verification, and validation; verification and validation methods; and reconciliation with user requirements.

D1 Data Review, Verification, and Validation

The following data and information will be evaluated to assess extent to which data quality objectives for the project were met:

- Did all required signatories (see Section A1) review and sign (approve) the QAPP
- Did all field crew members receive planned training and GRAIP road inventory procedures?
- Were agreed to field procedures used in the project area (e.g., GRAIP process and sediment/erosion plots, as appropriate)?
- Was equipment maintained in proper working order?
- Were instrument calibration procedures performed according to manufacturer requirements?
- Were project DQOs achieved?
- Were field audits performed?

Corrective actions for unmet data quality objectives will also be evaluated.

D2 Verification and Validation Methods

The USFS Project Manager, or designee, will be responsible for data review, verification, and validation. The evaluation will be performed prior to demobilizing from field activities so that any necessary corrective actions may be performed. The following sources of information will be used to evaluate data quality objectives.

- Signed "Review and Distribution Acknowledgement" QAPP forms
- Field notebooks and related forms
- Field audit report(s)
- Records of relevant communication between project team members and agencies

D3 Reconciliation with User Requirements

A data evaluation report will be produced that documents the known quantity and quality of the data and information collected (based on results of data review, validation, and verification). The data evaluation report will also provide an assessment of why any DQOs were not met, corrective actions taken, and an assessment of the overall usability of the data for the project.

REFERENCES

Black,T. A..; Luce, C. H. and R. M. Cissel 2009. The Geomorphic Road Analysis and Inventory Package (GRAIP) Road Inventory Manual. U.S. Forest Service Rocky Mountain Research Station. May 5, 2009.

Black,T. A..; Luce, C. H. 2007. Measuring Water and Sediment Discharge from a Bordered Road Plot using a Settling Basin and Tipping Bucket. U.S. Forest Service Rocky Mountain Research Station. May 13, 2009

Blake G. R.and K. H. Hartage 1986. Particle Density. In Methods of Soil Analysis, Part 1 Physical and Mineralogical Methods-Agronomy Monographs no. 9. pp377-379.

Hunt, D.T.E., and A. L. Wilson. 1986. The Chemical Analysis of Water: General Principles and Techniques. Second Edition. Royal Society of Chemistry, London, England.

Prasad, A., 2007, "A Tool to Analyze Environmental Impacts of Roads on Forest Watersheds," MS Thesis, Civil and Environmental Engineering, Utah State University http://www.neng.usu.edu/cee/faculty/dtarb/graip/AjayThesis.pdf

U.S. Environmental Protection Agency. 2001. EPA Requirements for Quality Assurance Project Plans (EPA QA/R-5). EPA/240/B-01/003. March 2001. Washington D.C.

U.S. Environmental Protection Agency. 2002. EPA Guidance for Quality Assurance Project Plans (EPA QA/G-5). EPA/240/R-02/009. December 2002. Washington, D.C.

U.S. Environmental Protection Agency. 2003. Guidance for Geospatial Data Quality Assurance Project Plans (EPA QA/G-5G). EPA/240/R-03/003. March 2003. Washington, D.C.

APPENDIX
Project Specific Details

Project area name & location	Bear Valley Watershed, ID	Middle Fork Payette Watershed, ID	Wall Creek Watershed, North Fork of John Day River, OR
303(d) Project Purpose	Support Category 4b Rationale	Support TMDL implementation	Support TMDL development
Impaired Waterbodies	Bear Valley Creek, Cache Creek down to Elk Creek (17060205SL012_04) Bear Valley Creek, confluence with Elk Creek to mouth (17060205SL012_05)	Middle Fork Payette River below Big Bulldog Creek (ID17050121SW001_04)	Alder Creek Big Wall Creek Hog Creek Porter Creek Swale Creek Wilson Creek
Cause of impairment	Sediment	Sediment	Sediment
USEPA EPA Project Manager	Leigh Woodruff (208.378.5774)		
USEPA Project QA Officer	Don Matheny (206.553.2599)		
USEPA IA Manager	Eric Monschein (202.566.1547)		
USFS Project Manager	Tom Black (208.373.4363)		
Data/GIS Processor	Rumika Chaudhry (208) 373-4340	Rumika Chaudhry (208) 373-4340	Chris Knechel (208) 373-4340
USFS Project QA Officer	Charlie Luce (208) 373-4382 Office, (208) 761-5017 Cell		
Field Crew Leader	Chase Fly (208) 373-4340	Chase Fly (208) 373-4340	Nathan Nelson
Field Crew "Experts	Chase Fly, Tom Black, Richard Cissel	Chase Fly, Tom Black, Richard Cissel	Nathan Nelson, Tom Black, Richard Cissel
Est. of roads to be inventoried (miles)	100	700	400
Watershed size	340 square miles	292 square miles	?
Road sediment production source	Literature values and/or locally collected sediment/erosion plots from Middle Fork Payette, ID	Locally collected sediment/erosion plots	Literature values
Project Schedule	Complete inventory May-August 2009	Complete inventory May-August 2009	Complete inventory May-August 2009

ATTACHMENT A
(GRAIP Field and Data Preparation Procedures)

To be included in QAPP update

ATTACHMENT B
(Sediment/Erosion Plot Procedures)

Measuring Water and Sediment Discharge from a Bordered Road Plot using a Settling Basin and Tipping Bucket

Thomas A. Black and Charles H. Luce
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Abstract
Although fine sediment production from forest roads has been a major water quality concern to land managers, the methods for quantifying local rates have been complicated and costly. A simple empirical method for quantifying sediment production from the forest road surface is presented. Bordered plots are installed on existing insloped road segments. Coarse sediment production is measured on an annual basis using a settling tank. Water and fine sediment production can also be measured using a tipping bucket gauge and a flow splitting device. This system allows for the collection of both coarse and fine sediment as well as a continuous discharge record. The tipping bucket is a practical tool for measuring flow and is widely used in rain gauges. A simple and inexpensive tipping bucket design, installation and implementation are described here for measuring plot discharge up to 35 gallons (132 liters) per minute. A system for measuring a complete sediment budget for the plot is described, including the necessary time and equipment.

Table of Contents

Introduction

Runoff and fine sediment production from forest roads are widely acknowledged as some of the more serious consequences of forest management for aquatic ecosystems (Lee et al.1997, Luce and Wemple 2002). Roads have been shown to influence a variety of watershed processes including sediment production (Megahan and Kidd 1972, Reid and Dunne 1984, Bilby 1985, Luce and Black 1999, 2001 MacDonald et al. 2001), hydrologic event timing (Wemple et al. 1996, Jones and Grant, 1996), and slope stability (Sessions et al. 1987, Montgomery 1994). As a consequence water quality regulations and the modeling of cumulative impacts of forest management have frequently focused on forest roads.

One of the limitations facing land managers and aquatic resource specialists attempting to predict runoff and erosion from forest roads is a general paucity of data on which to base decisions. The R1-R4 method (Cline et al., 1984) is an empirical model that is widely used to predict sediment production in the western United States. This model and its derivatives rely on a data set from the Idaho Batholith measured in the 1960s and 1970s. Developments since that time have utilized results from other studies to parameterize the effects of various road treatments (Washington Department of Natural Resources 1994, Dube et al. 2002). However, interpolation to new areas with unique geology, precipitation, and design standards still relies on professional judgment.

Physically based models are another approach for interpolating to novel conditions outside the range of existing data. WEPP (Elliot et. al.1999) and DHSVM (Doten et. al. 2006) are two physically based models that have been used to predict sediment and water output from forest roads. While the general intention is to improve estimates, even physically based models rely on calibration (e.g. Luce and Cundy, 1994 Tysdal et. al.1999) and require observations to validate their application in new environments. As a consequence the greatest precision and accuracy in estimating erosion from forest roads can only be achieved with local observations as a means of calibrating one of the various modeling tools available.

While the need for local observations has been clear to many watershed specialists for years, questions and concerns exist about appropriate methods, costs, and data quality. This manual has been prepared to clarify methods for collecting high quality road erosion and runoff data at a reasonable cost. One of the benefits of a rich literature on road erosion, is that a variety of methods have been used, and much has been learned (Megahan and Kidd 1972, Reid and Dunne 1984, Ice 1986, Bilby et. al 1989, Kahklen 1993, Foltz and Trube 1995, Luce and Black 1999, MacDonald et al. 2001). This manual derives from 12 years experience using sediment trap based systems (Luce and Black 1999, 2001a, 2001b, Turaski 2004, Toth 200?, Alto , Sugden 2004, NOAA -CA).

The manual provides detailed designs, material lists and costs for the construction of plots, sediment traps, tipping bucket devices, and the associated suspended sediment samplers. It also provides information on measurement and maintenance after installation has been completed. This document will be of interest to the watershed professional, student or scientist planning to gather data on road sediment production, road hydrology or attempting to validate a model.

Available methods

Sediment

The quantification of sediment production from roads in the western Unites States has evolved considerably through the yeats, but generally began with the work of Megahan and Kidd (1972). They collected sediment data below newly constructed roads using settling ponds in the Zena Creek study in the 1960s. A large rain on snow event in April 1964 produced a sizeable road fill failure, which generated the majority of the sediment during the study period. It was concluded that 30% of the 6,030 cubic feet (171 cubic meters) measured in one watershed was due to road related surface erosion and that overall erosion increased 770 times as compared to a reference watershed. This study provides the base data for the R1-R4 model (Cline 1984). Several large paired basin studies measuring sediment accumulation in settling ponds after a watershed was first roaded and logged reached similar results of substantial treatment effects (Friedrickson 1970, Beschta 1979). These paired basin studies compared small watersheds with various treatments to undisturbed reference watersheds. Even so the signal form roads was not always easily resolved from the background rate and only coarse sediment could be captured by in stream settling basins.

One of the limitations of the settling pond approach was resolved by moving the settling basin close to the road by using a tank(Ice 1986). This allowed for the sampling of only road sediment and runoff. Fine sediment sampling was also made possible with fractional flow splitting devices such as the Conshocton wheel and automated pump samplers such as the ISCO. Sediment sampling systems have the advantage of collecting all of the sediment in transport but require an accurate flow record to calculate the total mass of sediment in transport.

Reid and Dunne 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 large impact of heavy vehicle traffic, but requires a substantial investment in field sampling during peak flows to calibrate the sedigraph for the expected range of discharge. This technique is useful to document the impact of 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, Sulivan 1985, Anderson and Potts 1987). The Johnson Creek study from southern Washington utilized 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, near the channel bottom. The channel gravels were sampled using a freeze coring device to determine weather sediment was being stored or mobilized between the samplers. Although the road contributed 20.4 tons of fine sediment to the reach, no significant storage was detected in the channel bed.

Sullivan (1985) documents nine years of sediment concentration and turbot measurements on the Middle Fork of the Santiam river in the Oregon Cascades, in an 8000 ha watershed. Suspended sediment was sampled every six hours from the fifth order channel above and below an area of active road building and timber harvest. 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 difference in fine sediment yields were detected at the two sample locations
Other researchers have mapped sediment accumulations above filter fabric dams and obstructions to record sediment transport from roads (Megehan and Ketcheson 1996, Brake 1999).

Discharge
Once it was demonstrated that roads play a pivotal role in generating fine sediment, the next logical steps was to examine the hydrology of the road system. Our understanding of runoff from forest roads is derived from methods 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 constrict discharge to a known cross section so that a stage to discharge relationship may be established and recorded by mechanical or electronic means (Ackers et al. 1978, USDA Agriculture handbook 224 1979, Replogle and Clemmens 1981, Kahklen 1993, Foltz 1996). Stage may be measured with a pressure transducer, magnetostrictive rod, or float and pulley system and recorded with a data logger. The stage based systems are often paired with continuous samplers for collecting suspended sediment so that a relationship between discharge and suspended sediment may be developed. When appreciable quantities of coarse sediment are in transport in traction or as bedload, then a settling basin or pit trap may be used upstream of the sampling location (Ice 1986, MacDonald et al. 2001). Difficulties may be encountered in measuring flows with appreciable coarse sediment load with a weir due to sediment and debris deposition, unsteady calibration and plugging of the inlet to the stilling well or weir (Grant 1988). Widespread deployment of these systems is limited by the cost of stage recorders, and flume equipment, and the availability of trained personal

These early studies have helped to parameterize the effects of major variables for different regions and treatments (Reid and Dunne 1984, Burroughs and King 1989, Washington Department of Natural Resources 1994, Dube SEDMODL 2 2002) and to quantify the role of fine sediment from road surfaces.

Overview
In order to make erosion plot measurements more accessible to the watershed professional we have developed a simple and low cost method for quantifying road sediment and water discharge. The system that we have developed consists of a bordered

road plot, ditch inlet and steel settling tank to capture sediment. Runoff and fine sediment may be measured at they exit the settling tank with a tipping bucket and a fractional sampler. The equipment can be installed by a small crew in a few days, requires some periodic maintenance and data retrieval. The cost of installation and one year of data collection is about $1,000 for a coarse sediment settling tank plot and an additional $600 to capture fine sediment and flow.

Sediment Plot Construction
A gravel surfaced forest road can be instrumented in order to determine the total discharge of water and sediment from the road cut-slope, road running surface and ditch. In order to ensure that all of the flow is captured, the road surface can be insloped if necessary to drain flow to an inboard ditch. In the following examples plots were sized to represent typical flow path lengths for gravel surfaced roads in the Oregon Coast Range. A plot length of 80 meters was selected based on typical culvert spacing and uniformity of road variables such as road slope and cutslope height. The factors of rainfall intensity, groundwater interception, road construction variables, and road surfacing were considered when selecting the capacity of the settling tanks and tipping buckets for the installation (Luce and Black 2001b). The plots produced flows that were well within the calibrated range of 0-35 gallons (132 liters) per minute.

Figure 1.
Downslope end of road runoff plot with ditch diversion inlet in foreground for collection pipe.

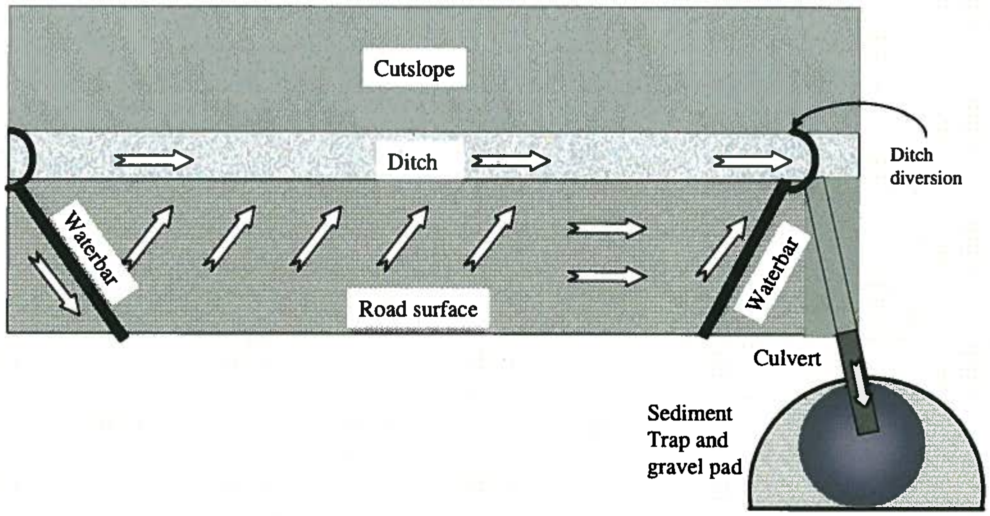


Figure 2.
Runoff plot schematic showing flow directions plot boundaries and sediment tank

Water bars were installed to divert flow coming down the road towards the ditch at the lower end of the plot (figures 1 and 2).
Water bars were constructed of a 9.25" (23.5 cm) wide by .38" (1 cm) thick segment of fabric reinforced conveyor belt bolted between two pressure treated 2" (5.1 cm) x 6" (15.2 cm) boards (figure 3). These were 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. Secure the ends of the water bars into the roadbed using reinforcing bar hooks driven through eyebolts attached to the water bar. The waterbar is installed with the top of the wood positioned at grade level, backfilled with gravel and mechanically compacted in place. This installation allows traffic to move across the plots unimpeded at normal forest road speed. A similar waterbar is installed at the upslope end of the plot to divert flow off of the road segment.

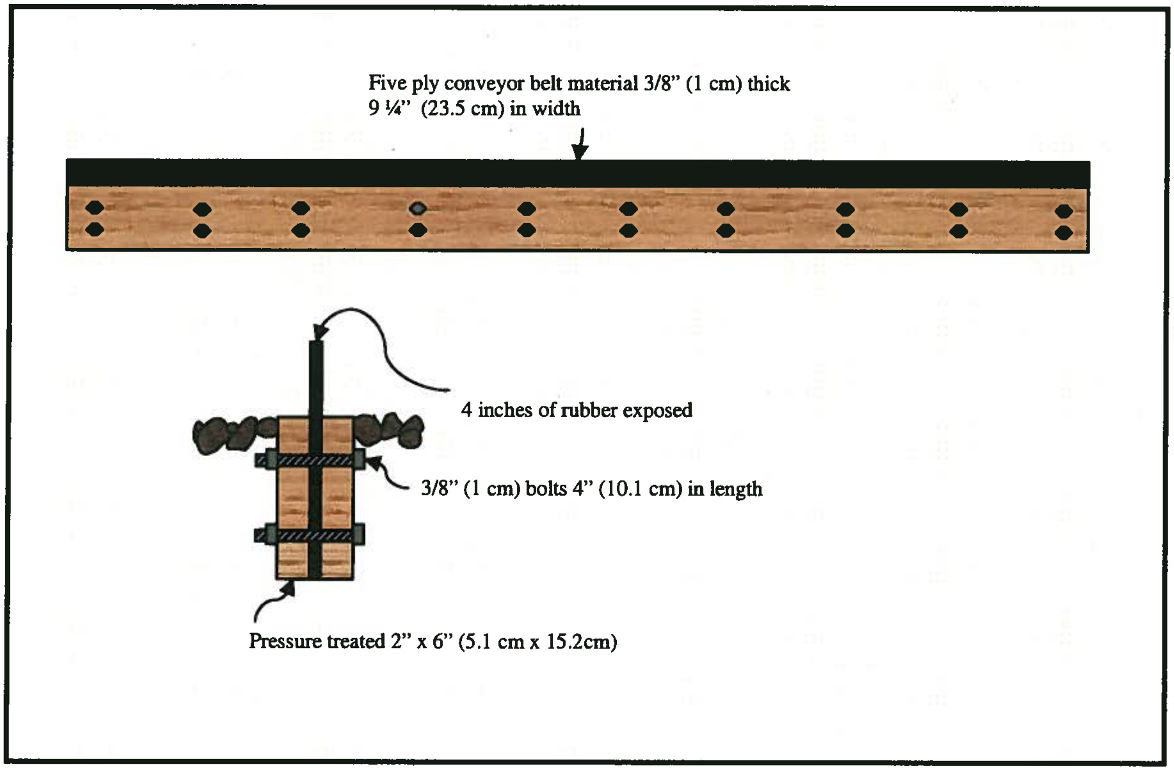


Figure3.
Detail of waterbar fabricated from rubber and fabric conveyor belt material

The ditch at the top of the plot is dammed and drained to the cutslope through a 6" (15 cm) inside diameter pipe. Flow accumulated in the ditch at the lower end of the plot is diverted into a similar pipe with the aid of a corrugated steel half round inlet structure with a concrete footing (figure 4). The pipe is placed beneath the road with the aid of a riding trencher. The pipe exits the road on the fillslope where it enters a 307 gallon (1.16 m^3) steel settling tank (figures 5 and 6). The tank is placed in an excavated alcove cut into the fillslope of the road. The alcove may be floored with compacted gravel or concrete in wet environments to allow for winter access.

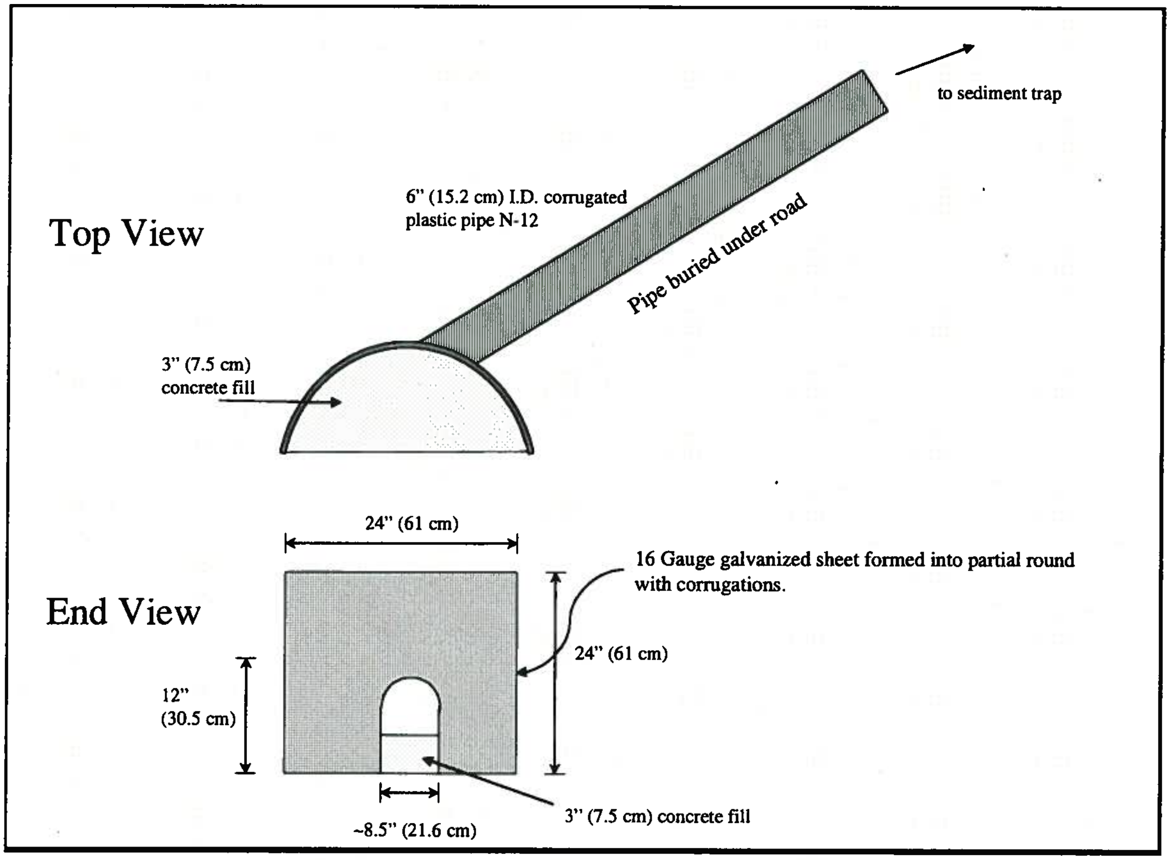


Figure 4
Ditch inlet structure that collects water and diverts it to the settling basin

Figure 5
Settling tank located on concrete pad behind steel retaining wall

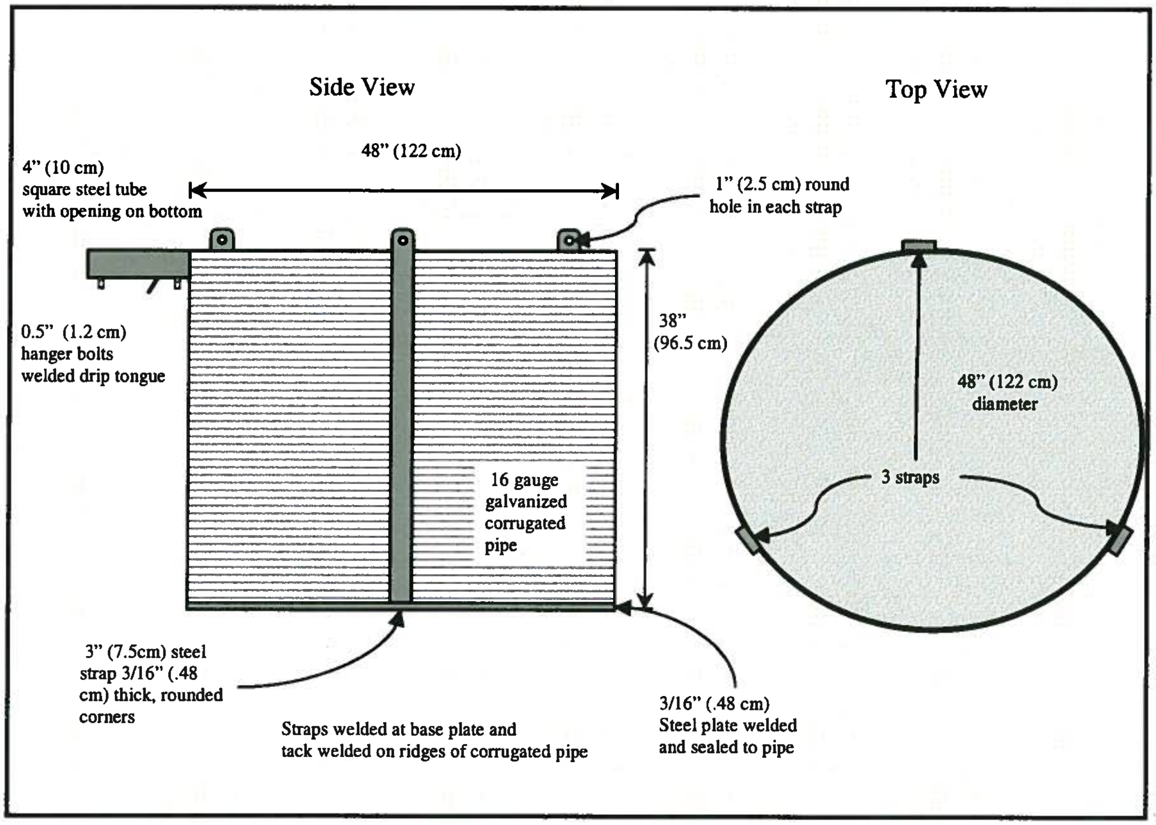


Figure 6
Detail of steel sediment settling tank with outlet for discharge measurements and lifting points for crane rigging.

Runoff and sediment enters the open system settling basin during precipitation events, where the coarse sediment settles from suspension. The tank continuously fills and overflows through the outlet that routes the flow to the optional tipping bucket. Appendix A contains a list of the equipment and hardware required to install 5 typical road sediment plots and the cost in 2004.

Plot Maintenance

Carefully installed sediment measurement plots will perform as designed for many years with periodic maintenance. Heavy traffic and large runoff events may cause road surface rutting. This may generate coarse sediment accumulation at the waterbars and ditch inlet where the flow velocity is reduced. These locations should be inspected monthly throughout the runoff season and after large events to ensure that flow does not escape the plot boundaries and that the settling tanks do not fill beyond half their designed capacity. As the tanks fill substantially their settling efficiency declines and subsequent events will not be equally collected. The conveyor belt material used in the waterbars has performed well for up to five years depending on the traffic loading. In the case of heavy truck traffic waterbars will need to be replaced or refurbished periodically.

Sediment Measurement Methods

Tripod Method

Several options are available to measure the sediment accumulated in the settling tanks. Previous studies have attempted to collect the entire volume of sediment in sealed containers and transport 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 converted to mass using a density conversion factor (Megahan and Kidd 1972). When the sediment masses large and the plots are numerous, it becomes quite cumbersome to handle and transport the sediment. Two methods were developed that use 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 100 lbs (45 kg) and there are fewer than 12 replicates, we found it is most efficient to determine the mass of the sample by using battery powered load cell suspended from a surveying tripod. This portable scale system is inexpensive to operate and does not require transporting the accumulated sediment to a lab facility for oven drying. A general equipment list for the tripod weighing procedure can be found in appendix B. The mass of sediment collected in settling tanks was measured and sampled twice a year. Observations about the site condition, maintenance needs and sediment weights are recorded on the field form (Appendix E).

To access the sediment in the tank carefully siphon the excess water from the sediment tanks close to the level of the sediment surface. Care must be taken to avoid disturbing the sediment with the siphon hose. Before removing the sediment from the tank, a measurement of the depth of the sediment is made. This number should reflect an average depth and if all of the mass is in a pile below the inlet pipe, an approximation should be made. A representative sample of the sediment is collected for particle density, and optional particle size or composition analysis.

The material in the tank is then shoveled into plastic buckets and the tank is then scraped with a plastic trowel or brush to remove any material adhering to the tank. After the tank is shoveled out, tip it on edge and use water to collect all the material into a corner where it may be more easily sampled. The sediment is transferred to plastic buckets and carried to the road where the measurements are taken.

The weight is determined with a 100 lb (45. kg) capacity digital load cell hanging from a portable tripod. An Intercomp CS 200 scale was used in this study with a reported accuracy of .1% of full-scale range. A heavy-duty survey style tripod is fitted with a hook made from threaded rod. The load cell hangs from a hook attached to the tripod at a height so that the suspended weighing bucket clears the ground (figure 7). The sediment weighing container is a 5 gallon (22 liter) steel bucket with three evenly spaced lifting point rings located equidistantly around the upper rim. Three turnbuckles are attached to rings on the lower end and are joined to a central lifting ring at the upper end for easy attachment to the load cell. The tripod is set up on the road above the tank. The load cell is turned on, allowed to warm up for ten minutes and zeroed before installation.

Figure 7
The tripod sediment determination system shown using a 100lb (45 kg) capacity load cell and a fiberglass survey tripod.

These turnbuckles are used to precisely level the bucket. The first measurement is made to determine the mass of clean water that the bucket will hold. The bucket is filled with water to obtain the weight of water and the container (Mtw). The bucket is filled until water begins to spill and then the turnbuckles are adjusted until water spills out in equal volumes from between each of the three quadrants defined by the attachment points. When the bucket is close to level, a half turn adjustment of the turnbuckle is sufficient to make an appreciable difference in height. It is 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.

To check the level of the water surface, a small volume of water is poured in to the bucket slowly using a cup. Observe in which of the three areas the water spills over. When water is spilling evenly within the three quadrants the bucket is repeatable leveled. Carefully add a small additional volume of water. After five seconds record the measurement. This is the $M2$ value that represents the mass of water and bucket. This measurement should be taken at the start of each sampling day to check the scale and the precision of the system, and should not vary significantly over the course of a day unless the water temperature changes significantly.

The weighing of sediment is done in the same fashion except that the weighing bucket is filled with the excavated sediment to a level close to full and then clean water is added to reach the full level as defined above. The container is re-leveled and topped with a small volume of water until it spills evenly. Wait five seconds for the scale to stabilize before recording the reading $M1$. Repeat the process until the entire sample is measured. The weighing container is carefully cleaned between measurements to prevent carry over.

The mass of the sediment is calculated from the difference between $M1$ and $M2$. The temperature of the water is recorded so that the appropriate value for water density may be used. See appendix D for water density values. A sub-sample of the sediment is collected to measure the particle density using a picnometer (Blake and Hartage, 1986).

The equation for determining the mass of the sediment is derived using the following terms.

Mt	is the mass of the sediment tank, kg
Mw	is the mass of the water, kg
Mtw	is the mass of the sediment kg
ρs	is the particle density of sediment in kg/m^3
ρw	is the density of water at the observed temperature kg/m^3
$M1$	is the observed mass of the tank, water and sediment
$M2$	is the observed mass of the tank filled with water

The observed mass of the full tank of sediment is composed of the mass of the tank, sediment and water.

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

The observed mass of the tank full of water is composed of the mass of the tank and the mass of the water.

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

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 three and four.

$$M1 = Mt + \rho wVw + \rho sVs \quad (5)$$

The mass of the tank with water can be written using equation three.

$$M2 = Mt + \rho wVt \quad (6)$$

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

$$M2 = Mt + \rho w(Vw + Vs) \quad (8)$$

Taking the difference between equation 8 and 5 removes the term for the tank mass.

$$M1 - M2 = \rho wVw + \rho sVs - \rho w(Vw + Vs) \quad (9)$$

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

$$M1 - M2 = Vs(\rho s - \rho w) \quad (11)$$

Expressed in terms of the volume of sediment

$$Vs = \frac{M1 - M2}{(\rho s - \rho w)} \quad (12)$$

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

$$Ms = \rho s \frac{M1 - M2}{(\rho s - \rho w)} \quad (13)$$

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

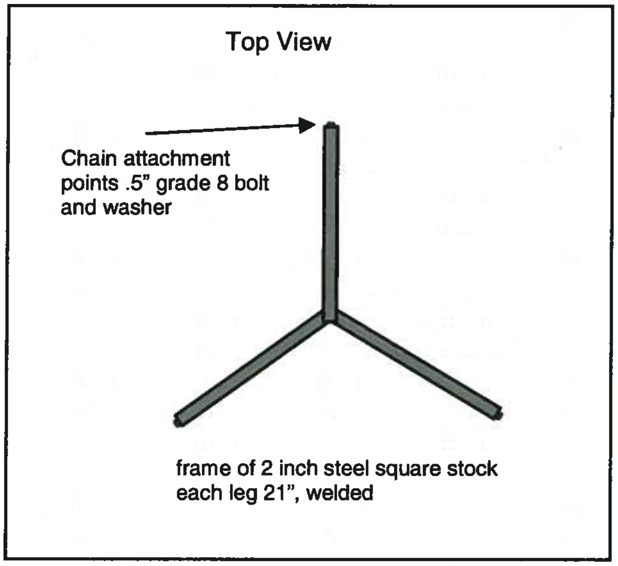
The tank weighing procedure has proven to be repeatable and sufficiently accurate when tested in the field. An experiment was performed to verify the ability of the system to measure the mass of a known amount of sediment Ms. The test was performed using 300 pounds (136.1 kgs) of clean graded quartz sand with a particle density of 2.65 g/cm^3. The initial mass of tank plus water and sand was 2987 pounds (1354.9 kgs). The mass of the tank and water was 2804.9 lbs (1272.3 kgs). In this case the calculated mass of the quartz sand was 300.5 lbs (136.3 kg). The .5 lb (.2 kg) error includes the uncertainty from the load cell, meter, and imperfect tank leveling.

The precision of the full water tank measurement $M2$ was tested by making repeated measurements of the mass of water under the same conditions. The median of the 7 observations was 47.15 lbs (21.4 kg) and the values varied over a range of .35 lbs (.16 kg).

Measuring large sediment masses using a crane

If the sediment mass is expected to exceed 200 pounds per sampler or there are a large number of samples to be taken, a more efficient means of moving and measuring the sample is required. We found that a truck mounted crane is a suitable tool for lifting, moving and weighing sediment tanks weighing as much as 5,000 pounds (2268 kg). A crane based system was used on disturbed road plots that producing as much as 2 tons per plot year. In this case a 10,000 lb (5,000 kg) capacity battery powered S-beam load cell (Dillon model ED 2000) with a reported accuracy of .1% of full-scale range was selected. A 12-ton truck mounted crane was used to lift, manipulate and empty the sediment tanks (figure 8). Tanks are lifted from their top edge using three welded lifting points (Figure 6). The load hook on the crane cable connects an alloy ring to the load cell via a shackle. Below the load cell are attached a roller bearing swivel, spreader bars between the three chain legs and a turn buckle in line with each chain leg. The turnbuckles allow the tank to be precisely leveled under load (figure 8, 9). A large supply of water is required to fill and cleanse the tanks. We used an 800 gallon (3028-liter) tank mounted on the bed of the crane truck and transferred too and from settling basins with a portable gas powered pump. A general equipment list for the crane weighing procedure can be found in appendix C.

Figure 8.
Crane and load cell system used to weigh large sediment samples. Water supply tank is mounted on the bed of the crane



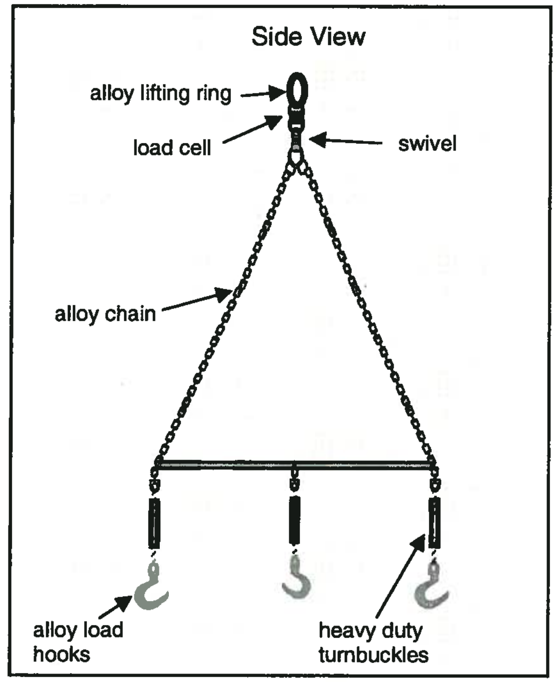


Figure. 9. Detail of tank lifting, leveling and weighing apparatus used with the crane.

Figure 10. Sediment collection tank suspended from crane by radio linked load cell. Notice the load distribution frame, turnbuckles used to level the water surface and steel tipping bars below tank.

The weighing process begins with the calibration and checking of the load cell and meter system. A 1000 lb. (453.6 kg) steel test weight was used for calibration at the start and end of each day's sampling. Move the crane into position as close to the collector as possible. Stabilize and level the crane in a solid location on the road surface paying attention to areas of soft fill. We used railroad ties to build solid footings and a level platform to spread the load applied by the hydraulic outriggers mounted to the chassis of the crane. Level the bed of the crane to within 1% of level in all directions or as recommended by the manufacturer. Attach the tank lifting assembly to the crane hook and zero the weighing system and lifting mechanism. A signal person aids the crane operator in lifting the sediment-laden tanks from the retaining wall enclosure to the roadway where the measurements are made. The sediment containing tank is topped off with water and leveled using the turnbuckles until water spills evenly across the top edge of the tank, as was described in the tripod method. The mass of the tank, water and sediment is recorded from the calibrated load cell. The tank is lowered onto a pair of steel C-channel brackets that are used to aid in the controlled spilling of the tank. The sediment tank tipping supports are composed of two pieces of 3 inch (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 (figure 11). These eye bolts are attached to crane using the hooks on the spreader frame and the tank is 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 and onto the road shoulder vegetation (figure 12). The hooks must have safety retainers that close under spring tension so that the hooks do not slip from the lifting eye bolts as the load shifts. A composite sample of sediment is collected from various depths in the homogenized mass at the bottom of collector. This sample is used to determine the sediment particle density so that the true dry mass of the sample can be determined. The tank is then cleaned out with a shovel and a fire hose driven by a small gasoline powered impeller pump. Use blocks or railroad ties to prevent the tank from rolling on a steep road when it is being cleaned. Care must be taken when emptying the tanks located close to stream channels to avoid unplanned sediment additions.

Sediment Tank Tipping Support

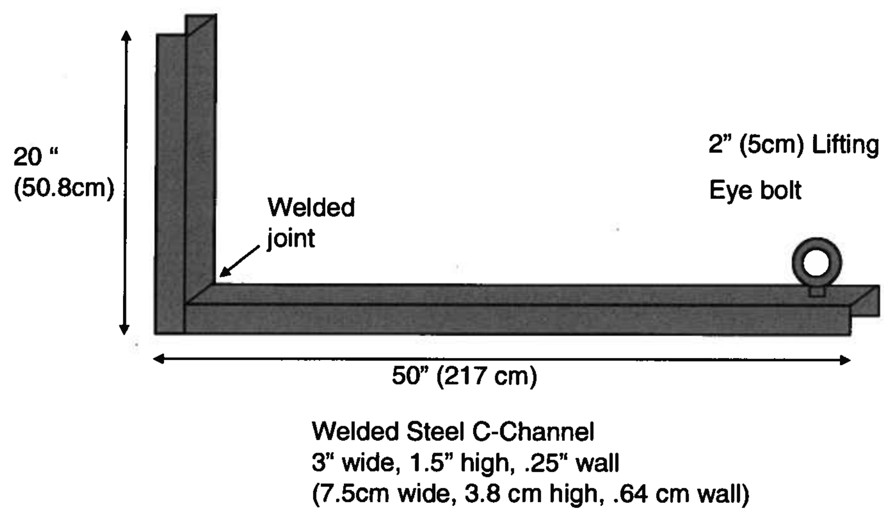


Figure 11.
Sediment tank tipping support dimensions.

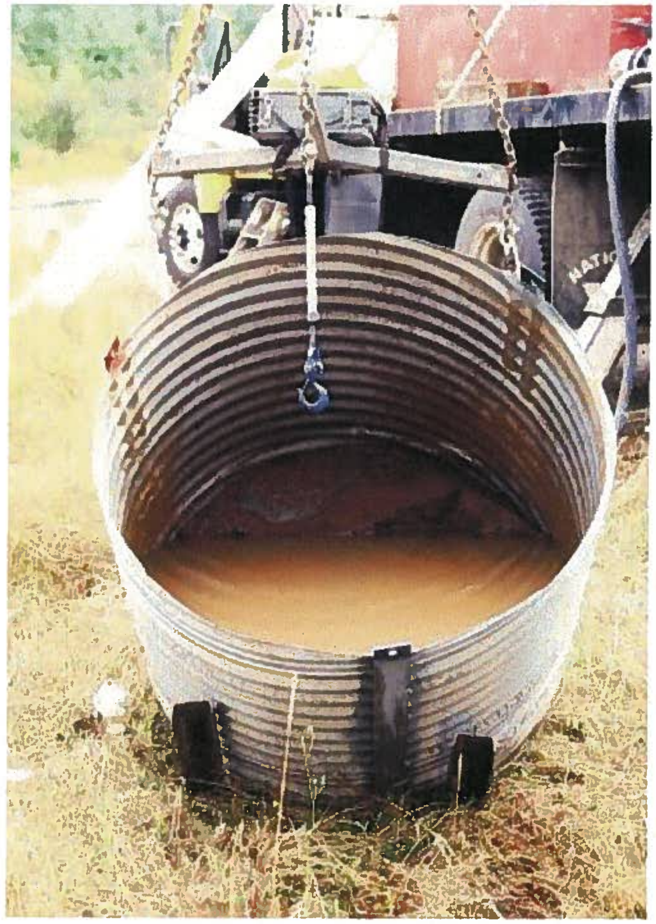


Figure 12.
Sediment tank being tipped over for sediment sampling. Note the L shaped tipper bars supporting the tank

The tank is then lifted upright again and refilled by gravity flow with water from the reservoir on the crane bed. The tank is lifted and leveled once again and a second reading is observed from the load cell meter for the mass of the tank and water. Lift the sediment tank above the crane and siphon the 307 gallons (1162 l) of water back into the reservoir using a large diameter rubber suction hose. The water is recycled at the end of the weighing process to reduce the time spent acquiring clean water from the nearest water supply. The empty tank is then lowered and replaced on the pad.
Extreme caution must be exercised when lifting, moving and emptying the tanks as they are extremely heavy and can easily injure a person who is in their path. Always obtain the proper training before operating heavy equipment and use the recommended safety equipment.

Trap Efficiency
The trap efficiency of the settling basin system alone is sensitive to several factors including particle size, sediment supply and the flow rate through the tank. The particle size available for transport may be the most easily addressed variable. Clay size particles have very slow settling velocities once suspended and will produce low trap efficiencies

in a small settling tank system. When there is minimal ground disturbance on a plot overall production of coarse sediment will like wise be low. In these situations a fine sediment capture system is recommended.

Comparisons were made of 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 material that was trapped by the settling basin. Heavy truck traffic produced finer sediment sizes that were not caught in the settling basin but were observed in the suspended sediment splitter. The range of trap efficiency for the traffic example show a low of 21%of total sediment retained for light traffic and no grading to a high of 68% for light traffic and grading of the ditch. These results support the use of a fine sediment sampler and flow monitoring on fine textured soils to ensure the entire sediment stream is being accounted for.

Measuring flow with a tipping bucket system

In many cases a settling tank system will address the immediate need to quantify the coarse sediment generation from a forest road system. However, with a small additional investment a great deal more hydrologic information may be gathered. In order to understand the fine sediment budget of plots, and the timing of that sediment generation we modified the sediment trap system to include the measurement of flow and suspended sediment. The minor incremental increase in cost increases the utility of the system to cover a broad range of problems and environments. When the soil textures are predominantly fine and the plot receives little disturbance, the sediment in transport may be principally fine. In this case the use of the tipping bucket and sediment splitter is also recommended.

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. As the bucket fills, the system becomes unbalanced and the heavier side tips and empties (figure 13). As the bucket rotates to empty a magnetically actuated reed switch records that passage of a magnet that is attached to the side of the container (figures 13-15). The opposing side is now in position to collect incoming flow and the process repeats itself.

Figure 13.
Tipping bucket and flow splitter in operation. The 20 gpm (66 lpm) design is shown.

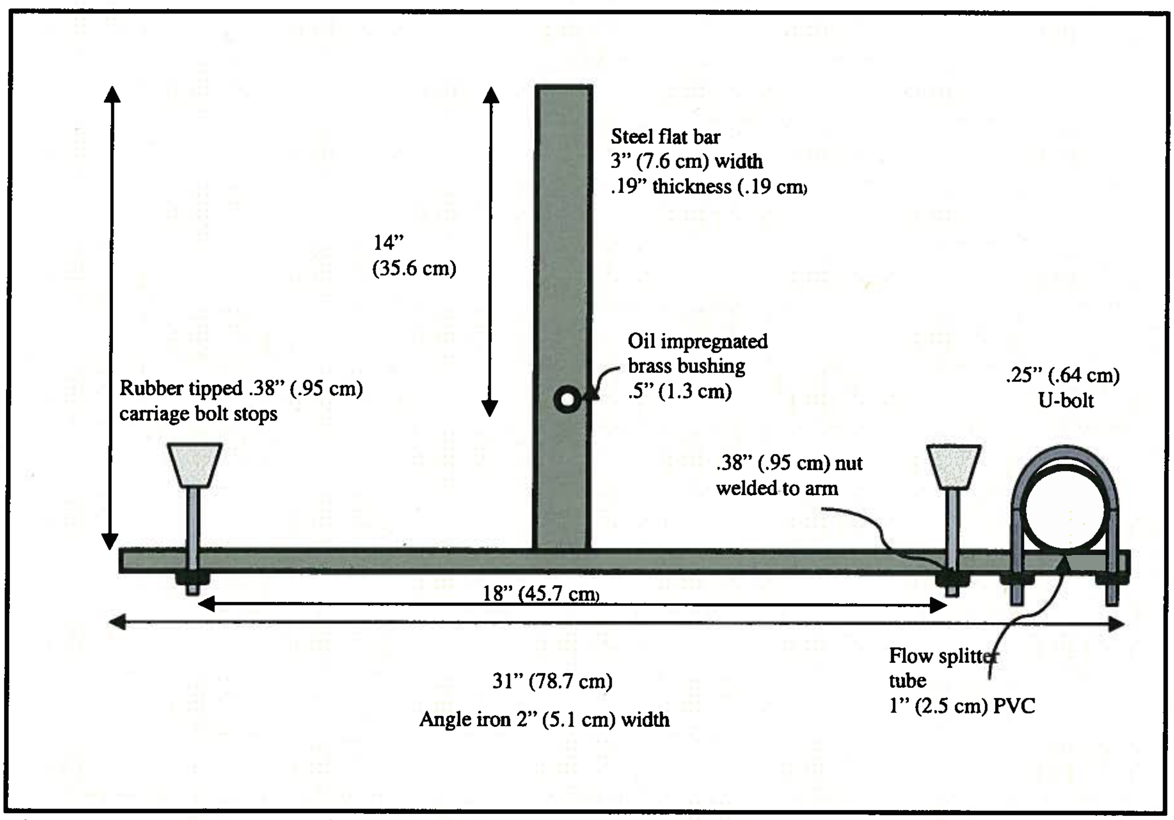


Figure 14. Hanger assembly and sediment splitter for tipping bucket

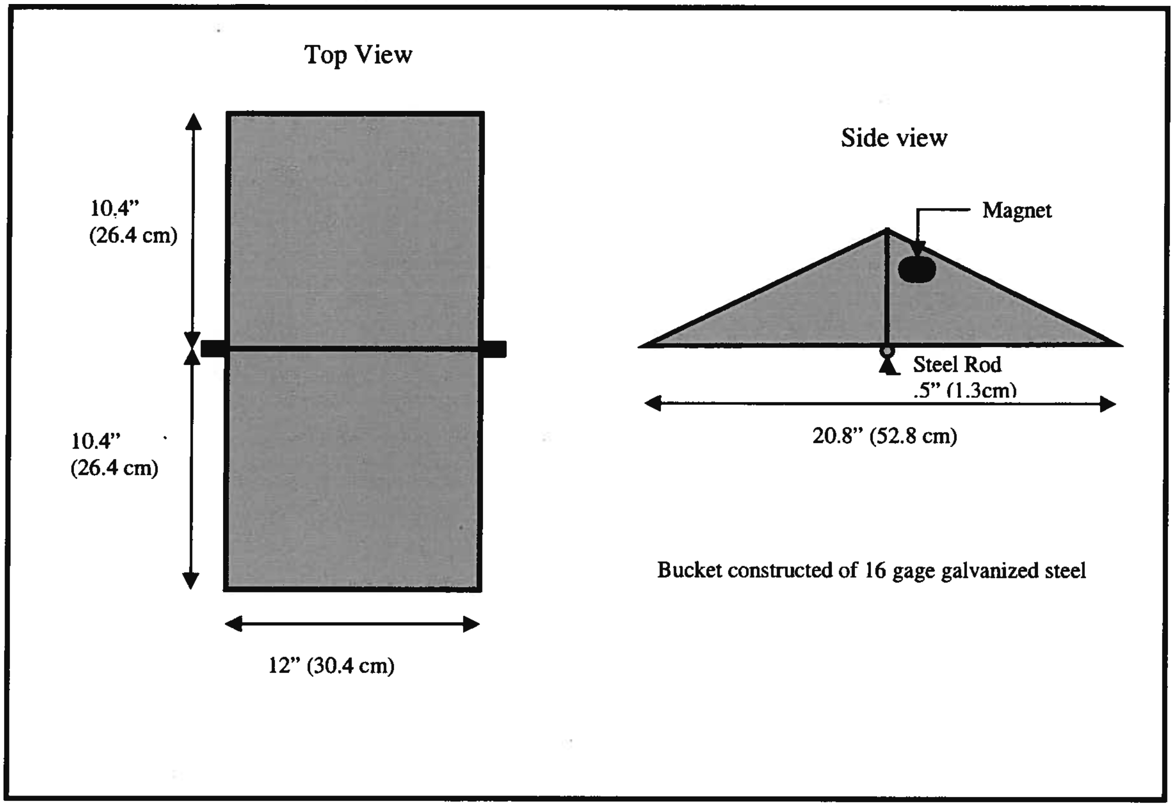


Figure 15. Small tipping bucket container for measuring flows less than 20 gpm (66 lpm)

A data-logging device located in a waterproof case is connected to the reed switch. In this case, an Onset Hobo Event data logger was used. Each time the magnet passes the reed switch a circuit closes causing the data logger to collect a time stamp. The time stamp file allows the user to calculate the time interval required to fill the bucket volume. The device is calibrated to determine the relationship between discharge and switch closures because the relationship is somewhat dependant on setup and leveling of the device. The calibration is applied to the record and a high resolution continuous hydrograph can be created.

Tipping bucket design

The devices are designed to be durable and sufficiently adjustable to accommodate a variety of field installations while minimizing complexity and cost. At the time of writing large size tipping buckets such as those described here were not available on the market so it was necessary to have them fabricated by a machine shop. The costs ranged from less than $100 for the 20 gpm (76 lpm) to $300 for the large 35 gpm (132 lpm) size. Three basic designs are described in this document. The small (figure 13) and medium sizes (figures 16-18) are suspended from the tank outlet. The largest size tipping bucket (figures 19 and 20) is free standing and more durable as a result.

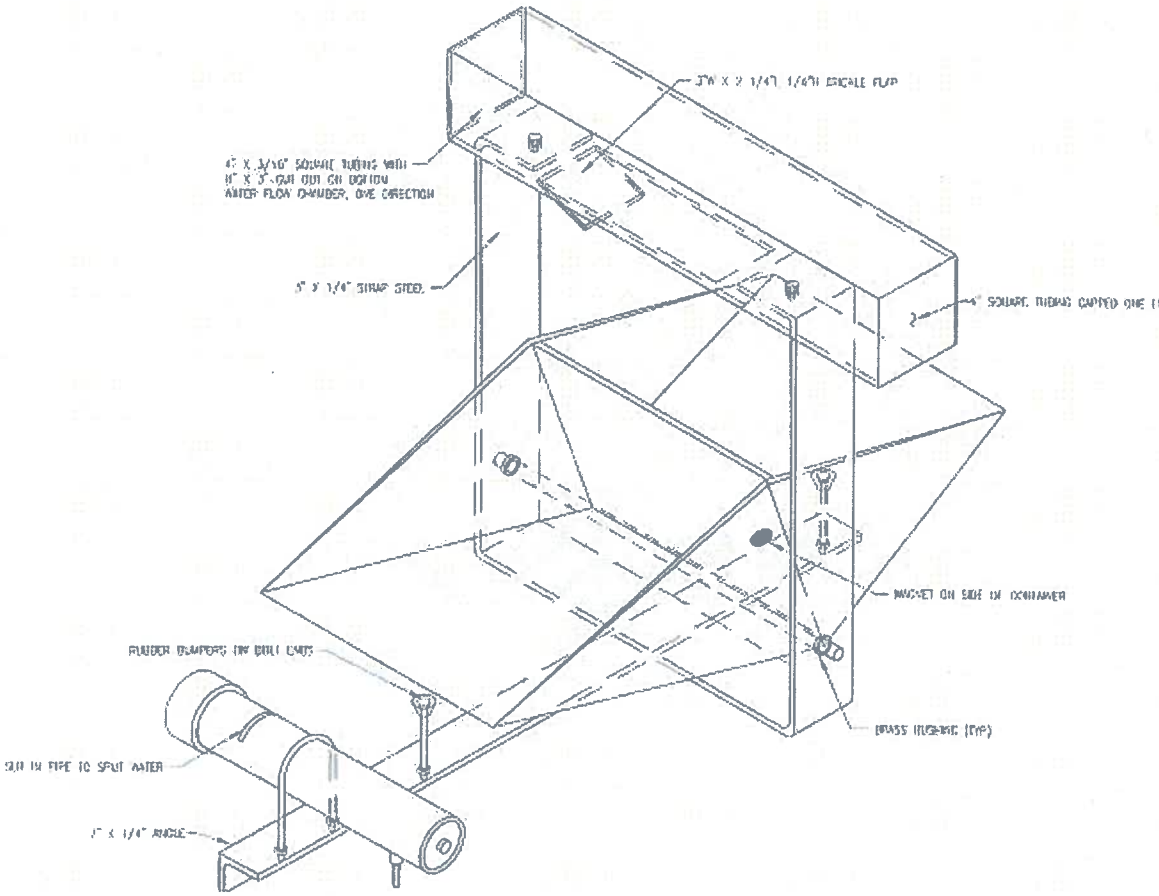


Figure 16
Isometric view of the medium size tipping bucket and attachment to tank outlet.

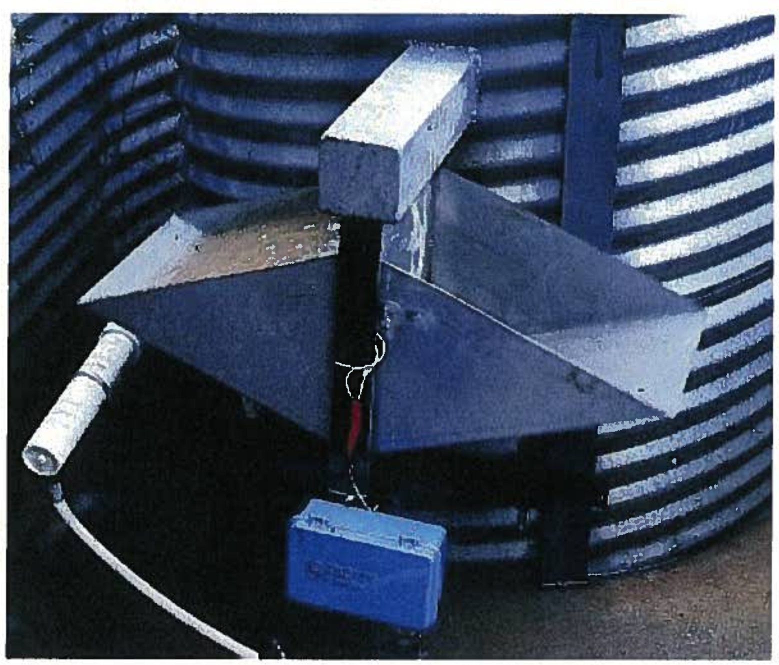


Figure 17.
Medium capacity tipping bucket and flow splitter in mid-cycle

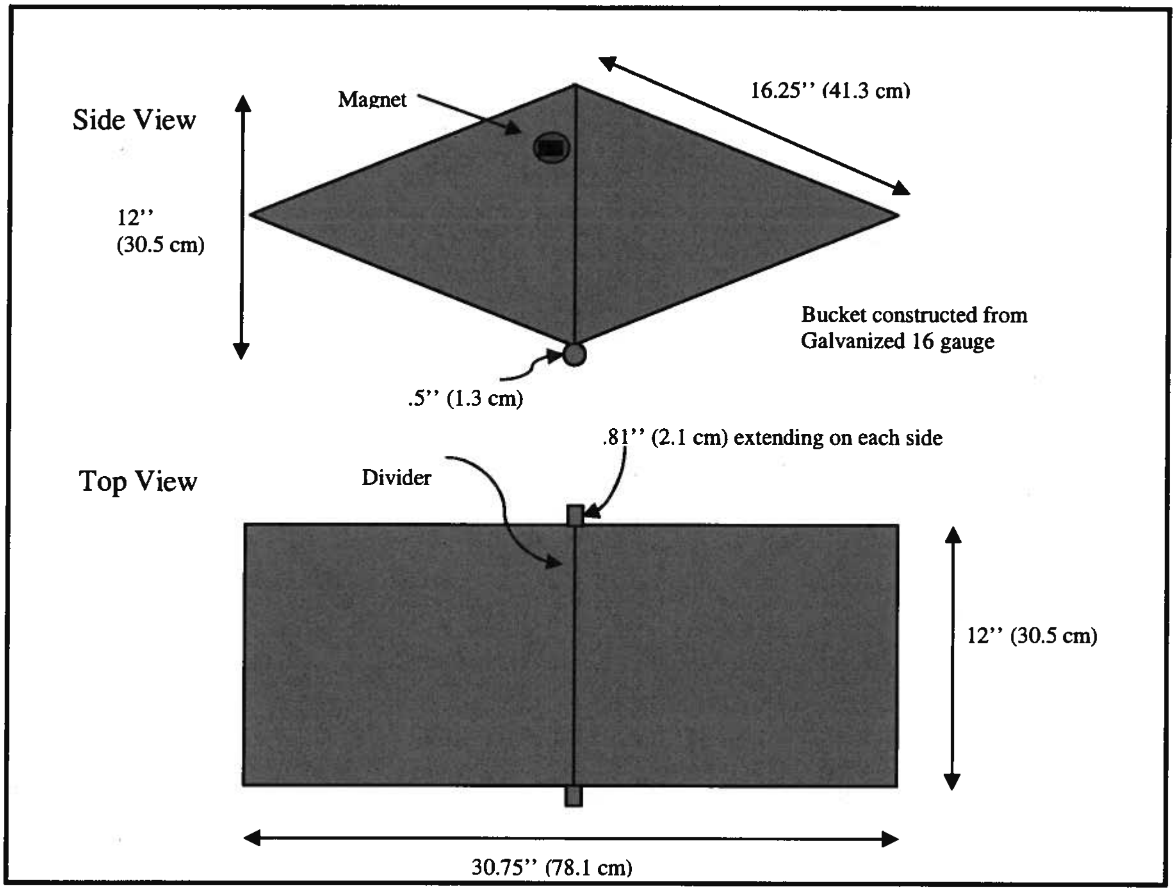
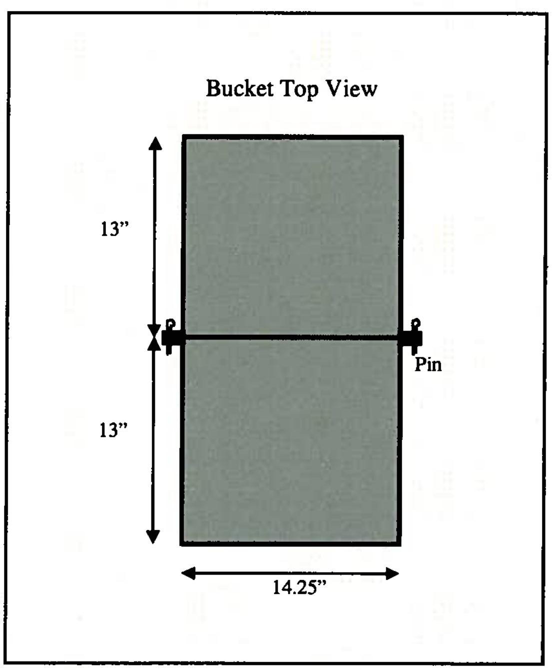
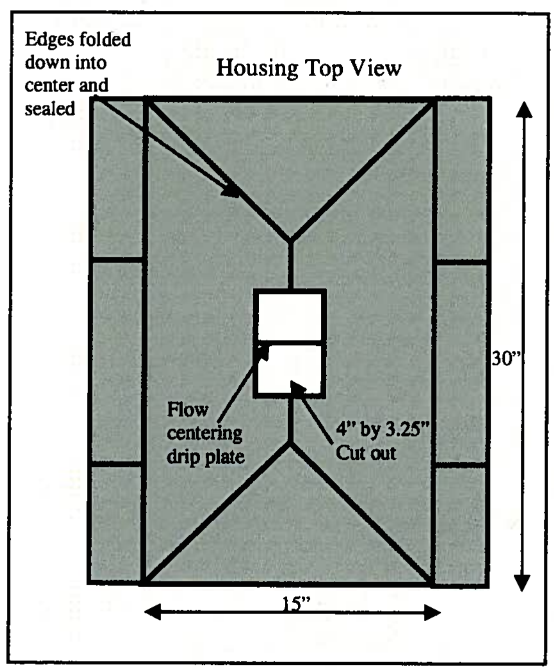
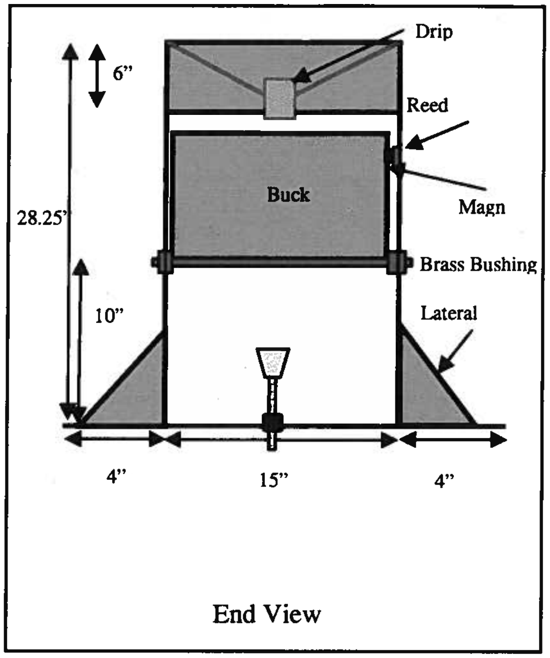


Figure 18.
Medium capacity bucket specifications.

Figure 19. Large free standing tipping bucket with pipe directing flow to inlet.







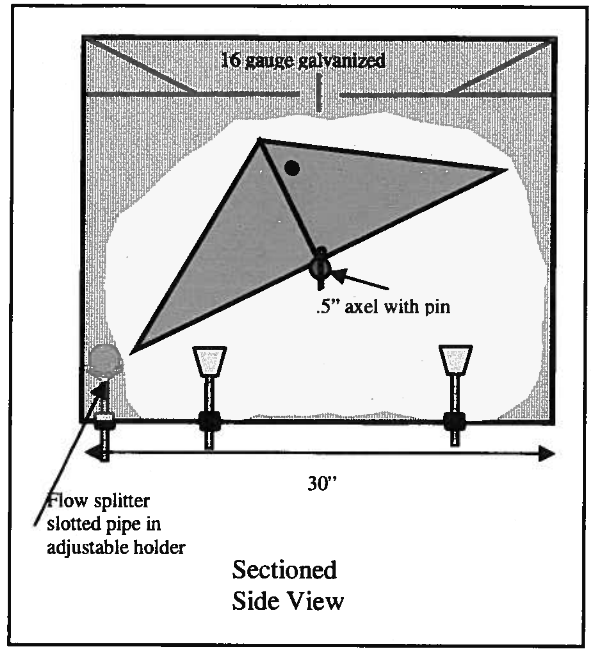


Figure 20.
Large size free standing tipping bucket specifications.

The support frame from which the small and medium buckets are suspended is constructed from steel flat bar. The frame hangs from the tank outlet suspended from two .5" (1.2 cm) bolts. The buckets are constructed of welded 16 gauge galvanized sheet metal sealed at the seams. The pan is welded to a half inch (1.3 cm) rod that acts as an axle. The buckets are connected to the frame by inserting the rod through a brass bushing in the frame before the frame assembly is hung from the bolts on the outlet of the tank. There are adjustable rubber stops on the frame that are used to set the travel of the tipping bucket pan. The stops are constructed from carriage bolts with a rubber crutch tip glued to the round head of the bolt. The stops attach to a transverse arm on the frame by a nut welted in place, and are secured by a second nut.
There are a variety of data loggers available on the market and new models appear each year. At the time of this design the Hobo Event logger was selected for ease of use, durability and value. The Hobo Event logger has a memory capacity of up to 8000 switch closure events. This translates to roughly 6,000 gallons (26,430 liters) of discharge with the small size bucket at .75 gallons (2.8 liters) per tip and 24,000 gallons (90,720 liters) for the medium size bucket holding approximately 3 gallons (11.3 liters). The small bucket size can be used to measure discharge of up to 20 gallons (76 liters) per minute and the larger size is suitable for flows up to 35 gallons (113 liters) per minute. The large free standing model supporting higher flow rates was tested at flow rates as high as 60 gallons per minute (227 l/min).
To select the appropriate size device consider both the expected peak flow rate and the desired low flow rate. The interval at which the data will be downloaded from the field

and the size of the data logger memory are also considerations. 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) (appendix A). 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 two seconds was used. The switch and wiring assembly is epoxied to the inside of the frame and the magnate 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 gasketed dry box 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 dry box assembly is attached with Velcro to the front of the tipping bucket frame (Figure 19).

Tipping bucket 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 one 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.

Use nylon lock nuts to secure the frame to the tank outlet hanger bolts.

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 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 calibration curve for each tipping bucket gauge 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. Use a stopwatch to measure the time. Create the calibration curve from 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 g/m (76 l/m) 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 in previous studies, 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 two 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, .38 inch (one cm) diameter bolts were used to secure the frame but they did not provide enough resistance to hold the larger devices in place when the flow reached high rates. It was found that many of the large capacity devices had become loose on their support bolts during a large event. When the hanger bolt size was upgraded to .5 inch (1.3 cm) and secured by nylon lock nuts the problem did not reoccur.

Fine sediment collection

A flow splitter was used to collect a sub-sample of the discharge from one side of the tipping bucket. A 1.5 inch (3.75 cm) diameter segment of PVC pipe was attached to the cross arm of the tipping bucket frame below the lower edge of the bucket (figures 16 and 17). 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 were collected. This water and fine sediment were routed through the inclined pipe and into a piece of rubber tubing and collected in a sealed bucket 5 gallon (19 l) bucket with an air vent.

The sub-sample water reservoir was examined each time the discharge data were collected (figure 17). If more than a gallon of water had accumulated then a sub-sample was taken and the reservoir cleaned. The fine sediment in the water reservoir was homogenized with an impeller driven by a portable drill for a period of three minutes. A .3 gallon (one-liter) 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 et al 1995). The sediment concentration may also be determined by oven drying the sample at 105 degrees

C when dissolved solid do not constitute an appreciable portion of the mass in transport (Eaton et al 1995).

Conclusions

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. The tipping bucket system provides a simple and inexpensive method to monitor discharge and sediment production from road surface plots. The tipping bucket devices described herein provides a detailed and reliable record of discharge up to132 liters per minute when properly calibrated and maintained. The system provided a complete sediment and discharge record when used with a settling basin and a flow splitter for the determination of fine sediment. On newly constructed roads and on coarse textured soils settling basins alone provide an adequate measurement of sediment leaving the road. On undisturbed plots and in conditions of traffic without ditch disturbance the tipping bucket and sediment splitter are recommended to adequately characterize the sediment production.

References:

Ackers, P. White, W. R., Perkins, J.A. and Harrison, A.J.M. 1978 *Weirs and Flumes for Flow Measurement*, John Wiley and Sons. New York, NY.

Bilby, R.E., Sullivan, K.O. and S.H. Duncan 1989. The generation and fate of road surface sediment in forested watersheds in Southwestern Washington. Forest Science 35(2):453-468

Blake G. R.and K. H. Hartage 1986 . Particle Density. In Methods of Soil Analysis, Part 1 Physical and Mineralogical Methods-Agronomy Monographs no. 9. pp377-379.

Black, Thomas A. Luce, Charles H. 1999. Changes in erosion from gravel surfaced forest roads through time. Sessions, John; Chung, Woodam, eds. Proceedings of the International Mountain Logging and 10th Pacific Northwest Skyline Symposium; 1999 March 28- April 1, Corvallis, OR; Corvallis, Oregon. Oregon State University and International Union of Forestry Research Organizations: 204-218.

Cederholm, C.J. Ried, L. M. and Salo, E. O. 1981. Cumulative effects of logging and road sediment on Salmonid populations in the Clearwater River, Jefferson County, Washinton. Pp38-74 in Proceedings the conference Salmon Spawning Gravel: A renewable Resource in the Pacific Northwest?, Water Research Center, Washington State University, Pullman, Washington.

Cline, R.G. Cole, W. Megahan, R. Patten, and J. Potyondy. Guide for predicting sediment yield from forested watersheds. USDA Forest Service Northern Region and Intermountain Region, Missoula MT and Ogden Utah, 1984

Coker, R. J. Fahey, B. D. and Payne, J.J. 1993. Fine sediment production from Truck Traffic, Queen Charlotte Forest, Marlbough Sounds, New Zealand. Journal of Hydrology (N.Z.) 312 (1), 56-64.

NCASI, 2003. Technical Documentation for SEDMODL Version 2.0, Road Erosion/Delivery Model. Report prepared for National Council for Air and Stream Improvement. http://www.ncasi.org

Eaton, D. A., Clesceri, L. S., Greenberg, A. E., 2540-D in Standard Methods for the Examination of water and Wastewater 19th edition. American Public Health Association 1995

Elliot, W.J.; Hall, D.E.; Graves, S.R. 1999. Predicting sedimentation from forest roads. Journal of Forestry, August 1999, 97(8):23-29.

Foltz R. B. and M. A. Truebe. 1995 Effect of Aggregate Quality on Sediment Production from a Forest Road. Proceedings of the Sixth Annual Conference on Low-Volume

Roads, Minneapolis Minnesota. Transportation Research Board, National Research Council.

Grant, D. 1988. *ISCO Open Channel Flow Measurement Handbook* Second Edition. ISCO Corporation, Lincoln Nebraska 227p

Ice, George G. 1986 A study of the Effectiveness of Sediment Traps for the Collection of Sediment from Small forest Plot Studies. NCASI technical bulletin #483

Jones J. A. and G. E. Grant, 1996 Peak flow responses to clear-cutting and road in small basin, Western Cascades, Oregon. Water Resources Research 32(4) 959-974

Kahklen, Keith 1993, Surface Erosion from Forest Roads, Polk Inlet, Prince of Wales Island Alaska. Masters thesis, Oregon state University

Lamarche, J. and D.P. Lettenmaier, 2001, Effects of forest roads on flood flows in the Deschutes River Basin, Washington, Earth Surface Processes and Landforms, 26(2): 115-134.

Lee, D; Sedell, J.; Rieman, B.; Thurow, R; Williams, J, and others. 1997. A broad-scale assessment of aquatic species and habitats. *in* T. Quigley and S. Arbelbide. tech. ed. An assessment of ecosystem components of the interior Columbia River Basin and portions of the Klamath and Great Basins. General technical report PNW-GTR-405. Portland, OR: USDA Forest Service, Pacific Northwest Research Station

Linde, David R. 2001. The Handbook of Chemistry and Physics 82nd Edition. CRC Press, Boca Raton, Florida.

Luce, Charles H. 2002. Hydrological processes and pathways affected by forest roads: what do we still need to learn? Hydrological Processes. 16: 2901-2904.

Luce, C. H. and T. A. Black, 1999. Sediment production from forest roads in western Oregon. Water Resources Research. 35(8): 2561-2570.

Luce, C. H. and T. Black, Thomas A. 2001a. Effects of traffic and ditch maintenance on forest road sediment production. Proceedings of the Seventh Federal Interagency Sedimentation Conference; 2001 March 25-29, Reno, NV. Washington, DC: Federal Interagency Sedimentation Committee: V-67-74.

Luce, C. H. and T. A. Black. 2001b. Erosion over time from gravel-surfaced forest roads in western Oregon. Proceedings of the Forest Sedimentation Conference; 1999 April 14-15, Tigard, OR. Northwest Forest Soils Council and Western Forestry and Conservation Association: 135-139.

Luce, C. H. and T. A. Black. 2001c. Spatial and temporal patterns in erosion from forest roads. Wigmosta, M. S. and S. J. Burges, eds. Land use and watersheds: human influence on hydrology and geomorphology in urban and forest areas – Water Science and Application 2. Washington, DC: American Geophysical Union: 165-178.

Luce, C. H and T.W. Cundy. 1994. Parameter identification for a runoff model for forest roads, Water Resources Research 30(4), 1057-1069

McDonald, L. K, Sampson, R. W. and Anderson, D. M. 2001. Runoff and Road erosion of the Plot and Segment Scales, St John, US Virgin Islands. Earth Surface Processes and landforms, 26, 251-272.

Megahan, W.F and Kidd, W. J 1972. Effects of Logging Roads on Sediment Production Rates in the Idaho Batholith. USDA Forest Service Research Paper INT-123.

Montgomery, David R. 1994 Road Surface drainage, channel initiation and slope instability. Water Resources Research 30(6) 1925-1932
Reid, L. M. and Dunne, T 1984. Sediment Production from Forest Road Surfaces. Water Resources Research V. 20(11) pp1753-1761

Reid, L. M. and T. Dunne. *Rapid Evaluation of Sediment Budgets*. Springer Verlag Reiskitchen, Germany. 164 pp. 1996

Replogle, J. A. and A. J. Clemmens. 1981. Measuring flumes of simplified construction. Transactions of the American Society of Agricultural Engineers 24(2) 362-266

Thurow, R.F.; Burns, D.C. 1992. Fish response to fine sediment deposition in the Idaho batholith. Pp-130 *in* Sommarstrom, ed. Proceedings of the Conference on Decomposed Granitic Soils: Problems and Solutions. Davis, CA: University Extension. University of California.

Tysdal, L. M., Elliot, W. J., Luce, C. H. and T. A. Black. 1999. Modeling erosion from insloping low-volume roads with WEPP watershed model. Transportation Research Record no. 1652. 250-256. Proceedings of the Seventh International Conference on Low-Volume Roads, Batton Rouge, LA. Transportation Research Board, National Research Council.

United States Department of Agriculture. Field Manual for Research in Agricultural Hydrology Handbook #224. Brakensiek, D. L., H. B. Osborn, and W. W. Rawls editors. US Government Printing Office WA. DC. 547 pp 1979

Washington Forest Practices Board. 1993. Standard methodology for conducting watershed analysis under Chapter 222-22 WAC. Version 2.0. Department of Natural Resources Forest Practices Division, Olympia, WA.

Wemple, B. C., Jones, J. A. and G. E. Grant, 1996. Channel network extension by logging roads in two basins, western Cascades, Oregon. Water Resources Bulletin, 32(6) 1195-1207.

Wigmosta, M.S. and W.A. Perkins, 2001. Simulating the effects of forest roads on watershed hydrology, in *Land Use and Watersheds: Human Influence on Hydrology and Geomorphology in Urban and Forest Areas*, M.S. Wigmosta and S.J. Burges, eds., AGU Water Science and Application Volume 2, p. 127-143.

Appendix A Cost for Installation of 5 Road Sediment Plots

Cost to install 5 road sediment plots

Materials	Units	Quantity	Cost per	Extended Cost
Sediment Tank, 330 gallon galvanized steel [a]	piece	5	$150	$750
Pipe, 6 inch plastic N12 pipe, each plot 90 feet	feet	450	$2	$675
Waterbars, conveyor belt [b, c]	piece	10	$110	$1,100
Ditch inlet structure, steel half round [a]	piece	10	$28	$280
Gravel for tank pad	cubic yards	5	$8	$40
Gravel delivery	trip		$200	$200
Load cell scale		1	$200	$200
Construction Equipment Rental				
Mini excavator	days	1	$225	$225
Riding trencher	days	2	$250	$500
Gravel packer	days	2	$100	$200
Labor				
Construction 3 person days per plot (@$18/hr)	days	3	$144	$300
Periodic plot maintenance (one year)	days	3	$144	$432
Sediment tank weighing	days	1.5	$144	$216
Sub-total				**$5,118**
Additions for tipping bucket system				
Tipping bucket and sediment collector [d]	5		$200	$1,000
Data loggers [e]	5		$89	$445
Reed switches [f]	5		$30	$150
Magnets [g]	5		$7	$35
Dry box enclosure	5		$18	$90
Labor $18/hr	days	2	$144	$288
Operational Costs				
Downloading flow data device and maintenance (one year)	days	8	$145	$1,160
Total				**$8,286**

Vendor	Email	Address	Phone
[a] Pacific Corrugated Pipe	www.pcpipe.com	89822 Highway 99 North, Eugene, OR 97402	(541) 461-0990
[b] Fabreeka International	www.fabreeka.com/	696 West Amity Road, Boise Idaho	(208) 342-4681
[c] Goodyear Rubber and Supply	www.goodyear-rubber.com/	765 Conger St. Eugene OR. 97402	(541) 686-9554
[d] Smitty-Bilt Industrial Fans, Inc		32060 Herman Rd. Eugene OR 97408	(541) 343-7584
[e] Onset Computer Corporation	www.onsetcomp.com	P.O. Box 3450 Pocasset, MA 02559-4377	(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

Appendix B _Tripod Weighing Equipment list

Battery operated load cell 100-pound (45 kg) capacity and spare
Load cell battery and spare
Survey tripod
Load cell hanger hook
Steel leveling bucket
Plastic buckets three gallon (11 l) and five gallon (19 l.) sizes
Plastic scoops, 2 large
Plastic cup
Squirt bottle
Hand trowel
Shovel, short handle flat blade
Brush to clean inside of tank
Water supply (55 gallon (208 l) drum or other)
Pump, portable gasoline powered
Hoses for pump, suction and discharge
Hose for water supply container
Pump fuel container
Tool box
Tape measure
Field book with data sheets
Sample bags, plastic 1 gallon (4 l) size
Sharpies
Pencils
Gloves
Rubber Boots
Digital camera

Appendix C _Crane Weighing Equipment list
Radio linked load cell 10,000-pound (5000kg) capacity
Spare batteries for load cell and receiver
Rigging and spreader bars for crane
Plastic buckets five gallon (19 l.) sizes
Plastic scoops, 2 large
Plastic cup
Shovels, long and short handled with flat blade and spade
Pulaski
Brush to clean inside of tank
Water tank
Pump, portable gasoline powered
Hoses for pump, suction and discharge
Hose for water supply container

Pump fuel container
Tipper bars
Railroad ties, 16
Tool box
Tape measure
Field book with data sheets
Sample bags, plastic 1 gallon (4 l) size
Sharpies
Pencils
Leather and rubber gloves
Hard hats
Rubber Boots
Eye protection
Digital camera

Appendix D
Density of Pure water at 101325 Pa (Linde 2001)

Degrees C	kg/m^3	Degrees C	kg/m^3
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

Appendix E.

Road Sediment Plot Field Sheet

Field Area:

Plot #: Date:

Crew:

Depth of Sediment (in):

Texture of Sediment (in):

Color of sediment:

Tare of bucket+water (lbs):

Tare water temp (F): Sample water temp (F):

Sample #	Sediment + bucket (lbs)
#1	
#2	
#3	
#4	
#5	
#6	
#7	
#8	

Sample #	Sediment + bucket (lbs)
#9	
#10	
#11	
#12	
#13	
#14	
#15	
#16	

Sub-sample taken?

Plot Condition:

Remarks:

ATTACHMENT C
(Particle Density Method)

14 Particle Density[1]

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14–1 INTRODUCTION

Particle density of soils refers to the density of the solid particles collectively. It is expressed as the ratio of the total mass of the solid particles to their total volume, excluding pore spaces between particles. Convenient units for particle density are megagrams per cubic meter (Mg m^{-3}), or the numerically equal grams per cubic centimeter (g cm^3).

Particle density is used in most mathematical expressions where volume or weight of a soil sample is being considered. Thus interrelationships of porosity, bulk density, air space, and rates of sedimentation of particles in fluids depend on particle density. Particle-size analyses that employ sedimentation rate, as well as calculations involving particle movement by wind and water, require information on particle density.

14–2 PRINCIPLES

Particle density of a soil sample is calculated from two measured quantities, namely, the mass and volume of the sample. The mass is determined by weighing; the volume, by calculation from the mass and density of water (or other fluid) displaced by the sample. The pycnometer and the submersion methods are based on the same principle. Both have long been in use. They are simple, direct, and accurate if done carefully.

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[1]Paper no. 11121 of the Scientific Journal Series, Minnesota Agricultural Experiment Station, St. Paul, MN.

14–3 PYCNOMETER METHOD (ASTM, 1958, p. 80; U.S. Dep. Agric., 1954, p. 122)

14–3.1 Special Apparatus

A pycnometer (specific-gravity flask) is employed. A pycnometer is a glass flask fitted with a ground-glass stopper that is pierced lengthwise by a capillary opening. A thermometer is sometimes an integral part of the stopper, the glass-enclosed mercury reservoir being in contact with the fluid in the flask, with the stem extending above the ground joint. A 10-mL pycnometer has sufficient capacity.

A small volumetric flask (25, 50, or 100 mL) may be used in place of a pycnometer when the sample is large enough to compensate for the decrease in precision of measuring fluid volume.

14–3.2 Procedure

Weigh a clean, dry pycnometer in air. Add about 10 g of air-dry soil sieved through a 2-mm sieve. If a 100-mL volumetric flask is used, add 50 g of soil. Clean the outside and neck of the pycnometer of any soil that may have spilled during transfer. Weigh the pycnometer (including stopper) and its contents. Determine the water content of a duplicate soil sample by drying it at 105 °C.

Fill the pycnometer about one-half full with distilled water, washing into the flask any soil adhering to the inside of the neck. Remove entrapped air by gentle boiling of the water for several minutes, with frequent gentle agitation of the contents to prevent loss of soil by foaming.

Cool the pycnometer and its contents to room temperature, and then add enough boiled, cooled, distilled water at room temperature to fill the pycnometer. Insert the stopper and seat it carefully. Thoroughly dry and clean the outside of the flask with a dry cloth, using care to avoid drawing water out of the capillary. Weigh the pycnometer and its contents, and determine the temperature of the contents after they have cooled to room temperature.

Finally, remove the soil from the pycnometer and thoroughly wash it. Fill the pycnometer with boiled, cooled distilled water at the same temperature as before, insert the stopper, thoroughly dry the outside with a cloth, and weigh the pycnometer and contents, being careful that the temperature remains the same as before.

Calculate the particle density as follows:

$$\rho_p = \rho_w (W_s - W_a)/[(W_s - W_a) - (W_{sw} - W_w)] \quad [1]$$

where

ρ_w = density of water in grams per cubic centimeter at temperature observed,

W_s = weight of pycnometer plus soil sample corrected to oven-dry water content,
W_a = weight of pycnometer filled with air,
W_{sw} = weight of pycnometer filled with soil and water, and
W_w = weight of pycnometer filled with water at temperature observed.

14–4 SUBMERSION METHOD (Capek, 1933)

14–4.1 Special Apparatus

1. A laboratory balance with a thin wire attached to the weighing beam, to which a light frame can be suspended. The frame serves as a platform for placing a weighing dish so that both frame and dish can be immersed in a container of liquid during weighing (see also section 13–4.2.1).
2. Sample containers. Aluminum weighing dishes of about 5-cm diameter and 3-cm height are suitable.
3. A container for water or a nonpolar liquid such as xylene or toluene, into which the weighing dish and sample can be immersed. Surface diameter should be about three times that of the weighing dishes.

14–4.2 Procedure

Moisten about 25 g of soil to a plastic consistency and force it by hand through a 2-mm sieve to form spaghetti-like threads. Dry the soil in a tared weighing dish to 105 °C, cool it to room temperature in a desiccator with a drying agent, and weigh it.

Add water to the dish to cover the soil, place weighing dish and soil in a vacuum desiccator, and evacuate for about 10 min to eliminate entrapped air from between the threads. Transfer weighing dish and sample to the weighing frame attached with a wire to the balance. Submerge weighing dish, frame, and soil sample into container of water and carefully reweigh while they are suspended in the water. Remove and discard the sample, clean the weighing dish, and weigh it while it is submerged in water. Determine the temperature of the water, and from handbook tables, determine its density. Use the same technique when working with a nonpolar liquid instead of water.

When a series of samples is analyzed using the same organic liquid, it is convenient at this point to submerge and weigh a small piece of metal such as 30 to 50 g of brass in the same container of liquid. Constancy of its submerged weight after each soil sample weighing assures the analyst that the organic liquid is not contaminated and allows re-use of the same liquid.

Calculate particle density as follows:

$$\rho_p = \rho_l (W_{sd} - W_d)/[(W_{sd} - W_d) - (W_{sdl} - W_{dl})] \quad [2]$$

where

ρ_l = density of water or organic liquid used, g cm^{-3},
W_{sd} = oven-dried weight of soil with weighing dish,
W_d = weight of weighing dish,
W_{sdl} = weight of sample and dish submerged in liquid, and
W_{dl} = weight of dish alone, submerged in liquid.

14-5 COMMENTS

The pycnometer method has the advantage of giving very precise densities if volumes and weights are carefully measured. The submersion method sacrifices some precision but offers ease of measurement, especially when measurements are made on a series of samples. It does not require a calibrated pycnometer, it avoids accurate drying and cleaning of containers during repeated measurements, and it is less laborious, since the care needed to obtain reproducible accuracy in filling the pycnometer or flask is unnecessary. These advantages of the submersion method are best realized when a nonpolar organic liquid is used. A disadvantage of the submersion method is that it cannot be used on sandy soils where coherence may be too small to allow one to make the spaghetti-like threads.

With the pycnometer or a flask, a weighing error of 1 mg on a 10-g soil sample gives an error in particle density of only 0.0003 g cm^{-3}. A weighing error of 10 mg on a 30-g sample gives a particle density error of 0.001 g cm^{-3}. Greater errors can result from lack of precision in the volume measurement. If W_{sw} in Eq. [1] is based on a volume that exceeds the volumetric flask marking by 0.2 mL, and W_w on a volume 0.2 mL deficient of the marking, the compounded particle density error is 0.05 g cm^{-3} on a 40-g sample. The analyst should check the calibration marking on the flask as well as his or her ability to measure a reproducible volume, by making a number of preliminary weighings of water in the flask to be used for the analysis. The submersion method, if performed as described with 25 samples each between 20 and 30 g, gives a standard error of 0.005 g cm^{-3} for homogenized material. If unmixed replicate samples are used from surface soils, standard error tends to be several times greater. In addition to weight and volume errors, one must assume some error due to nonrepresentative sampling in either method.

Particle density values for finely divided active soil obtained by weighing in water are greater than those obtained with nonpolar organic liquids. There appears to be little difference between organic liquids. Anderson and Mattson (1926) found the average specific gravity of the clay fractions of six soils to be greater in water than in toluene by 0.13, while Capek (1933), using xylol, benzol, petroleum ether, and benzene, found an increase averaging 0.001 for quartz and 0.01 to 0.1 or even more for loam and chernozem soils. Smith (1943) found that water gave higher values for five soils than xylene, tetralin, or dichloroethyl ether by 0.01 to 0.03; and Gradwell (1955) found that the value for the specific gravity increased as the content of minerals with expanding lattices increased, or as the presence of finely divided, amorphous minerals increased. As the internal surface of non-allophane minerals increased from 33 to 306 m^2 g^{-1}, the increase in specific gravity determined in water over that determined in toluene varied from 0.014 to 0.094. Allophane values were greater in water by 0.05 to 0.3.

Water density is known to be affected by surfaces of finely divided particles. Though interactions of nonpolar organic molecules with clay surfaces are incompletely understood, it seems evident that the more accurate particle densities of clays would be obtained by use of nonpolar inorganic liquids in a pycnometer. Nevertheless, as Gradwell (1955) pointed out, where finely divided amorphous minerals or minerals with expanding lattices are present, it may be undesirable to substitute other liquids for water in determinations of specific gravity if the measurements are to be applied in computing the volume of solids in a soil in contact with water. For many applications, however, densities inaccurate by 0.05 g cm^{-3} will suffice. Whether to use water or organic liquids is thus largely a question of how the data are to be used.

An advantage of nonpolar organic liquids is that soil samples, especially those high in organic matter, are wetted more easily than they are with water. Boiling is unnecessary when the pycnometer or flask is used; gentle shaking or stirring lightly with a glass rod is sufficient. It is desirable, however, when using nonpolar liquids, to evacuate the half-filled container in a vacuum desiccator for 10 min to facilitate removal of air. Another advantage in using organic liquids, especially for organic soils and peat, is that the soil or organic particles sediment faster after stirring than they would in water. In the submersion method this is important in reducing buoyancy when one weighs the sample in a weighing dish submerged in the fluid. Disadvantages of using organic liquids are their high vapor pressure and their low heat capacities. Because of the former, work in a well-ventilated hood is necessary. Since the low heat capacity presents the hazard of thermal dilation, it is essential to use only tongs for handling the containers.

Both the pycnometer and the submersion methods give the weighted mean density of all particles in the sample. This is the value needed for calculations mentioned in the introduction. Densities of individual soil grains may vary widely from the weighted mean. For example, handbook densities of silt and sand-sized particles are 2.65 for quartz, 2.5 to 2.8 for feldspars, 2.7 to 3.3 for micas, and 3.1 to 3.3 for apatite. The density of humus is usually < 1.5 Mg m^{-3}.

14-6 REFERENCES

Am. Soc. Test. Mater. 1958. Procedures for testing soils. American Society for Testing and Materials, Philadelphia.

Anderson, M. S., and S. Mattson. 1926. Properties of the colloidal soil material. U.S. Dep. Agric. Bull. 1452.

Capek, M. 1933. Cited by DiGleria, J., A. Klimes-Szmik, and M. Dvoracsek. 1962. Bodenphysik und Bodenkolloidik. German edition jointly by Akademiai Kiado, Budapest, and VEB Gustav Fischer Verlag, Jena.

Gradwell, M. W. 1955. The determination of specific gravities of soils as influenced by clay-mineral composition. N.Z.J. Sci. Technol. 37B:283–289.

Smith, W. O. 1943. The density of soil colloids and their genetic relations. Soil Sci. 56:263.

U.S. Department of Agriculture. 1954. Diagnosis and improvement of saline and alkali soils. USDA Handb. 60.

84-030 PARTICLE DENSITY OR SPECIFIC GRAVITY (After Blake 1965)

1. Application

1.1 The particle density or specific gravity of soil is expressed as the ratio of the total mass (in grams) of solid particles to their total volume (cm^3). The soil volume is determined by observing the displacement of a fluid with a known density and is dependent on the liquid completely surrounding each individual particle.

2. Apparatus

2.1 Pycnometer (Specific Gravity Flask, 50 mL capacity with a capillary tube).

2.2 Balance (Sensitive to 0.001 g)

2.3 Desiccator (Vacuum)

2.4 Thermometer (range 5°-40°C Sensitive to 0.5°C)

2.5 Vacuum Flask (2 liter)

2.6 Syringe (10 mL with a 22 gauge needle)

2.7 Beakers (250 mL)

3. Reagents

3.1 Degassed distilled water

4. Procedure

4.1 Thoroughly clean and dry the pycnometer.

4.2 Fill the pycnometer with degassed distilled water, insert the pycnometer top ensuring that all air bubbles have been dispelled. The problem of air entrapment is reduced if the following steps are followed:

(a) The flask portion of the pycnometer is filled until an inverted meniscus forms.

(b) The pycnometer top is thoroughly cleaned and dried, taking care to remove any water from the capillary tube.

(c) On insertion of the top it is rotated slowly as it is lowered into place.

(d) When the water level nears the capillary tube opening, tilt the top slightly such that the air bubble is directed towards the capillary opening, tap the pycnometer top until the air bubble moves away from the edge, slowly lower the top the remaining distance.

(e) Should an air bubble remain, seat the pycnometer top; fill the syringe with 5 mL of degassed distilled water; expell any air inside the syringe and the needle; insert the syringe needle into the capillary tube ensuring that the tip of the needle is below the capillary opening; very carefully withdraw water from the pycnometer until the entrapped air bubble is dislodged; slowly replace the water while tapping the top of the bottle. The top of the air bubble should always be directed towards the capillary opening; continue to add water as the syringe needle is being withdrawn; leave a drop of water on top of the capillary tube as an evaporation check.

(f) Dry the outside of the pycnometer and adjust the drop of water on top of the capillary tube until the meniscus is just visible in the capillary; the adjustment is best achieved with a small piece of paper towel while the pycnometer is on the balance thus reducing the evaporation problem.

(g) Record the weight of the pycnometer and water (Ww) to the nearest 0.001 g.

(h) Remove the pycnometer from the balance and take the top off, insert a thermometer, observe and record the temperature (used to determine the water density).

4.3 Empty, clean and dry the pycnometer; add approximately 10 g of air dry soil; add about 25 mL of degassed distilled water and stir the contents with a glass rod (the glass rod should be wiped clean between samples); fill the pycnometer flask to the top, allowing any organic matter to float over the side.

4.4 Place the pycnometer in a desiccator and apply 7-8 cm of Hg vacuum for 2 hours (stir the sample after one hour).

4.5 Release the vacuum and remove the pycnometer from the desiccator, wipe the outside clean and rinse off any soil on the inside of the neck.

4.6 Repeat steps 4.2 a-f record the weight of the pycnometer plus soil plus water as Wsw; remove the pycnometer top and record the water temperature.

4.7 Empty and carefully rinse the contents of the pycnometer into a preweighed 250 mL beaker (B).

4.8 Place the beaker and contents in a drying oven set at 105°C for 24 hours (the period of 24 hours commences from the point at which free water is no longer visible in the beaker).

4.9 Weigh the beaker plus soil and record as Bs.

4.10 The weight of soil Ws = Bs - B.

5. Calculation

5.1 The equation used to determine particle density (Dp) is:

$$Dp = \frac{dw \cdot (Ws)}{(Ws)-(Wsw-Ww)}$$

Where dw = density of water (g/cm^3) at the temperature observed.
Ws = weight of soil sample (oven dry)
Wsw = weight of pycnometer, soil and water
Ww = weight of pycnometer and water.

6. References

6.1 Blake, G.R. 1965. Particle density. pp. 371-373. in Methods of Soil Analysis, Part I, Agronomy, No. 9, C.A. Black, ed., American Society of Agronomy, Madison, Wisc.

ATTACHMENT D
(Sample Syllabus for GRAIP Road Inventory Training)

Training Week Three

Monday 6/15/09	8	Emplyee Orientation
	12	Lunch
	13	Defensive driving
	1530	Safety training videos
Tuesday 6/16/09	800	First Aid
	1100	CPR/First Aid
	1200	Lunch
	1300	Drivers tests
		Organize field gear
Wednesday 6/17/09	800	GRAIP Overview
	900	GRAIP inventory method
	1200	Lunch
	1230	Field exercise local
	1830	Return to Boise
Thursday 6/18/09	800	GRAIP data correction/file management
	1030	go to Garden Valley for field exercise
	1230	Data collection practice
	1800	camp in Garden Valley
Friday 6/19/09	800	Data collection practice
	1430	regroup to discuss findings
	1530	Drive to Boise
	1800	Wilderness First Aid in Boise
Saturday 6/20/09	800	Wilderness First Aid in Boise
	1200	Lunch
	1300	Wilderness First Aid in Boise field
	1700	End class