# MODIFIED PHILIP-DUNNE INFILTROMETER TESTING

FINAL REPORT

March 2014

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# *EXECUTIVE SUMMARY*

Simple, rapid and repeatable field observation protocols to determine the condition of urban stormwater treatment best management practices (SWT BMPs) are critical tools that inform stormwater managers of conditions and trigger maintenance activities. The Best Management Practices Maintenance Rapid Assessment Methodology (BMP RAM) User Manual V.1 (2NDNATURE *et al.* 2009) uses a Constant Head Permeameter (CHP) to assess condition of three common infiltration SWT BMPs in the Tahoe basin: dry basins, infiltration basins and bed filters. The purpose of the CHP protocol is to measure the saturated hydraulic conductivity ($K_{sat}$) of the media of a treatment BMP. The CHP measures $K_{sat}$ in the soil profile via a bore hole 4” below the soil surface. Due to the nature of the CHP testing protocol, infiltration impedance due to the accumulation of fine sediment particles at the soil surface, termed surface caking, may go undetected.

The Modified Philip-Dunne (MPD) infiltrometer (Ahmed *et al.* 2011) measures soil surface $K_{sat}$, including the presence of any restrictive layer (such as surface caking) which may impede SWT BMP performance. The primary purpose of this study was to evaluate the utility of the MPD infiltrometer to serve as an alternative to the CHP. This study compared four methods of $K_{sat}$ measurements (MPD, CHP, tension disk infiltrometer and double ring infiltrometer) in three different SWT BMPs in which surface caking was evident to test the following hypothesis:

1. The MPD measured soil surface hydraulic conductivity rates are comparable to those derived from the other tested infiltrometers (TDI and DRI).
2. Caking of surface soils is an influencing factor in the sampled SWT BMPs, evidenced by the CHP $K_{sat}$ values differing significantly from the infiltrometer methods.
3. The MPD infiltrometer is a suitable rapid assessment methodology alternative to the CHP test, in that the expediency and convenience of field operation between the MPD and CHP are similar.

Findings indicate that MPD measurements are comparable to those collected using the other methods: that is, within an order of magnitude at two of the three sample locations. The third sample location exhibited extreme variability in measurements between all methods due to hydrophobic soils, presence of shallow groundwater and a storm event which changed soil moisture levels. We concluded that the three $K_{sat}$ measurement methods were functionally equivalent in the field. The coefficient of variation (CV) for all locations and all methods ranged from 20% to 64% for all locations and methods.

Results to inform the suitability of MPD as an alternative BMP RAM testing methodology were confounded, particularly in that no consistent differences were observed between CHP and MPD data, suggesting that surface caking was not an issue in the sample locations. While the CHP and MPD were equivalent in construction costs, durability and maintenance attributes favored the MPD. Conversely, the CHP was determined easier to use and operational times to obtain measurements were about half that of the MPD. MPD operational times were hampered by the requirement to obtain soil moisture readings before and after the tests and the need to obtain multiple data points to calculate $K_{sat}$ in a proprietary computer spreadsheet. Although beyond the scope of this project, modification of the MPD method to obviate the need for soil moisture data and employ a direct-read scale may enable more rapid $K_{sat}$ measurements to be obtained in the field.

# INTRODUCTION

To protect the substantial public investment in water quality improvements over the past several decades, the Lake Clarity Crediting Program (LCCP) requires jurisdictions to assess and report the condition of key and essential stormwater treatment best management practices (SWT BMPs). The Best Management Practices Maintenance Rapid Assessment Methodology BMP RAM User Manual V.1 (2NDNATURE *et al.* 2009), the LCCP-approved tool for this purpose, specifies the use of the Constant Head Permeameter (CHP) to measure the saturated hydraulic conductivity ($K_{sat}$) of various stormwater treatment BMPs (infiltration basin, dry basin and bed filter) in the Tahoe Basin. The results of the testing are used to inform local jurisdictions when maintenance is needed. Permeameters such as the CHP measure hydraulic conductivity at a certain depth within the soil profile, whereas infiltrometers measure hydraulic conductivity at the soil surface. Infiltration BMPs may fail at the soil surface due to the deposition and accumulation of fine sediment particles which creates a restrictive layer commonly referred to as "caking" (Rice 1974; Metcalf and Eddy 1972; Gonzalez-Merchan *et al.* 2011; Hatt *et al.* 2008). According to the developer of the Tahoe adapted CHP (Woody Loftis; Natural Resource Conservation Services (NRCS) personal communication 2012), the CHP is not capable of detecting whether BMP condition is influenced by caking. This stems from the fact that the CHP requires a bore hole installed 4" below the soil surface.

The Modified Phillip-Dunne (MPD) Infiltrometer was designed by investigators at the University of Minnesota to rapidly and accurately measure $K_{sat}$ of the engineered soils in the Upper Midwest's rain gardens (Ahmed *et al.* 2011). These rain gardens are backfilled with an engineered soil to increase infiltration rate, and thus are considered comparable to the rapidly draining native soils of the Tahoe Basin. Minnesota's equivalent to the BMP RAM*, Assessment of Stormwater Best Management Practices* recommends the MPD to assess soil surface hydraulic conductivity in SWT BMPs such as rain gardens. The MPD measures $K_{sat}$ in the top 12 inches of soil—including any restricting layers at the soil surface, is rapid, simple to construct, and requires a low volume of water to operate (which can be difficult to transport for field measurements).

# OBJECTIVES AND HYPOTHESIS

The primary objective of this study was to evaluate the utility of the MPD infiltrometer to serve as an alternative RAM to the CHP test. To make this assessment, the measured hydraulic conductivity values of the MPD were compared to those derived from the double-ring (DRI) and tension disk infiltrometer (TDI), widely regarded as standard procedures for assessing soil surface hydraulic conductivity (Bouwer 1986; Hillel 1998; White *et al*. 1992). The study tested the following hypothesis:

1. The MPD measured soil surface hydraulic conductivity rates are comparable to those derived from the other tested infiltrometers (TDI and DRI).
2. Caking of surface soils is an influencing factor in the sampled SWT BMPs, evidenced by the CHP $K_{sat}$ values differing significantly from the infiltrometer methods.
3. The MPD infiltrometer is a suitable rapid assessment methodology alternative to the CHP test, in that the expediency and convenience of field operation between the MPD and CHP are similar.

## SITE DESCRIPTION

The Lake Tahoe Basin straddles the border between California and Nevada and encloses Lake Tahoe - a large sub-alpine lake. Lake Tahoe comprises 191 square miles of the 506 square miles of the Lake Tahoe Basin. The Lake formed 2 million years ago as a result of the rising of the Sierra Nevada and Carson Mountain Ranges and the falling of the Basin between the Ranges. Elevations in the Basin range from around 6,225 feet at the Lake to 10,891 feet atop Freel Peak. National Forest covers roughly 85 percent of the Tahoe Basin. Basin soil parent materials are primarily of andesitic lahar (volcanic) and granodiorite (granitic).

Three sampling sites were selected to represent the stormwater treatment BMPs for which Tahoe Basin jurisdictions are required to obtain $K_{sat}$ measurements as defined in the BMP RAM; a bed filter in Cave Rock, NV; an infiltration basin in El Dorado County, CA; and a dry basin in the City of South Lake Tahoe, CA. Sites were selected for BMP type and size, surface caking extent, soil type and maintenance practices. Site description and properties are presented in Table 1 and Appendix A, Map #1 displays the sample site locations.

**Table 1. Sample site description and properties.**

| Site | BMP Type, Location | Date Installed | BMP Size ($ft^2$) | NRCS Soil Survey Soil Type | NRCS Mapped $K_{sat}$ (in/hr) | Surface 'Caking' Depth (in) | Maintenance Performed |
|---|---|---|---|---|---|---|---|
| **1** | Bed Filter, Cave Rock, NV | 1992 | 16,500 | Meeks Gravely Loam Coarse Sand (7485) | 14 | 0 | No |
| **2** | Infiltration Basin, Pioneer Trail, El Dorado County, CA | 2001 | 8,460 | Jabu Coarse Sandy Loam (7461) | 4 | ~1 | No |
| **3** | Dry Basin, 12th St, South Lake Tahoe, CA | 1994 | 2,872 | Marla Loamy Coarse Sand (7471) | 4 | ~1 | No |

Sample site #1 is a bed filter (BF) in Cave Rock, NV (Figure 1). This site was chosen to represent bed filters as defined in the BMP RAM. The bed filter was installed in 1992 as part of the Cave Rock Estates Erosion Control Project, and is located on Meeks gravelly loamy coarse sand (see soil series is included in Appendix B). Due to its location above-gradient to a major highway, the bed filter does not infiltrate into the surrounding soil, as it is installed with an impermeable liner and a filter media. However, because of the sandy filter media, it was expected that the field $K_{sat}$ measurements will be similar to the 2007 NRCS Soil Survey mapped rate for the parent soil. See Appendix A, Map #2 for a map of the Cave Rock bed filter sample site.

**Figure 1. Cave Rock Bed Filter Sample Site.**

Sample site #2 is an infiltration basin (IB) located near the intersection of Pioneer Trail and Kokanee Trail in the jurisdiction of El Dorado County near South Lake Tahoe, CA (Figure 2). This site was chosen to represent infiltration basins as defined in the BMP RAM. This site was selected in California due to the lack of adequately sized infiltration basins in Nevada. The Kokanee basin was installed in 2001 as part of the Marshall Trail Erosion Control Project. The basin is located on Jabu coarse sandy loam (see soil series is included in Appendix B). Due to the high sediment load into the basin and the level of maintenance performed, it was expected that the field $K_{sat}$ measurements will be less than the mapped rate. See Appendix A, Map #3 for a map of the Kokanee infiltration basin sample site.

Figure 2.  Kokanee Infiltration Basin Sample Site.

Sample site #3 is a dry basin (DB) located near the intersection of 12$^{th}$ Street and Patricia Lane in South Lake Tahoe, CA (Figure 3).  This site was chosen to represent dry basins as defined in the BMP RAM, and was selected in California due to the lack of adequately sized dry basins in Nevada.  The Patricia basin was installed in 1994 as part of the 12$^{th}$ - 13$^{th}$ Street Erosion Control Project.  The basin is located on Marla loamy coarse sand (see soil series is included in Appendix B).  Due to the extent of surface caking and the shallow groundwater elevation, it was expected that the field $K_{sat}$ measurements will be less than the mapped rate.  See Appendix A, Map #4 for a map of the Patricia dry basin sample site.

Figure 3. Patricia Dry Basin Sample Site.

## EXPERIMENTAL METHODS AND MATERIALS

Transects were established across the bottom of each sampling site. Each transect contained sampling points spaced approximately 3 feet apart. The sampling points were sometimes shifted in the field to avoid geographical obstructions such as rocks, burrows, roots or uneven ground. Sample points included vegetated as well as non-vegetated sites to obtain a representative sample based on observed vegetative cover. Sampling points were recorded with GPS. MPD, CHP and TDI tests were performed around the sampling point. At some sample points, DRI tests were also performed. The number of DRI tests performed was limited due to the time involved in performing the DRI tests and the scope and budget of the study. 30 sample points were acquired at each of the three sample sites.

Measurements were taken as close as possible to each other so as to minimize environmental site differences between tests, yet not influence adjacent test results. Tests were performed in the vicinity of the designated sampling point in the following sequence and location (Figure 4):

1. A nine inch diameter sampling point was prepared for the TDI tests. Preparation included trimming the vegetation as close to the ground as possible, removing surface debris and leveling the site with a thin layer of capping sand. The TDI test was then performed.
2. The MPD tests were conducted within 12 inches of the TDI test site.
3. The CHP tests were conducted approximately 12 inches from the MPD and TDI site.
4. The DRI tests were conducted on undisturbed soil as close to the MPD or TDI site as possible. Occasionally the DRI test was conducted within the TDI sand cap or the exact same test location as the MPD test, when these prior test sites remained undisturbed/intact enough for a valid test.

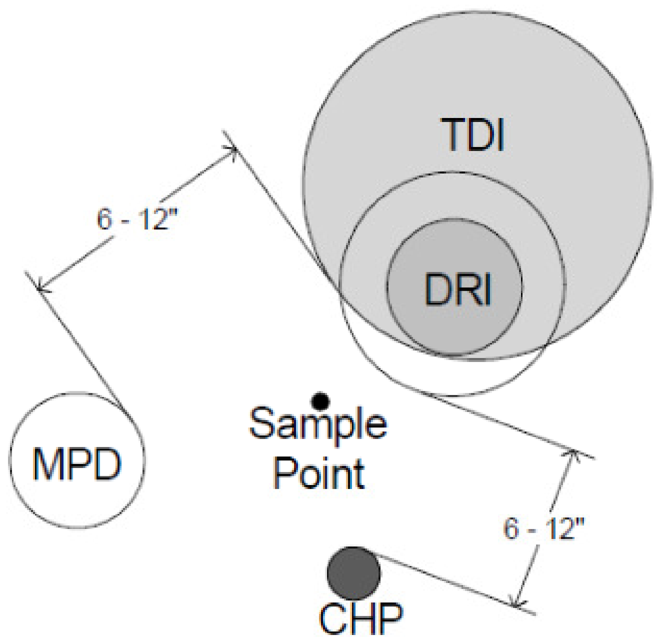


Figure 4. Typical layout of infiltrometer and permeameter tests at each sample point.

When taking measurements at each sample point along a transect, care was taken not to compact the undisturbed soil in each BMP at the other proposed sampling points while collecting the data. Working from one end of the sample site to the other, field personnel systematically tested along each transect to eliminate foot traffic across unsampled points along the other transects. The specific testing methods are discussed in detail below.

## Modified Philip-Dunne Infiltrometer

A Modified Philip-Dunne Infiltrometer, the software and manual were purchased from the St. Anthony Falls Laboratory in the summer of 2012 for use in the study. The purchased MPD served as a template for fabricating three additional MPDs. Instructions for fabricating MPDs are included in Appendix C. The MPD operational procedures are outlined in *Manual Modified Philip-Dunne Infiltrometer* (Ahmed *et al.* 2011). Soil moisture adjacent to the sampling point was obtained with a Time Domain Reflectometry (TDR) probe (Spectrum Technologies, Inc.; Field Scout TDR 300 Soil Moisture Meter) and/or by weighing a soil core sample (1cm x 5.4cm brass ring).

Each sample point had a level and debris-free surface. MPD bases were pounded into the ground to a depth of two inches with a hand sledge and the installation tool. Field personnel ensured the soil around the MPD base was tight to prevent water seepage. A disk of highly permeable filter fabric (Lifegard Aquatics; Bonded Filter Pad) was installed in the base of the MPD to prevent soil scour upon filling with water. The silicone seal was checked to verify presence of lubricant (Parker Seals; O Lube) and absence of debris. The MPD body was then installed firmly onto the base. Figure 5 shows the MPD test kit.

Figure 5. MPD test kit.

The MPD was filled with water, the initial height ($h_o$) recorded and the stopwatch activated. The time required for the water level to drop 1 cm determined the testing interval (Table 2).

Table 2. Testing interval for MPD determined by time required for 1 cm drop in initial water height.

| Time to drop 1 cm | <10 sec | 10 sec | 20 sec | 40 sec | 1 min | 2 min | 5 min | >10 min |
|---|---|---|---|---|---|---|---|---|
| **Testing interval** | 30 sec | 40 sec | 1 min | 2 min | 4 min | 6 min | 10 min | 30 min |

The time elapsed and corresponding water height were noted at the appropriate testing interval until at least 12 data points were obtained. After testing, the base was removed and a soil moisture sample was obtained in the nearly saturated soil within the MPD sampling point as described below. Field data was later input into a proprietary *Excel* spreadsheet to calculate the $K_{sat}$.

## Constant Head Permeameter

As part of the Backyard Conservation Program, NTCD owns and maintains several CHPs which were fabricated by NRCS staff. The CHP operational procedures were followed according to the directions outlined in *Constant Head Permeameter (CHP) Construction and Implementation Guide* (USDA, NRCS 2012). Each CHP sample point had a level and debris-free surface. A bore hole was created by hammering the bore hole tool vertically into the ground and then removing the tool and soil plug in 2-inch increments until a final depth of 4-6 inches was obtained. The CHP was filled with water and gently inserted into the bore hole through the spacer base. With the tip of the CHP gently resting at the bottom of the bore hole, the Moody Coupler was slid down and tightened against the spacer base. The spacer was inserted between the moody coupler and the spacer base to raise the CHP tip off the bottom of the bore hole. Figure 6 shows the Constant Head Permeameter test kit.

**Figure 6. Constant Head Permeameter test kit.**

The CHP flow valve was slowly opened to fill the bore hole. Approximately two minutes was allowed for the water level to stabilize and for the surrounding soil to saturate. An initial water level reading was obtained and the stopwatch started. A water level reading was obtained every minute for 8 minutes or until the water level drop between readings was stable. The change in water level per minute was calculated. The $K_{sat}$ readings were then averaged to determine $K_{sat}$ for that sample point.

## Tension Disk Infiltrometer

Tension disk infiltrometer tests are based on the theory and applications described by White *et al*. (1992). The TDI sample point was prepared by trimming any vegetation as close to the ground as possible, removing surface debris and leveling the site with a thin layer of clean sand (Silica Resources; SRI Supreme #30 washed sand). As little sand as possible was used to minimize horizontal flow through the cap, yet ensure positive contact between the infiltrometer head and soil surface. A 9 inch diameter level area was prepared before TDI measurements were taken. Figure 7 shows the Tension Disk Infiltrometer test kit.

**Figure 7. Tension Disk Infiltrometer test kit.**

The Marriotte bubble chamber was pre-filled with water to just below the access tube, sealed with a stopper and hose clamp, and the Marriotte tube adjusted to 1 cm of tension. The large water reservoir was filled by placing the TDI in a bucket of clean water and applying suction to the one-way valve at the top, until water filled the tube. To determine antecedent soil moisture, a small soil core of known volume was obtained immediately adjacent to the sample area with the TDR probe or by inserting a .4 inch (10mm) thick, 2.125 inch (54mm) diameter brass cylinder ring into the soil surface. The sample was stored in soil tins sealed with electrical tape until weighing and drying in the laboratory to determine soil moisture content (described in detail below).

TDI measurements began by recording the initial water level and then placing the infiltrometer solidly onto the sand cap while simultaneously starting the stopwatch. Water level readings from the main water supply reservoir were recorded at 10 second intervals. Tests were continued until at least three measurements with the same drop in water level (steady state infiltration) were recorded or for 10 minutes. Immediately following the test, the infiltrometer was removed and a soil moisture reading was taken with the TDR probe, or a soil core of known volume was obtained by scraping away the capping sand and collecting the core and determining soil water content as previously described. Post test observations were made of the soil wetting depth, symmetry of wetting, and any other unusual features. Using the fingertip method, a small sample of soil was tested and the surface soil texture recorded.

TDI measures hydraulic conductivity under tension K(θ) which eliminates macropore infiltration. The hydraulic conductivity of a soil matrix at near saturation is likely closer to $K_{sat}$ in fine-textured soils than that for coarser soils. To calculate hydraulic conductivity under tension from the field data, a least-squares approach to the Phillip equation was used to estimate the sorptivity ($S_p$) and the ponded hydraulic conductivity ($K_p$) which in this case equals the saturated hydraulic conductivity ($K_{sat}$). The Phillip equation is a truncated infinite series solution of Richard's equation. Richard's equation describes the forces of soil matric potential and hydraulic head and their effects on the rate of water entry into soils.

The Phillips equation relies on three assumptions:

1. Infinitely deep soil profile;
2. Homogeneous, semi-infinite soil column;
3. Uniform, sharp wetting front that serves as the boundary between saturated and unsaturated soil.

The $S_p$ and $K_{sat}$ were estimated using linear regression after the infiltration data had been arranged to represent the dependent and independent variables used in the Phillip equation. When the slope of the infiltration rate versus time reached a plateau or essentially became zero, it represented the K at the applied tension and volume water content. When the slope of the cumulative infiltration versus square root of time became constant (approaches zero), it represented the $S_p$ of the soil at the applied tension.

## Double-Ring Infiltrometer

The double-ring infiltrometer tests followed the modification of the ASTM Standard D 3385-03 as described in Appendix E of the *Low Impact Development Manual for Michigan* (SEMCOG 2008). The DRI test kit consisted of 4 inch diameter and 6 inch diameter by 5 inch high metal rings with beveled leading edges for driving into the ground. The larger ring minimizes the lateral movement of water through the soil, thus more accurately represents the performance of the BMP when filled with water. Each DRI sample point had a level and debris-free surface. Double-ring tests were often performed at the same location as the TDI tests or MPD tests, when those locations remained undisturbed and intact. The outer ring was installed into the ground to a depth of 2 inches by placing a sturdy flat board on top of the ring and driving the ring with mallet strikes. The inner ring was installed in the center of the outer ring to a depth of 2 inches in the same manner as the outer ring. To prevent soil surface scour and minimize floating organics, a disk of highly permeable filter fabric (Lifegard Aquatics; Bonded Filter Pad) was installed at the bottom of the inner ring. Field personnel ensured that the soil around the base of the rings was tight to prevent seepage. Figure 8 shows the double-ring infiltrometer test kit.

**Figure 8. Double-ring infiltrometer test kit.**

The sample point was saturated before measurement began by filling both rings and maintaining water level for 20 minutes before initiating the test. 33.8 fluid ounces (1000ml) of water in a graduated cylinder was placed next to each DRI test for maintaining the inner ring water level. The volume of water added to the inner ring was measured using a graduated cylinder.

To start the DRI test, both rings were topped off with water and the stopwatch started. Water level was maintained in both rings (water drop never exceeded ¼”). Water volume required to maintain full outer rings was not tracked, while water volume required to maintain full inner rings was tracked via the graduated cylinders. Readings of the water volume required to maintain full inner ring were recorded every 10 minutes. Tests continued until 4 readings were obtained or until a stabilized rate of fall was achieved. A stabilized fall rate was defined as a difference of 1.75 fluid ounces (52ml) (volume equivalent for ¼” drop in the 4”diameter inner ring) or less between 2 consecutive readings. The measured drop from the last reading expressed as inches per hour represented the $K_{sat}$ for that sample point.

## Volumetric Soil Moisture Content

Volumetric soil moisture content data was obtained in support of the TDI and MPD tests. Volumetric soil moisture content data was obtained in two ways: 1) through soil samples and 2) TDR Probe readings.

Soil samples were collected at all TDI sample points and some MPD sample points to characterize the changes in soil moisture. Initial samples were collected adjacent to the sample sites, while post-testing samples were collected from the center of the testing location. A .4 inch (10mm) thick, 2.125 inch (54mm) diameter brass ring was inserted into the soil. A small mason’s trowel was slid beneath the ring to remove the ring and sample from the surrounding soil. Excess soil was removed from the ring and the sample was placed in a clean and dry soil tin. The tin was sealed with electrical tape and stored in the shade until transport to the laboratory. At the lab, the tape was removed and the tin and sample weighed before drying in the oven at 221° F (105° C) for at least 24 hours. The samples were removed from the oven and weighed to determine volumetric soil moisture content.

Wet soil – dry soil = weight of water.
Convert the weight of water to volume (1 g water ≈ 1 $cm^3$ of water)
Volumetric Water Content (θ) = volume of water / total volume of soil (V)
Soil Bulk Density ($\rho_b$) = dry mass of soil / total volume of soil (V)
Volumetric Water Content (θ) = mass water content (w) * soil bulk density = (w)($\rho_b$)

The TDR probe expressed the volumetric soil water content as the ratio of the water volume to the total soil volume. The percent pore space equals the volumetric water content at saturation. TDR probe readings were obtained according to the user’s manual. The 1.5 inches (‘turf’) probes were used to most closely correspond to the soil profile measured by the TDI and MPD. Readings were obtained with the TDR probe in ‘Standard’ mode (rather than ‘Clay’). To obtain a reading, the TDR probe was powered on, the clean probes fully inserted into the soil and the ‘Read’ button pressed to obtain the volumetric soil water content. The soil water content was then recorded on the field spreadsheet.

## Bulk Density

Bulk density soil samples were obtained with a 1.9 inches (48.5mm) diameter by 1.98 inches (50.5mm) high sample sleeve (93.3 $cm^3$) in a sliding hammer. Two bulk density samples were collected at 5 sample points within each of the 3 sample sites to represent the 0-2 inch soil profile and the 6-8 inch profile. Sample point soil surfaces were cleared of debris and the sample head and sleeve cleaned. The sleeve was inserted into the sample head and then screwed onto the slide hammer. The slide hammer was positioned on the sample point and the head driven into the soil to the proper depth. The slide hammer handle was rocked to the side to free the head of the soil. The head was carefully unscrewed and the sample sleeve removed. The core was removed from the sleeve and placed in the soil tin. The tin was sealed with electrical tape and stored in the shade until transport to the laboratory. At the lab, the tape was removed and the tin and sample weighed before drying in the oven at 221° F (105° C) for at least 24 hours. The samples were then removed from the oven and weighed to determine bulk density. Particle density was not measured, but given an assumed value of 2.65 g/cm$^3$ to represent a sandy soil.

Soil Bulk Density ($\rho_b$) = dry mass of soil / total volume of soil (V)
Porosity = 1 - bulk density ($\rho_b$) / particle density ($\rho_p$)

# DATA ANALYSIS

## Background

Saturated hydraulic conductivity ($K_{sat}$) in soils has a high level of natural variability due to soil textures, micro-site characteristics such as root channels, insect burrows, voids around rocks, and soil water repellency. This natural variability makes a comparison between individual samples difficult, therefore requiring a statistical analysis of data to evaluate changes. In the current study, data was collected at three different sample sites using four different testing methods (3 infiltrometers and 1 permeameter). Analysis of the data collected was expected to demonstrate a potential relationship among the different testing methods, i.e., that the data collected using the MPD is statistically the same as the other infiltrometer methods. Conversely, a statistical difference between infiltrometer and permeameter methods at those sample points exhibiting surface caking would be expected. Using the statistical software package GraphPad Prism, variability in the data collected across the BMPs using the different methods of measurement were analyzed to assess whether or not the variability in results was due to random sampling or actual differences in measurement. Due to the natural variability of $K_{sat}$, a comparison between individual samples is inappropriate, instead a statistical comparison of the means is the best way to assess changes in $K_{sat}$ (Cody and Norman 2011). An additional assumption was made that taking measurements with one method in the same geographic location as a measurement previously made would result in similar $K_{sat}$ values between the two methods. This comparison is shown in Results and Discussion.

## Statistical Analysis

The null hypothesis states that there is no difference between the groups, that the data collected using one method is statistically the same as another method. Summary results (means or medians) from each method at each site were analyzed, and a “P-value” calculated. The P-value is defined as the probability of observing a difference as large as or larger than observed if the null hypothesis were true (if there is no difference between the groups). The P-value has a range of 0 to 1. If the P-value is small enough, one concludes that the difference between samples is unlikely due to chance, that instead the populations are different. A standard P-value is set at 0.05; a value less than this means the data has failed the null hypothesis, that the populations do not have the same mean; they are significantly different. A P-value greater than 0.05 indicates the null hypothesis is true; that the population means are not significantly different.

Outliers (extremely high/low values) were first detected with a stem and leaf plot (Stedinger 1992), then confirmed using the median and median absolute difference (MAD) method developed by Rousseeuw (1990) with a critical value of 2.5. The outliers were removed to obtain a dataset free of potential erroneous measurements caused by experimental error or other field related anomalies. We acknowledge that the elimination of statistical outliers can in some studies bias interpretive data. However, in this study we are not trying to assess the true $K_{sat}$ of the basin but are instead trying to assess differences in results by comparing the means or medians across methods of measurement. Hence we believe it appropriate to remove outliers from the dataset similar to that of other studies comparing methods of measurement. Such removal of outliers is typical with physical data such as this when the potential of measuring the $K_{sat}$ of an insect burrow, plant root hole or other anomaly (Nestingen 2007), which produce values that are not representative of $K_{sat}$ of the soil. Of note are the development of the two methods of outlier detection in the early 1990s (Stedinger; Rousseeuw), making outlier detection and removal standardized for use in all research. Outliers may be the result of soils shrinkage/swelling, or infiltration into a preferential flow path (root channels), and their presence will skew possible statistical trends (Munoz-Carpena et al. 2002). Field notes indicate that one outlier was caused by experimental error with equipment, while the remaining outliers represent anomalies in the environment. It is not surprising that the MPD and DRI (infiltrometer) methods exhibited more outliers than the CHP (permeameter) and TDI (infiltrometer under tension) methods; in that one would expect more variability in $K_{sat}$ at the soil surface than in the soil profile.

The first step in a statistical analysis is to test if the data fits a Gaussian (bell shaped) distribution. If data does not fit a Gaussian distribution, the data may need to be transformed in order to perform the statistical analysis. The underlying assumption for most statistical tests such as t-tests (comparing 2 groups) or ANOVA (comparing three or more groups) is to assume that the data in the population have a Gaussian (Normal) distribution. While this assumption is not too important with large samples, it is important with small sample sizes, especially when n is less than 10. If data do not conform to a Gaussian distribution, the best approach is to transform the values to make the distribution more Gaussian. Alternatively, one can apply a nonparametric test (compares medians) instead of the parametric t-test (compare means). Application of the t-test should remain, since it is fairly robust to departures from a Gaussian distribution with large samples. In this study we analyzed the data using both parametric (unpaired t-test) and nonparametric (Mann-Whitney) tests.

Three different tests for normality were conducted. Most of the data fit a normal distribution. However, the reliability of normality tests on data sets of less than a few dozen values is low (Prism 2010), therefore care should be taken when accepting these results.

In a review of similar studies, $K_{sat}$ data usually fit a log normal distribution. Although data transformations were applied to the data that did not fit a normal distribution, normality was not achieved. Testing the data for other types of transformations similar to the work of Munoz-Carpena *et al.* (2002) was beyond the scope of this study. However, only probability distributions that are equivalent can be compared, so all of the data must be transformed for the statistical analysis. Because of the small number of data points in the current study, and the statistical requirement to transform all the data using the same technique to compare means, multiple statistical tests were performed on all the data, using both parametric (t-test, comparing means) and nonparametric (Mann-Whitney, comparing medians) tests, in case the Gaussian assumption is not correct. For example, if one data set is transformed using a log-normal distribution, while the other data set for comparison requires a power distribution to yield a normal distribution, the data cannot be compared statistically; they must both undergo the same transformation, or not be transformed at all.

## Summary of Statistical Findings

The results from the outlier detection and resultant number of data points removed are shown in Table 3. The basic statistics such as mean, median, geometric mean, and variance are shown in Table 4. Results from the three different tests for normality are shown in Table 5.

**Table 3. Results from outlier detection methods.**

| Method | Number of samples collected | | | Number of outliers | | | Percent of data removed | | |
|---|---|---|---|---|---|---|---|---|---|
| | BF | IB | DB | BF | IB | DB | BF | IB | DB |
| **CHP** | 30 | 30 | 30 | 0 | 2 | 0 | 0 | 7 | 0 |
| **DRI** | 9 | 15 | 15 | 2 | 1 | 2 | 22 | 7 | 13 |
| **MPD** | 31 | 31 | 31 | 3 | 3 | 5 | 10 | 10 | 16 |
| **TDI** | 30 | 30 | 23 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 4. Summary Statistics of all data (excluding outliers).**

| | Min (in/hr) | Max (in/hr) | Mean (in/hr) | Median (in/hr) | Geo. Mean (in/hr) | SD | CV (%) | N | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|---|---|---|
| **Bed Filter** | | | | | | | | | | |
| **CHP** | 0.5 | 2.67 | 1.63 | 1.6 | 1.52 | 0.55 | 34 | 30 | -0.06 | -.022 |
| **DRI** | 1.27 | 2.43 | 1.81 | 1.8 | 1.77 | 0.35 | 19.5 | 7 | 0.48 | 1.83 |
| **MPD** | 0.23 | 4.02 | 2.14 | 2.2 | 1.67 | 1 | 47 | 28 | -0.25 | -0.43 |
| **TDI** | 0.69 | 2.63 | 1.23 | 1.3 | 1.1 | 0.57 | 47 | 30 | 0.72 | -0.41 |
| **Infiltration Basin** | | | | | | | | | | |
| **CHP** | 0.75 | 6.6 | 3.6 | 3.6 | 3.27 | 1.45 | 40 | 28 | 0.04 | -0.6 |
| **DRI** | 0.76 | 3.75 | 2.05 | 2.1 | 1.8 | 0.88 | 43 | 14 | 0.15 | -0.5 |
| **MPD** | 1.13 | 5.9 | 3.2 | 2.7 | 2.8 | 1.4 | 45 | 28 | 0.27 | -1.3 |
| **TDI** | 0.33 | 2.6 | 1.7 | 1.9 | 1.58 | 0.56 | 33 | 30 | -0.18 | 0.12 |
| **Dry Basin** | | | | | | | | | | |
| **CHP** | 0.37 | 4.12 | 1.5 | 1.4 | 1.23 | 0.97 | 63.8 | 30 | 0.95 | 0.59 |
| **DRI** | 2.28 | 7.62 | 4.6 | 4.0 | 4.3 | 1.7 | 36.92 | 13 | 0.67 | -0.7 |
| **MPD** | 1.16 | 17.93 | 7.6 | 7.3 | 6.28 | 4.36 | 57.46 | 26 | 0.69 | 0.12 |
| **TDI** | 0.06 | 0.65 | 0.3 | 0.3 | 0.23 | 0.16 | 60 | 23 | 1.33 | 2.8 |

Table 5. Results of normality tests, where Y indicates passed normality test, N did not.

| | CHP | | | DRI | | | MPD | | | TDI | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | KS | DP | S-W | KS | DP | S-W | KS | DP | S-W | KS | DP | S-W |
| **BF** | Y | Y | Y | Y | ** | Y | Y | Y | Y | N | Y | N |
| **IB** | Y | Y | | Y | Y | | N | N | | N | Y | |
| **DB** | Y | Y | | Y | Y | | Y | Y | | N | N | |

Where: ** = not enough data
KS = Kolmogorov-Smirnov Normality Test
DP = D'Agostino and Pearson Omnibus normality test
SW = Shapiro-Wilk normality test

While the means of the BF and IB data are all relatively close and within an order of magnitude, the means for the DB are very different across all four methods. Results may have been influenced by a precipitation event on October 12, 2012 and/or hydrophobic layers at the soil surface (Figure 9). The TDI measurements appear to be considerably lower than all other methods at all three sites. This may be due to the fact that the TDI eliminates flow into soil macropores and simulates infiltration under very low tensions. Thus, true saturation in the field is not attained and the maximum natural hydraulic conductivity is often less than that at actual saturation ($K_{sat}$).

Figure 9. Hydrophobicity at the dry basin sample site. This DRI soil core had 3 inches constant head sustained for an hour.

In reviewing the summary statistics, the skewness or kurtosis of <0 or >0 indicate departures from normality; this is confirmed with the TDI of the dry basin not passing the normality test, similar to the MPD in the infiltration basin. If data are from a Gaussian distribution, the mean, median and geometric mean will have similar values. The standard deviation (SD) is the average distance a value is to the mean; if all values are the same, the SD will be zero (0). The CV is a way to interpret the relative magnitude of the standard deviation by dividing it by the mean. The higher the CV, the greater the variability in the data. This is a helpful statistic in comparing the degree of variation from one data series to the other, although the means are considerably different from each other. The coefficient of variation (CV) for all locations and all methods are not very wide in the current study, ranging from 20% to 64% for all locations and methods. These results are well within the bounds reported in the literature. Asleson (2007) found the variability of $K_{sat}$ was extremely large and the CV ranged from 57% to 174%. Munoz-Carpena *et al.* (2002) found the CV was highest for the laboratory permeameter at 101%, followed by the Philip-Dunne at 56% and Guelph Permeameter at 56%.

In the current study, t-tests and nonparametric Mann-Whitney tests were applied to the data two groups at a time (i.e., MPD vs. DRI, TDI vs. MPD). Therefore, 6 comparisons were performed for each of the three BMPs, for a total of 18 comparisons. This allowed for comparison of means and medians, using both of the parametric and nonparametric tests to account for some data distributions not meeting normality assumptions. All tests yielded similar results (Table 6). In summary, the following methods showed statistical significance:

- Bed filter:
  - The means and medians of the CHP and DRI were not significantly different.
  - The means and medians of the MPD and DRI were not significantly different.
- Infiltration basin:
  - The means and medians of the CHP and MPD were not significantly different.
  - The means and medians of the DRI and TDI were not significantly different.
- Dry basin:
  - There were no results of significance found.

Table 6. Results from statistical tests (blank cells denote a significant difference).

| Method | Comparison of Means | Comparison of Medians |
|---|---|---|
| | **Bed Filter** | |
| **CHP vs DRI** | Not significantly different | Not significantly different |
| **CHP vs MPD** | | |
| **CHP vs TDI** | Not significantly different | |
| **DRI vs MPD** | Not significantly different | Not significantly different |
| **DRI vs TDI** | Not significantly different | |
| **MPD vs TDI** | | |
| | **Infiltration Basin** | |
| **CHP vs DRI** | | |
| **CHP vs MPD** | Not significantly different | Not significantly different |
| **CHP vs TDI** | | |
| **DRI vs MPD** | | |
| **DRI vs TDI** | Not significantly different | Not significantly different |
| **MPD vs TDI** | | |
| | **Dry Basin** | |
| **CHP vs DRI** | | |
| **CHP vs MPD** | | |
| **CHP vs TDI** | Not significantly different | |
| **DRI vs MPD** | | |
| **DRI vs TDI** | | |
| **MPD vs TDI** | | |

Figures 10 through 12 illustrate the data collected at the three different sites (with outliers removed). From these, one can note the similarity to the statistical results, but also the range in measurements among the four methods.

Using the TDI as the comparative standard, as it is widely regarded as standard procedure for assessing soil surface infiltration rates (Hillel 1998; White *et al*. 1992), the following are the relative differences in means between methods:

Bed filter
DRI 47% higher than TDI
MPD 74% higher than TDI
CHP 32% higher than TDI

Infiltration basin
DRI 20% higher than TDI
MPD 88% higher than TDI
CHP 111% higher than TDI

Dry Basin
All methods were 5 to 20 times higher than the TDI.

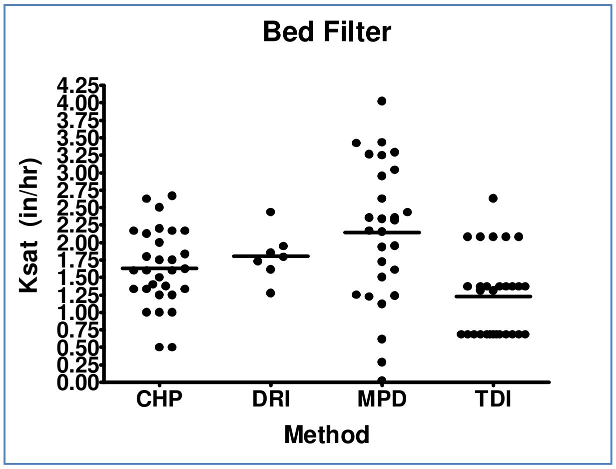


Figure 10. Comparison of raw data collected at bed filter using all 4 methods (outliers excluded).

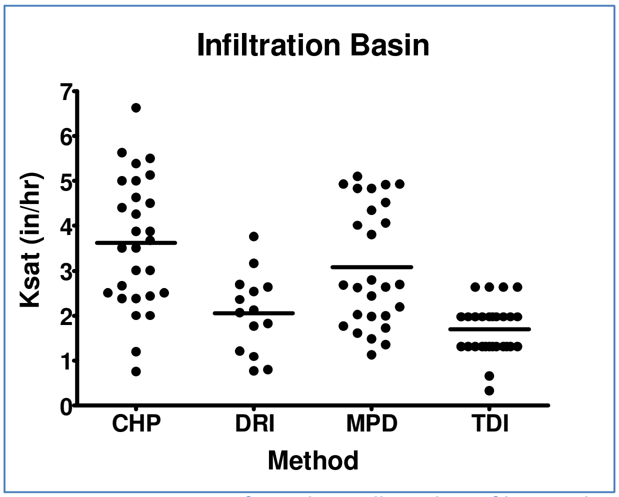


Figure 11. Comparison of raw data collected at infiltration basin using all four methods (outliers excluded).

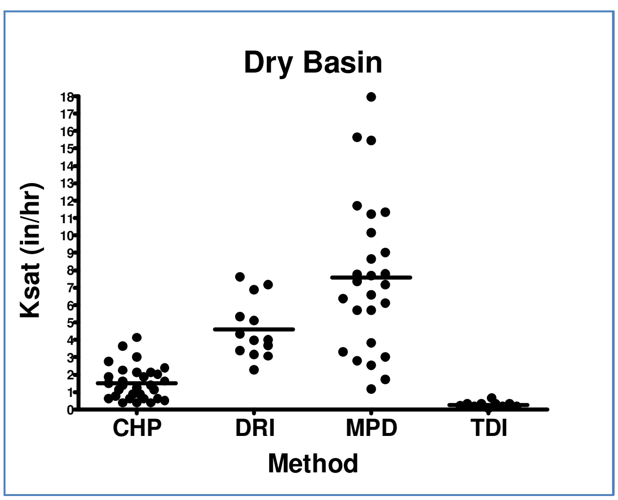


Figure 12. Comparison of raw data collected at dry basin using all four methods (outliers excluded).

# RESULTS AND DISCUSSION

Based on the findings, no apparent trends are seen among the different methods. Although the extreme variability in measurements taken in the dry basin may be explained due to groundwater elevation, hydrophobic soils and a storm event which affected soil moisture levels, the results from the other sites are within an order of magnitude. All test methods demonstrated the ability to measure of wide range of $K_{sat}$ rates.

Similar significant variability was reported in nearly all literature reviewed. $K_{sat}$ is known to not only have the greatest statistical variability of soil hydrologic properties (Deb and Shukla 2012), but is also one of the most problematic measurements at the field scale relative to variability and uncertainty. Rubio *et al.* (yr), Reynolds *et al.* (2000), Ahmed *et al.* (2011), Phillips and Kitch (yr), Gupta *et al.* (2006) and Munoz-Carpena *et al.* (2002) all found that of the many methods to measure $K_{sat}$, the methods often yield substantially different $K_{sat}$ values. This extremely large variability can range from one to several orders of magnitude. Lack of a statistically significant correlation or trends among the methods of measuring $K_{sat}$ has been attributed to sample size, flow geometry, sample collection, inherent soil physical/hydrological characteristics, groundwater elevation, and type of infiltration system. Rubio *et al*. (yr) found a significant difference between different methods and different seasons. Ahmed *et al*. (2011) found spatial variation of greater than 2 orders of magnitude at the same location due to compaction, loss of soils structure, freezing and thawing cycles. Mohanty *et al.* (1994) found that variability can be caused by the method, its susceptibility to such factors as pore-size distribution, horizontal/vertical pore ratio, soil texture and soil water content. This demonstrates the need to take a potentially large number of infiltration measurements to capture the spatial variability and to determine a representative infiltration capacity.

## Normality

Much of the literature states that a log-normal data transformation is appropriate for $K_{sat}$ data (Cody and Norman 2011; Munoz-Carpena *et al*. 2002; Mohanty *et al*. 1994; Reynolds *et al*. 2000). Attempts were made in the current study to transform the data, but a log-normal transformation did not result in a Gaussian distribution in the infiltration basin for either the MPD or TDI. The TDI did not show a normal distribution, and attempts to log-normally transform the data were not successful. This may be an artifact of the data collection method for the TDI itself. TDI tests are run until the rate of drop stabilizes (at least three measurements with the same drop in water volume are recorded). This typically leads to the compartmentalized data that corresponded to the rate of drop over 10 seconds (1mm =.6”/hr; 2mm=1.3”/hr; 3mm=2”/hr; 4mm=2.6”/hr), resulting in the three ‘layers’ of results as seen in the figures.

Additional work such as that by Nestingen (2007) or Munoz-Carpena *et al*. (2002) to test other transformations to the data to determine a more appropriate type of transformation could be conducted; however, such an approach was beyond the scope of this investigation. Because only probability distributions that are equivalent can be compared, care must be taken to find the appropriate transformation.

## Comparison of Results to Similar Studies

Munoz-Carpena *et al*. (2002), Mohanty *et al*. (1994), Gwenzi *et al*. (2011), Reynolds *et al*. (2000), and Philips and Kitch (no date) all found that data among different methods and different conditions varied significantly, probably reflecting differences in scales of measurement, flow geometry, assumptions in computation routines and inherent disturbances during sampling. In particular, Munoz-Carpena *et al*. (2002) found that the basic statistics of mean, median and summation of $K_{sat}$ values showed that the $K_{sat}$ values measured using the Philip-Dunne (PD) are one order of magnitude greater than those obtained by the Guelph Permeameter (GP). Their comparison of the means of the log-transformed results confirms that the GP, PD and laboratory permeameter (LP) are significantly different, whereas the Vieira GP and single head GP are not significantly different.

Mohanty *et al*. (1994) found that the different methods in all studies showed different trends under various soil types and field conditions, and in general, results from the velocity permeameter (VP) were greater than those of the Guelph Permeameter (GP), while the results from the VP were less than the Disk Permeameter (DP). Gwenzi *et al*. (2011), measuring surface $K_{sat}$ and values from deeper measurements in a trench, found that mean $K_{sat}$ values were high for all methods tested (PD, GP), compared to a constant-head laboratory method (LP). Kolmogorov-Smirnov normality tests, frequency distribution curves and probability/probability plots showed that surface $K_{sat}$ for both methods conformed to a normal distribution, while trench data deviated significantly from normality ($p>.05$). Attempts to normalize the trench data by transformation had no effect on kurtosis, skewness and results of the KS normality test, therefore such data cannot be subjected to parametric statistical analysis.

Similar to the current study, Reynolds *et al*. (2000) compared $K_{sat}$ using 3 methods on 3 soils under 3 managements, in order to evaluate the tension infiltrometer (TI) and pressure infiltrometer (PI) techniques for measuring $K_{sat}$. With only 4 of the 27 correlations between $K_{sat}$ values significant at $P<0.05$, the general lack of correlation between the methods might be related to sample size and/or flow geometry and/or soil disturbance. The current study resulted in 4 out of 18 correlations to be significant. The TI infiltrates through a much larger area, and is three-dimensional, whereas flow is one-dimensional in the PI and soil core (SC) methods. Reynolds *et al*. found that the TI almost always yielded lower results relative to the other methods, findings similar to the TDI data in the current study.

Statistical analysis on measurements from a DRI and GP by Gupta *et al*. (2006) indicates that the mean value of $K_{sat}$ obtained by the DRI to be 44% greater than the mean value obtained by the GP.

Munoz-Carpena *et al*. (2002) found that their data lie within three distinctive regions, with some overlapping between the data sets. Because the three types of measurement had been carried out under similar conditions, such differences are likely due to the methods used. The three methods have very different infiltration surface areas, sample volumes, and flow geometries, resulting in $K_{sat}$ distributions that have very different mean values and/or shapes. Some permeameters characterize the vertical flow component (PD, LP) and others the horizontal (GP). Despite considering the numerous differences between methods, the large $K_{sat}$ values obtained with the PD remained unexplained. The difference between the methods by a factor of two to three from the GP and LP corresponds to other research.

## Additional Analysis

### Pre- and Post-Storm Event

The data collection of the DB sample site data was affected by the following environmental challenges: 1) groundwater elevation; 2) hydrphobic soils; and 3) a precipitation event which affected soil moisture levels. The composition of the vegetation community, the presence of standing water at the basin inlet and observed water 38 inches below the basin surface (in the outlet standpipe) suggested that groundwater elevations at the DB site were relatively close to the soil surface. The hydrophobic soils at the DB sample site affected the TDI data. Ten TDI tests were performed before replacing the TDI with DRI tests due to the hydrophobic soils. On October 12, 2012, the area received 0.28 inches of precipitation according to the South Lake Tahoe airport weather station. The precipitation event changed the hydrophobicity and moisture levels of the soil. Field personnel resumed TDI testing on October 17 and obtained 12 TDI post-storm tests results. No post-storm DRI data was obtained. Analyzing the pre-storm data and post-storm data separately for the DB site may yield insight into if the storm affected the hydrophobicity and residual soil moisture levels. In a summary review of the data collected in the DB (excluding outliers), Table 7 shows that $K_{sat}$ values are lower after the storm event for the CHP and MPD, while the TDI exhibited a higher average after the storm event. The TDI readings may be explained by hydrophobic soils being less of a factor after the storm event. As seen in Table 7 the MPD had the smallest percent change (2.3%) in $K_{sat}$ measurements between pre-storm and post-storm data, while the CHP exhibited a 23.8% change and the TDI a 100% change in $K_{sat}$ measurements. Thus, the MPD proved to be the most consistent testing method (least percentage change) in regards to the environmental challenges of hydrophobic soils and a change in soil moisture due to a precipitation event.

**Table 7. Mean values of pre- and post-storm $K_{sat}$.**

| | Number Pre-storm samples | Pre-storm average $K_{sat}$ (in/hr) | Number Post-storm samples | Post-storm average $K_{sat}$ (in/hr) | Percentage Change |
|---|---|---|---|---|---|
| **CHP** | 18 | 1.68 | 12 | 1.28 | -23.8% |
| **MPD** | 13 | 7.68 | 12 | 7.5 | -2.3% |
| **TDI** | 11 | 0.27 | 12 | 0.54 | 100% |

### Exact Same Location

An additional comparison was made to the data that was taken at exactly the same geographic location within the IB. Although the MPD and TDI measurements provide slightly different information ($K_{sat}$ vs $K(\theta)$) one would still expect the results to be similar, since the data was collected consecutively. One would also expect the MPD and DRI data to be similar since both measure $K_{sat}$ at the same soil profile (rings 2 inches deep) and the same surface area (4 inch diameter ring). Unfortunately, no apparent trends were identified with the MPD to TDI comparison for data in the exact same location. All of the TDI data had a $K_{sat}$ value of 1.31 in/hr at the 7 locations, while the MPD $K_{sat}$ values ranged from 1.12 to 4.8 in/hr (Figure 13). After removal of the noted outlier from the MPD data set, the comparison of the

MDP and DRI $K_{sat}$ values yields a regression equation of y = 0.4653x + 0.9313, r2=.474, which indicates a moderate correlation between the data sets (Figure 14).

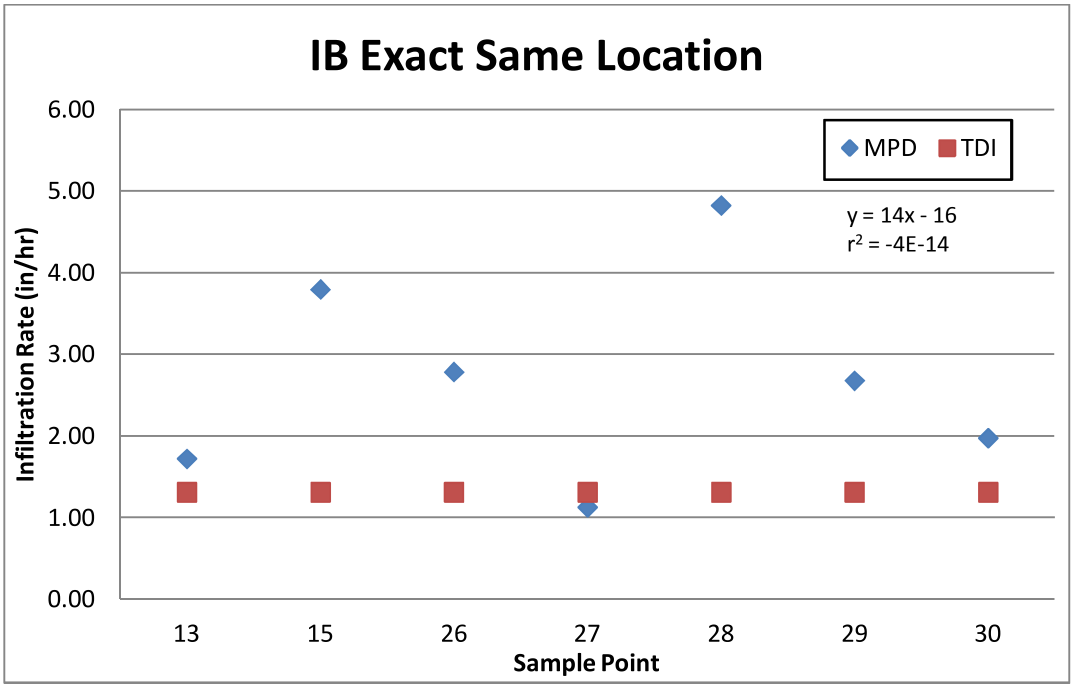


Figure 13. Comparison of MPD and TDI values obtained in the exact same location within the infiltration basin.

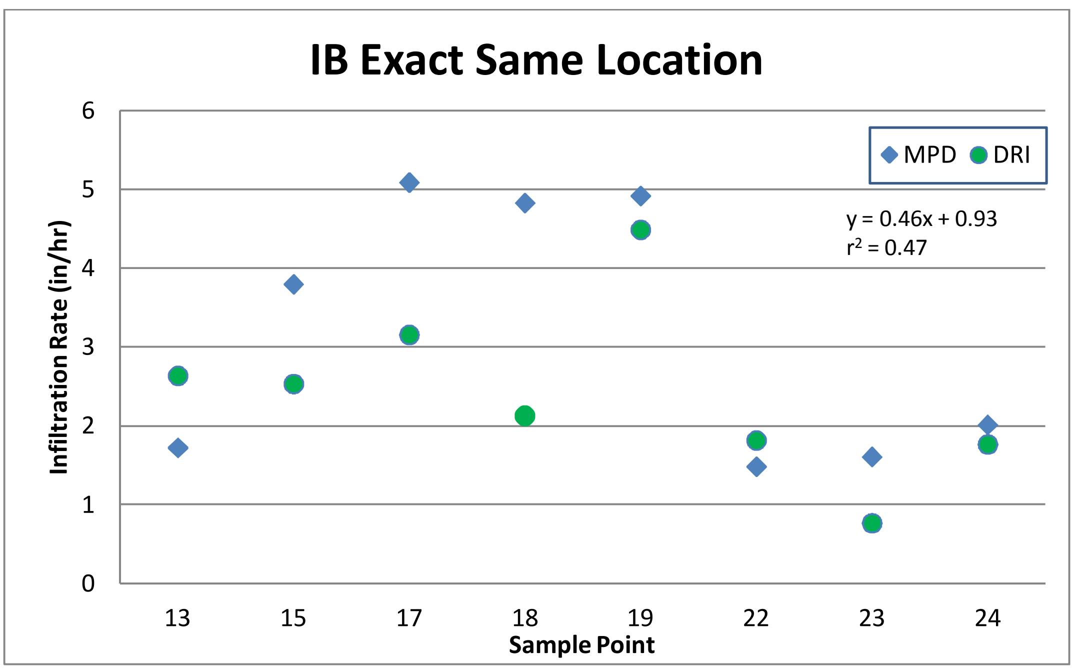


Figure 14. Comparison of MPD and DRI values obtained in the exact same location within the infiltration basin.

## Regression Analysis

A statistical comparison of the means and medians was first performed for this study to determine the statistical significance of the differences between the methods and determine if the data collected using one method was statistically the same as the data collected with another method. The intent of the study was not to predict values of one test on another, but compare the mean/medians of different methods, therefore a regression analysis of the datasets was not ideal due to the high spatial variability of the soils. Nonetheless a simple regression analysis was performed for the different testing methods at the three test locations and determined that there were not strong correlations between testing methods at the 3 locations. The strongest relationship was found between the MPD and DRI at the DB test location with an $R^2$ of 0.75, where an $R^2$ of 1 indicates a strong relationship between the dataset and an $R^2$ of 0 indicates no relationship between the datasets. This suggests that the MPD is potentially a comparable tool for assessing soil surface infiltration rates at this site. Table 8 contains a summary of the $R^2$ values of the regression analysis.

**Table 8. Summary of Regression Analysis comparison**

| Location | Comparison | Equation | $R^2$ values |
|---|---|---|---|
| **Bed Filter** | CHP vs MPD | y=0.0834x + 1.408 | 0.0954 |
| | DRI vs MPD | y=0.6833x + 1.3808 | 0.3503 |
| | TDI vs DRI | y=0.1104x + 3.2669 | 0.0559 |
| | CHP vs DRI | y=0.5127x + 1.0558 | 0.3503 |
| **Infiltration Basin** | CHP vs MPD | y=0.0737x + 4.2179 | 0.0078 |
| | DRI vs MPD | y=0.1373 + 1.7454 | 0.0495 |
| | TDI vs DRI | y=-0.0524x + 1.8025 | 0.0065 |
| | CHP vs DRI | y=0.8667x + 1.6042 | 0.3461 |
| **Dry Basin** | CHP vs MPD | y=0.0311x + 1.1488 | 0.155 |
| | DRI vs MPD | y=0.1781x + 2.7388 | 0.7479 |
| | TDI vs DRI | y=-0.0106x + 0.2733 | 0.1884 |
| | CHP vs DRI | y=0.1184x + 0.9116 | 0.3638 |

## Sample Size Determination

A number of different methods can be applied to determine whether or not the number of samples taken is sufficient to describe the mean. The easiest is to use the sample size determined from similar previous studies. U.S. Forest Service (USFS) soil monitoring results from the Tahoe basin suggest that 60 samples be taken at each site. As part of these USFS monitoring efforts, Christensen and Norman (2007) collected 67 samples, Cody and Norman (2011) collected 60 samples, and Norman *et al*. (2006) collected 60 samples. In a large forest, where researchers were monitoring effects of forest management practices on soils, a large number of samples were necessary to characterize soils.

The USDA Forest Soil Disturbance Monitoring Protocol, Volumes I and II, describe how to obtain a representative estimate of the disturbance within a particular area. The minimum number of monitoring samples recommended is 30. This number is required to get the site specific variability for a statistically valid sample size. In the current study, 30 samples were collected for the CHP and MPD methods at each site. For the TDI, 30 samples were collected at the BF and IB sites, while 23 samples were collected at the DB site. For the DRI method, 15 samples were collected at the IB and DB sites, while 9 samples were obtained at the BF site.

Another published procedure to estimate number of testing samples is that from the University of Minnesota, Capacity Tests for Infiltration Practices. One can determine the number of testing samples required by using the estimated variance of the $K_{sat}$ of the soil. Once an estimate of the mean and variance are obtained, an equation can be applied to calculate the appropriate number of samples required. Using this method, the number of samples can be obtained from the following equation (Moore and McCabe 2009):

$$n = \{z * \sigma/m\}ok$$

Where,

n = number of measurements
z = standard normal random variable (varies for different confidence levels)
σ = standard deviation
*m* = margin of error (usually half the width of the confidence interval).

Using a margin of error of half the confidence interval for each data set the sample size required for the 90% confidence level was achieved for all sites in the current study. This number varied from method to method from site to site, and results are shown in Table 9.

It is not unreasonable to have a different number of required samples for the different tests. Munoz-Carpena *et al.* (2002) compared results from MPD, CHP, GP. The MPD methodology required a smaller number of samples (41% less than GP and 69% less than LP) to estimate the population mean $K_{sat}$. For the datasets and with a 10% tolerance and 80% CL, the minimum number of samples necessary to estimate the $K_{sat}$ was met only by the PD and one head GP; at 20% tolerance and 95% CL by the PD and the GP, and by the three methods at 20% tolerance and 80% CL. Reducing the tolerance and increasing the CL made the sampling number impractical (460 samples with the LP).

**Table 9. Results from sample size analyses.**

| BED FILTER | Actual # Samples | Moore & McCabe |
|---|---|---|
| CHP | 30 | 21 |
| DRI | 7 | 5 |
| MPD | 28 | 26 |
| TDI | 30 | 28 |

| INFILTRATION BASIN | Actual # Samples | Moore & McCabe |
|---|---|---|
| CHP | 28 | 26 |
| DRI | 14 | 12 |
| MPD | 28 | 25 |
| TDI | 30 | 28 |

| DRY BASIN | Actual # Samples | Moore & McCabe |
|---|---|---|
| CHP | 30 | 29 |
| DRI | 13 | 12 |
| MPD | 26 | 24 |
| TDI | 10 | 8 |

## Surface Caking

Surface caking in stormwater treatment BMPs occurs as the suspended fine sediment in stormwater runoff deposits on the soil surface as the runoff filters through the soil profile (Rice 1974; Metcalf and Eddy 1972; Gonzalez-Merchan *et al.* 2011; Hatt *et al.* 2008). This caking may act as a restrictive layer at the surface reducing infiltration.

Where surface caking was observed, it is expected that permeameter $K_{sat}$ measurements will be higher than infiltrometer $K_{sat}$ measurements because the permeater measures $K_{sat}$ at 4" below the restricting layer (caking). Field observations indicated surface caking of approximately 2.5 cm (1 inch) to be present at the infiltration basin and dry basin sample sites (Figure 15). Detailed measurements, including depth of caking layer and particle size distribution or sieve analysis of the surface caking versus soil profile, were not performed. Visual observation suggested that surface caking was not a significant issue at the bed filter site where only 4 of 30 sample points exhibited surface caking (approximately 0.75 inch or 2 cm). Analysis of the CHP and MPD data indicated that surface caking was not a factor at the dry basin and bed filter sample sites. At the infiltration basin, CHP $K_{sat}$ measurements were higher than MPD measurements, but this difference was not significant (see Table 6) and thus surface caking could not be attributed as the cause of higher CHP readings.

Figure 15. Surface caking extent at the bed filter sample site.

Although this study did not find consistent differences between CHP and MPD data where surface caking was observed, other studies suggest that surface caking may be mitigated through the presence of vegetation which creates macropores through annual root growth and senescence (Le Coustumer *et al.* 2008, Gonzalez-Merchan *et al.* 2011). Thus, surface caking may have been mitigated at the sample sites in this study by the existing vegetation. Field observations estimated vegetation cover at 60% for DB, 50% for IB and 20% for BF. Additionally, the act of pounding the infiltrometer into the soil surface also may have disturbed the caking enough to cause over-estimation of soil surface $K_{sat}$.

## Bulk Density and Porosity

Average bulk density and porosity for the sample sites is shown in Figure 16 and Figure 17. Bulk density and porosity are inversely related, meaning the lower the bulk density, the higher the porosity and vice versa. Lower total porosity is associated with higher soil bulk densities, and the porosity of 0-2 inches soil profile relates to the soil moisture content at saturation. The bulk density results correlate with field observations of organic matter present in the top soil layer. The bed filter sample site had very little organic matter and the media used in the filter was sandy soil material from the site excavation. Although the native material was reused for the filter, this material was very low (>2%) in organic matter (USDA, NRCS 2007). The high bulk density data of the bed filter is consistent with low organic matter subsoil.  Bed filter porosity data is significantly different that the IB and DB sites.  The higher bulk density data typically corresponds to lower $K_{sat}$ measurement data, while the higher porosity values corresponded to higher $K_{sat}$ measurement data.

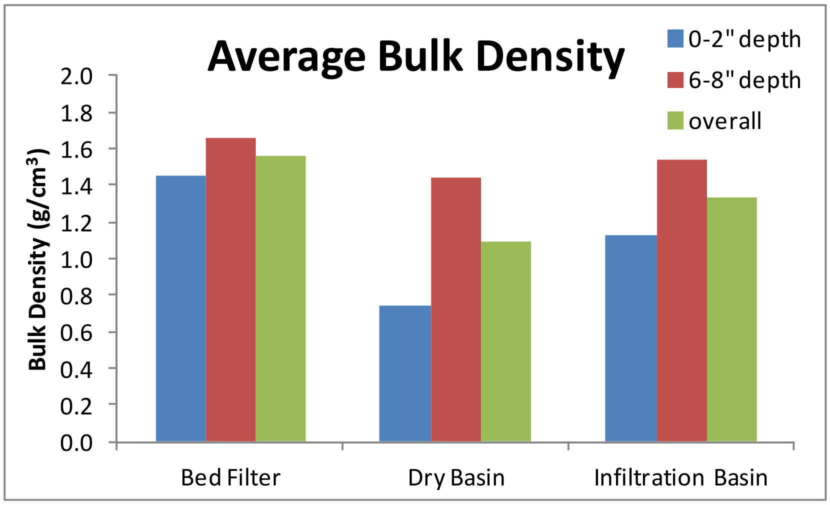


**Figure 16.  Average Bulk Density for the sample sites.**

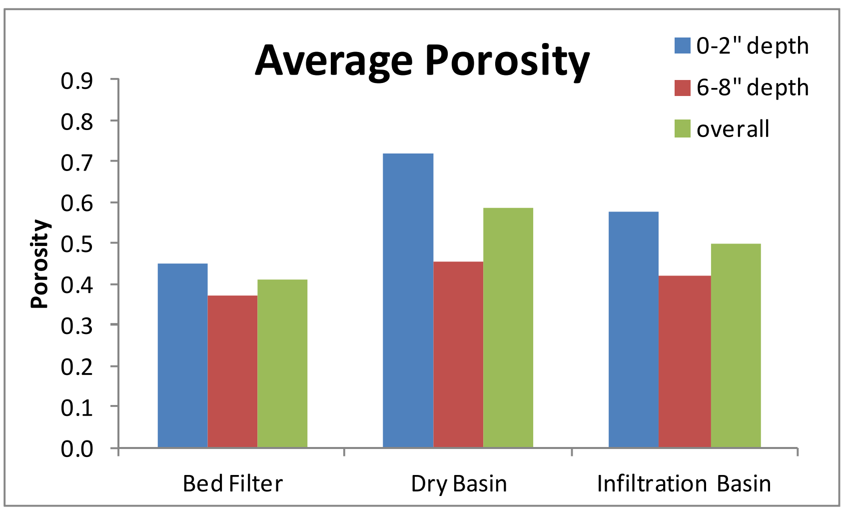


**Figure 17.  Average Porosity for the sample sites.**

## Soil Moisture

Soil moisture determinations were required in order to calculate $K_{sat}$ for the MPD and TDI tests.  Soil moisture data was obtained with a TDR probe or through soil mass wetness samples of a known volume.  Because obtaining soil moisture data is not consistent with a RAM protocol (not *rapid*), the study examined whether performing the MPD tests with soil moisture default values similar to Center for Neighborhood Technology 2012 is valid.

Through inputting the MPD field data into the spreadsheet and through communication with the developers of the MPD, it was discovered that soil moisture data was not a sensitive input variable (Ahmed personal communication).  Despite differences of field observed organic matter content and bulk density and porosity data between the sample sites, initial soil moisture content was consistent between sample sites (excluding post precipitation data). As shown in Table 10, the dry basin soil moisture levels were slightly higher than the other sites, but this may be explained due to the groundwater elevation and the observed stormwater present at the basin inlet. Based on collected sample point data pre-testing soil moisture can be given a default value for the summer sample period. Post-testing soil moisture levels were very similar between the sample sites, thus a default soil moisture value may also be applied to expedite the MPD test process.

**Table 10. Average Soil Moisture Percent between sample sites.**

| | Bed Filter | Infiltration Basin | Dry Basin | All Sites |
|---|---|---|---|---|
| **Average pre-test soil moisture %** | 1.1 | 2.4 | 6.6 | 2.9 |
| **Average post-test soil moisture %** | 36.7 | 39.4 | 35.7 | 37.4 |

Additionally, the climate at Tahoe is ideal for applying default soil moisture values as Tahoe receives the majority of its precipitation in the winter as snowfall and very little precipitation in the summer months when field testing $K_{sat}$ would occur. Table 11 shows the Western Regional Climate Center's monthly average precipitation data for the last 110 years at Tahoe City, CA.

**Table 11. Western Regional Climate Center's monthly precipitation summary for the last 110 years at Tahoe City, CA.**

| *Period of Record: 9/13/1903 to 3/31/2013* | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Average Total Precipitation (in.)** | 5.97 | 5.29 | 4.12 | 2.14 | 1.20 | 0.65 | 0.26 | 0.30 | 0.59 | 1.82 | 3.57 | 5.55 | 31.46 |
| **Average Total Snow Fall (in.)** | 45.9 | 36.5 | 35.2 | 15.9 | 3.7 | 0.2 | 0.0 | 0.0 | 0.3 | 2.4 | 15.5 | 35.2 | 190.7 |
| **Average Snow Depth (in.)** | 23 | 30 | 28 | 13 | 2 | 0 | 0 | 0 | 0 | 0 | 3 | 11 | 9 |

Operating the MPD under default soil moisture values could result in a more rapid test process and yield valid $K_{sat}$ readings as long as the initial soil moisture does not exceed 10%. The MPD spreadsheet calculated consistent $K_{sat}$ results when the initial soil moisture content varied up to 27%. The CHP currently operates under similar soil moisture restrictions. Both the MPD and CHP are intended to measure saturated hydraulic conductivity; i.e., when all pores are full of water and are freely conducting through the zone of measurement. As such, the measurement is a function of water content at saturation and should be unaffected by initial soil moisture content. However, differences in underlying soil properties can reduce the effective saturated hydraulic conductivity of the zone of interest. Changes in soil texture, an underlying layer of reduced permeability, or the presence of a shallow water table under certain conditions can all reduce the effective saturated hydraulic conductivity of an overlying layer. Conditions of initially high water content in the zone of measurement may be indicative of an underlying restriction to water flow, hence the need for measurement limits relative to initial soil moisture content.

## Field Operations

A secondary purpose of this study was to compare the different testing methods for convenience of field operations. Evaluation criteria consisted of ease of use, time required, volume of water required, durability and costs. Testing methods were ranked on a scale of 1 to 3 for the above field operation evaluation criteria with a score of 1 representing a desired trait and 3 representing an undesirable trait (Table 12).

**Table 12. Field operations evaluation between testing methods.**

| Evaluation Criteria | DRI | TDI | CHP | MPD |
|---|---|---|---|---|
| Ease of Use | 2 | 3 | 1 | 2 |
| Time Required | 3 | 2 | 1 | 2 |
| Volume of Water Required | 3 | 1 | 2 | 3 |
| Durability and Maintenance | 1 | 3 | 3 | 2 |
| Material Costs and Availability | 1 | 3 | 2 | 2 |
| TOTAL | 10 | 12 | 9 | 11 |

Where: 1 = most desired, 2 = average, 3 = least desired

### Ease of Use

The 'ease of use' evaluation criteria consisted of the ease with which the site was prepared, the testing unit installed, and the difficulty in operating and obtaining the necessary measurements to calculate $K_{sat}$ with the test instrument. The CHP ranked most desirable in ease of use, followed by the MPD and DRI; while the TDI ranked least desirable in ease of use.

The CHP required a one-inch diameter, level site free of debris, with a 4 inch bore hole in the center. Creating a viable bore hole for the CHP was challenging with rocks, loose soil and subsoil irregularities occasionally present to undermine the integrity of the bore hole. CHP installation in shallow (4 inch) bore holes was difficult because the instrument is top heavy and required a level site to operate, otherwise it was prone to topple; which occurred twice during the study. Three CHP tests were easily conducted at the same time. The CHP produced a direct read $K_{sat}$ in the field. Direct read measurements could be easily checked and verified with subsequent measurements to ensure valid data collection before ending the test.

The MPD did not require specific site preparation other than installation of the base 2 inches into the ground and placement of the permeable filter fabric. The shallow depth allowed for avoidance of rock and other obstructions, although this shallow depth sometimes allowed for leaking of water between the MPD base and the soil (especially in coarse-textured soils) due to the head pressure of the water column, thus invalidating the measurement. The two-piece MPDs required diligence to ensure a good seal between the clear PVC tube and the silicon of the base. O-ring lube was used to ensure a good seal and care was taken to ensure the mating surfaces remained free of debris. Operating three or four MPDs at one time was possible though very challenging as each MPD required its own data recording interval. The MPD did not produce a direct read $K_{sat}$ measurement in the field, but instead required that the field data be input into a proprietary spreadsheet in order to calculate $K_{sat}$. The MPD required volumetric soil moisture measurements before and after tests were conducted, which was not accounted for in this evaluation criteria.

The DRI did not require specific site preparation other than installation of the concentric rings 2 inches into the ground and placement of the permeable filter fabric in the inner ring. The shallow depth allowed for avoidance of rock and other obstructions. Operating three DRIs at one time was possible though very challenging as each DRI required filling of water at different time intervals in order to maintain a constant head. The DRI did not produce a direct read of $K_{sat}$ in the field, but instead required that the field data be calculated to determine $K_{sat}$. Direct read testing methods are possible with the DRI, but those methods were not employed in this study.

The TDI required careful site preparation of preselecting a level site, clearing vegetation and debris, and placing a thin layer of capping sand to level and create an adequate seal. Soil moisture samples were required before and after each test. Soil texture classification was also conducted at each site before testing. It was only possible to conduct one TDI at a time. The TDI did not produce a direct read $K_{sat}$ measurement in the field, but instead required that the field data be calculated in an excel spreadsheet to determine $K_{sat}$.

### Time Required

Of the testing methods, the CHP required the least amount of time on average to operate at each sample point, while the DRI required the most amount of time on average to operate at each sample point. Field personnel operated the CHP, DRI and MPD in sets of three, while performing the TDI tests one at a time. Time required for site preparation and equipment installation was taken into consideration under this evaluation criteria. Not including the time involved to obtain soil moisture samples (approximately 2 minutes per sample point using the TDR probe or 25 minutes obtaining and drying soil core samples), the CHP required 15 minutes; the TDI required 25 minutes; the MPD required 30 minutes; while the DRI required 65 minutes total on average to install and operate.

### Volume of Water Required

The amount of water required to conduct a test is an important factor when considering that the water must be transported to the sampling site. Of the testing methods, the TDI required the least amount of water on average to operate at each sample point, while the MPD required the most amount of water on average to operate at each sample point. The MPD required 1 gallon of water to operate at each sample point; the DRI required .5 gallon; the CHP required 0.2 gallon; while the TDI required .1 gallon of water on average to operate at each sample point.

### Durability and Maintenance

Of the testing methods, the DRI proved the most durable and required the least amount of maintenance, while the CHP and TDI proved least durable and required frequent maintenance on average to operate at each sample point. The DRI required no maintenance during the study. The MPD required occasional cleaning and lubrication of the silicone to ensure a watertight seal between the base and body. The CHP required occasional lubrication of the ball joint to ensure proper operation. The CHP bore-hole tool required periodic sharpening in order to maintain a bevel. The bore-hole tool is fabricated from a soft metal that deforms easily when rock is encountered. Additionally, a CHP unit broke when it toppled due to high winds and sheared the ¾ inch male thread-female slip PVC adapter. Repair required a $.50 part; 20 minutes repair time and overnight for the PVC cement to cure. The PVC plastic construction of the CHP required care in transport and handling to avoid breakage. The TDI required careful handling and storage to avoid damage in transport. The TDI required repair of a hose leak and replacement of the silk membrane during the study.

### Material Costs and Availability

CHP cost estimates based on figures provided by the NRCS are listed in Table 13 (NRCS 2012). NRCS staff estimated the time required to obtain materials and fabricate a CHP at about 4 hours. The CHPs can be fabricated mostly from parts available in a local hardware store and require no specialized tools or knowledge on behalf of the builder. The only material not available locally is the 3-inch diameter clear schedule 40 PVC pipe.

Table 13. CHP material costs.

| Item | Cost ($) | Supplier |
|---|---|---|
| **3" clear sch 40 PVC** | 2ft. @ 18.00/ft. =36 | Clearpvcpipe.com |
| **3" ABS cap** | 6.50 | Meeks |
| **3"x2" slip-slip ABS reducer** | 4.00 | Meeks |
| **2"x¾" PVC bushing slip-thread** | 2.50 | Meeks |
| **¾" close nipple sch 80** | .50 | Scotty's |
| **¾" PVC ball valve thread-thread** | 5.00 | Scotty's |
| **¾" male thread-female slip PVC adapter** | .50 | Scotty's |
| **¾" sch 40 PVC pipe** | 2ft. @ 0.25/ft. = 0.50 | Meeks |
| **¾" Moody Coupler** | 4.50 | Meeks |
| **½" sch 40 PVC pipe** | 1/3 ft. @ 1.50/ft. = 0.50 | Meeks |
| **Scale** | N/A | NRCS |
| **TOTAL:** | **$60** | Does not include sales tax |

Two styles of MPD infiltrometer were fabricated for this study. For constructing the one-piece style, the construction directions in Appendix C of *Assessment of Stormwater Best Management Practices* (Gulliver and Anderson 2007) were followed. The two-piece style was based on a unit purchased from St. Anthony Falls Laboratory. Directions to fabricate the two-piece style are included in Appendix C.

Material costs for the two-piece style are provided in Table 14. Material costs for the one-piece style are provided in

Table 15. The two-piece style MPD required 20 minutes to fabricate, while the one-piece style required 25 minutes to fabricate. Many of the materials required to fabricate both styles of the MPD are not available locally. The MPDs both require beveled leading edges which will likely require the services of a machine shop to accomplish. The one-piece style requires drilling metal, tapping holes and riveting, but a well-stocked garage or maintenance department should contain the tools necessary to perform these tasks. The installation tool from the purchased MPD kit was used to install the fabricated two-piece MPDs. A suitable installation tool may be created with a 4 ½ inch hole saw and a scrap 2"x6" piece of lumber to fashion a wooden circle that fits inside the MPD base enabling installation in the soil with repeated mallet blows.

Table 14. Two-piece style MPD material costs.

| Item | Cost ($) | Supplier |
|---|---|---|
| 4" clear thinwall PVC | 1.5 ft. @ 20.00/ft. = 30 | Clearpvcpipe.com |
| 4" dia x 2.75" Stainless T-304 sch 10 pipe | 12.64 | OnlineMetals.com |
| 4" Silicone Coupler | 11.86 | Racinginnovationandsupply.com |
| 4.5" hose clamps | 2 @ 1.85 ea = 3.98 | Home Depot |
| Scale | N/A | NTCD |
| **TOTAL:** | **$58.48** | **Includes shipping costs and sales tax (NV 7.5%)** |

Table 15. One-piece style MPD material costs.

| Item | Cost ($) | Supplier |
|---|---|---|
| 4" 16 gauge mild steel tube | 1.5 ft. @ 18.10/ft. = 27.15 | Columbia River Mandrel Bends |
| ¼" threaded 90 degree hose barb | 3.19 | C. N. E. Small Engines |
| ¼" clear tubing | 1.5 ft. @ 0.19/ft. = .30 | Kingsbury Hardware |
| Scale | N/A | NTCD |
| **TOTAL:** | **$30.64** | **Includes shipping costs and sales tax (NV 7.5%)** |

Material costs for the DRI are listed in Table 16. The rings were ordered to length (5 inches) and required additional labor to cut a bevel. The DRI may be fabricated more inexpensively by repurposing commonly available items such as metal coffee cans.

Table 16. DRI material costs.

| Item | Cost ($) | Supplier |
|---|---|---|
| 4" 16 gauge aluminum tube | 14.69 | OnlineMetals.com |
| 6" 16 gauge aluminum tube | 17.95 | OnlineMetals.com |
| **TOTAL:** | **$32.64** | **Includes shipping costs and sales tax (NV 7.5%)** |

Material costs are similar between the one-piece MPD and DRI, while the two-piece MPD and CHP are roughly double the cost. However, not all of the materials are available locally for these units. TDI units are impractical to fabricate and not readily available for purchase.

# CONCLUSIONS

The field comparison results analysis indicates that the study hypotheses ranged from being Supported to Not Supported as summarized below:

1. **Supported**. The MPD measured soil surface hydraulic conductivity rates are comparable to those derived from the other tested infiltrometers (TDI and DRI).
2. **Not Supported.** Caking of surface soils is an influencing factor in the sampled SWT BMPs, evidenced by the CHP $K_{sat}$ values differing significantly from the infiltrometer methods.
3. **Partially Supported.** The MPD infiltrometer is a suitable rapid assessment methodology alternative to the CHP test, in that the expediency and convenience of field operation between the MPD and CHP are similar.

We found that $K_{sat}$ values collected using the MPD are within the same order of magnitude as the other sampling methods, all methods obtained measurements more than 1 inch per hour (aside from the TDI), and had a low coefficient of variation within the site. Additionally, the MPD proved to be the most consistent testing method at the dry basin sample site which had the environmental challenges of hydrophobic soils and a change in soil moisture due to a precipitation event.

Greater variability existed in the $K_{sat}$ datasets for the MPD and DRI versus the CHP. These results suggest that there may be greater variability at the soil surface than in the subsurface. This study did not find consistent differences between CHP and MPD data where surface caking was observed. Surface caking may have been mitigated in this study by the existing vegetation by macropore development through annual root growth and senescence.

The study analyzed the convenience of field operation between the MPD and the CHP (the Tahoe accepted RAM tool for *rapidly* measuring $K_{sat}$) to determine if the MPD could be a suitable and comparable RAM tool. While not quite as efficient to operate, the MPD proved more durable than the CHP and was similar in cost to fabricate. The primary disadvantages of the MPD for use as a RAM tool is the requirement to obtain soil moisture readings before and after testing and inputting multiple data points into a spreadsheet to calculate $K_{sat}$. However, it may be possible to modify the MPD to obviate the need for soil moisture data and employ a direct-read scale to produce more rapid readings in the field. These modifications could cut the current operating times in half while still providing relatively accurate results.

# ACKNOWLEDGEMENTS

This study was made possible through grants from the Nevada Division of State Lands License Plate Grant Program and from the Nevada Division of Environmental Protection. NTCD would like to thank the Cave Rock Estates General Improvement District, Russ Wigart with El Dorado County and Robert Ehrlich with the City of South Lake Tahoe for their support and cooperation in facilitating sampling site permission. NTCD appreciates the support of the University of Minnesota and the St. Anthony Falls Laboratory in supplying the MPD kit and assisting in processing the MPD data. The Tahoe Science Consortium coordinated peer review services for the Sampling and Analysis Plan and this Final Report. Dr. Wally Miller at the University of Nevada, Reno partnered with NTCD on this study and provided support, guidance and resources.

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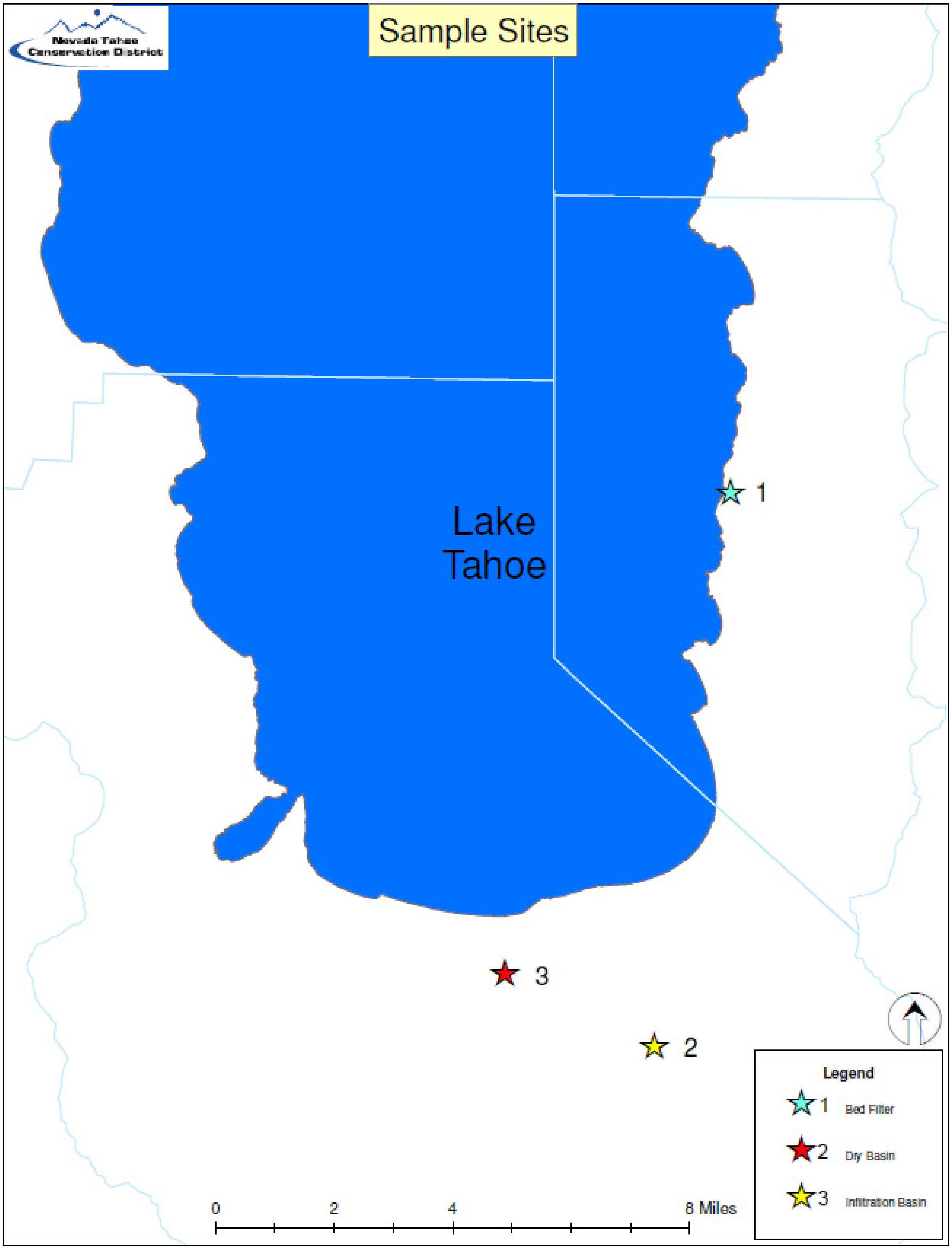
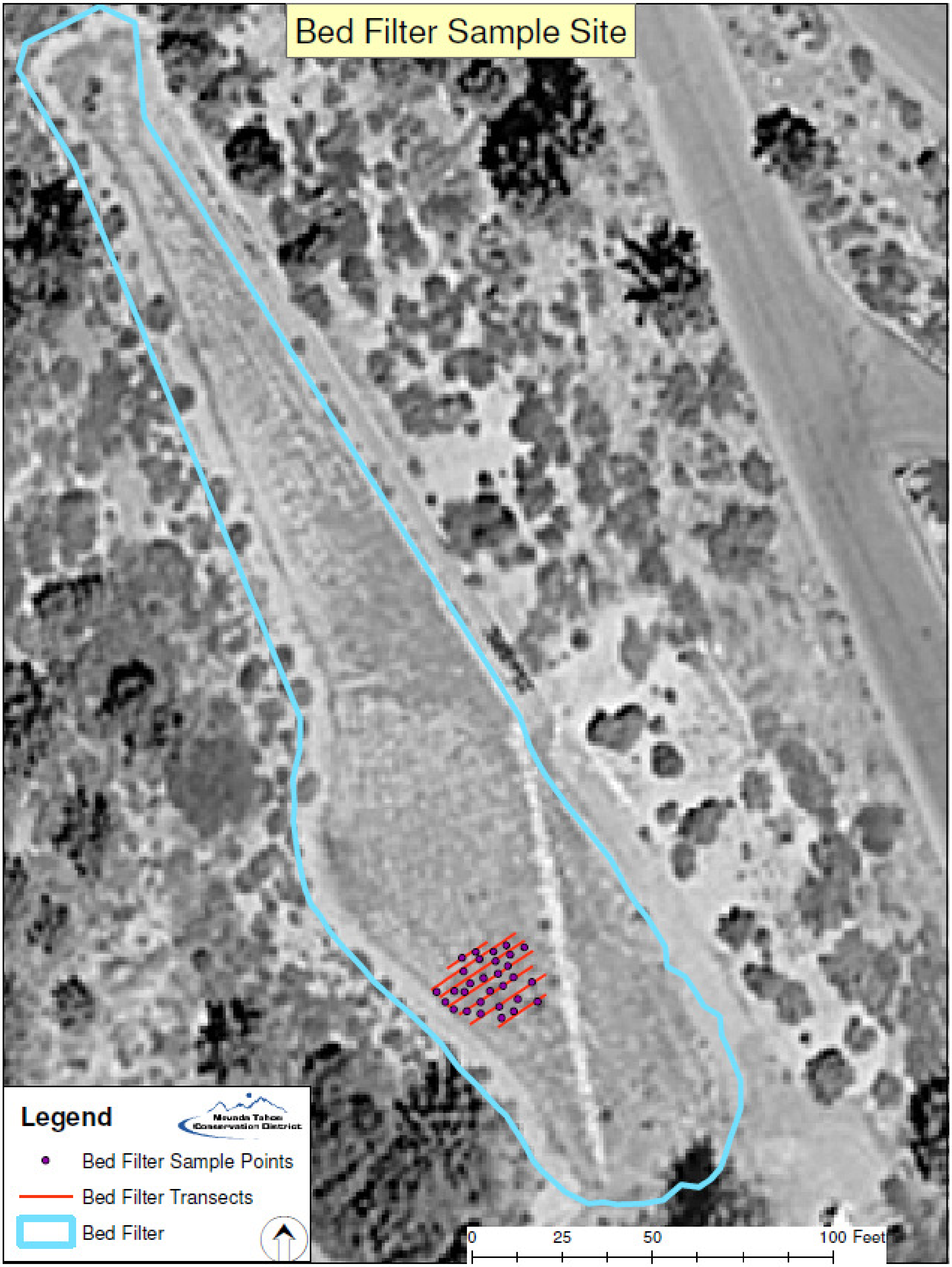
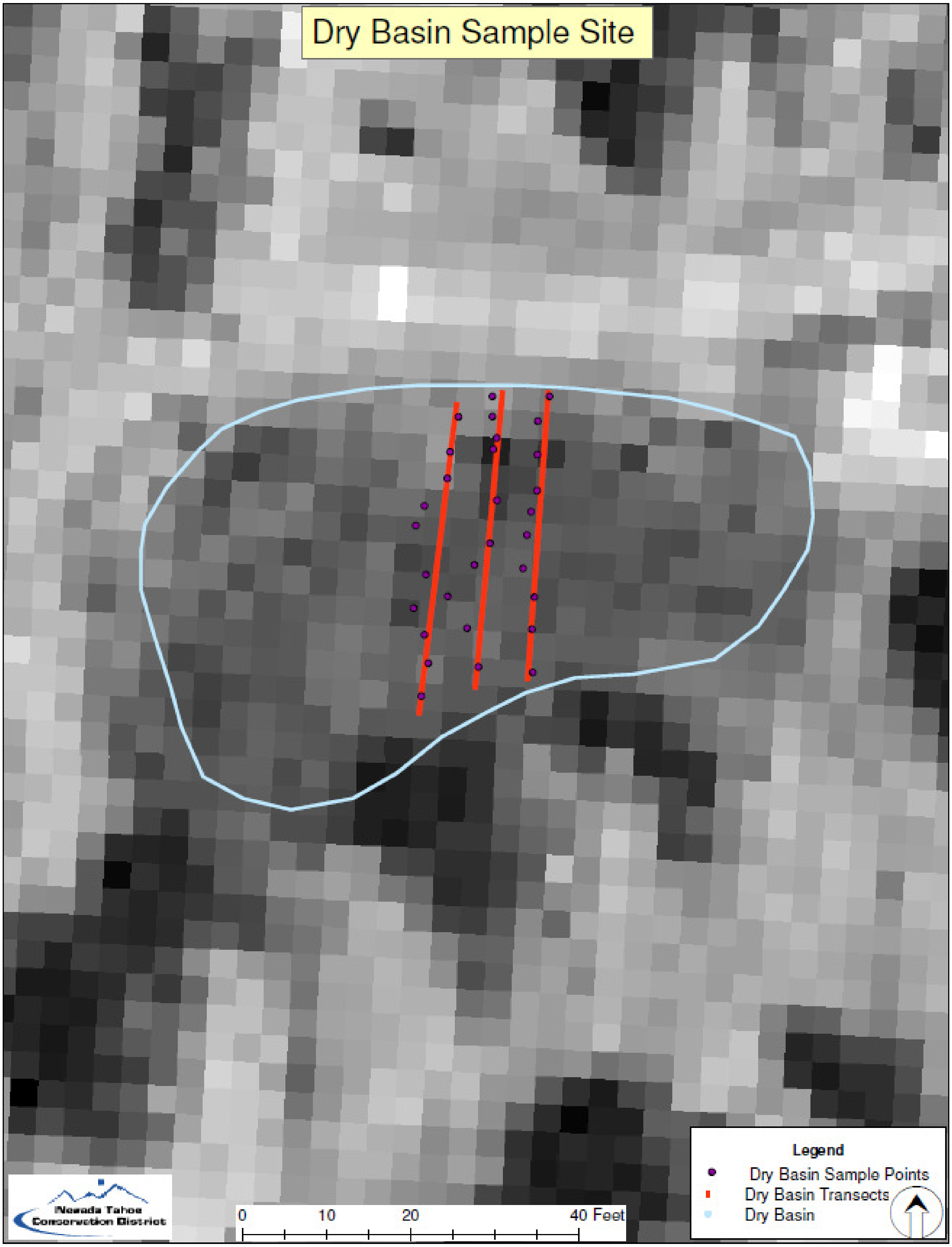
# APPENDICES

# APPENDIX A – Maps




Bed Filter Sample Site
Legend
Nevada Tahoe Conservation District
Bed Filter Sample Points
Bed Filter Transects
Bed Filter
0
25
50
100 Feet


Infiltration Basin Sample Site
Legend
Infiltration Basin Sample Points
Infiltration Basin Transects
Infiltration Basin
0
25
50
100 Feet
Nevada Tahoe Conservation District


Dry Basin Sample Site
Legend
Dry Basin Sample Points
Dry Basin Transects
Dry Basin
0
10
20
40 Feet
Nevada Tahoe
Conservation District

## APPENDIX B – Soil Series Descriptions

### 7485 - Meeks gravelly loamy coarse sand, 15 to 30 percent slopes, extremenly bouldery

**Composition**

- Meeks, extremely bouldery and similar soils: 80 percent of the unit
- Burnlake and similar soils: 5 percent of the unit
- Meeks, rubbly and similar soils: 5 percent of the unit
- Dagget, moist and similar soils: 3 percent of the unit
- Tallac, very stony and similar soils: 3 percent of the unit
- Roadcat and similar soils: 2 percent of the unit
- Aquic Xerorthents and similar soils: 1 percent of the unit
- Jabu and similar soils: 1 percent of the unit

**Setting**

*Landform(s):* moraines, mountains
*Elevation:* 6217 to 8120 feet
*Precipitation:* 23 to 63 inches
*Slope gradient:* 15 to 30 percent
*Air temperature:* 41 to 46 °F
*Frost-free period:* 40 to 90 days

**Characteristics of Meeks, extremely bouldery and similar soils**

*Average total avail. water in top five feet (in.):* 3.0
*Available water capacity class:* Low
*Parent material:* till derived from granodiorite
*Restrictive feature(s):* duripan at 41 to 73 inches
*Depth to Water table:* none within the soil profile
*Drainage class:* somewhat excessively drained
*Flooding hazard:* none
*Ponding hazard:* none
*Soil loss tolerance (T factor):* 5
*Wind erodibility group (WEG):* 7
*Wind erodibility index (WEI):* 38
*Land capability class, non-irrigated:* 6e
*Hydric soil:* no
*Runoff class:* low
*Potential frost action:* low

*Representative soil profile:*

| Horizon -- Depth (inches) | Texture | Ksat (inches per hour) | % cobbles | % stones and boulders | Excavation Difficulty |
|---|---|---|---|---|---|
| Oi -- 0 to 2 | Slightly decomposed plant material | 56 | - | - | Low |
| A -- 2 to 13 | Gravelly loamy coarse sand | 14 | 0 - 28 | 0 - 0 | |
| Bw -- 13 to 63 | Extremely stony loamy coarse sand | 14 | 20 - 35 | 22 - 36 | |
| Bqm -- 63 to 73 | Gravelly loamy coarse sand | 0.1274 | 0 - 20 | 0 - 0 | Very high |

*Ecological class(es):* NRCS Forestland Site - Abies concolor-Pinus lambertiana/Quercus vacciniifolia-Amelanchier utahensis/Pyrola picta

## 7461 - Jabu coarse sandy loam, 0 to 9 percent slopes

***Composition***

- Jabu and similar soils: 80 percent of the unit
- Christopher, Loamy coarse sand and similar soils: 10 percent of the unit
- Oneidas and similar soils: 5 percent of the unit
- Gefo, gravelly loamy coarse sand and similar soils: 3 percent of the unit
- Marla and similar soils: 2 percent of the unit

***Setting***

*Landform(s)* mountains, hillslopes on outwash terraces
*Elevatio* 6234 to 6808 feet
*Precipitatio* 23 to 35 inches
*Slope* 0 to 9 percent
*Air temperature:* 41 to 46 ºF
*Frost-free* 40 to 90 days

***Characteristics of Jabu and similar soils***

*Average total avail. water in top five feet* 12.0
*Available water capacity* High
*Parent* outwash derived from granodiorite
*Restrictive* fragipan at 39 to 79 inches
densic bedrock at 59 to 79 inches
*Depth to Water* 53 inches
*Drainage* well drained
*Flooding* none
*Ponding* none
*Saturated hydraulic conductivity* Moderately Low
*Soil loss tolerance (T* 4
*Wind erodibility group* 7
*Wind erodibility index* 38
*Land capability class, irrigated:*
*Land capability class, non-* 4e
*Hydric soil:* no
*Hydrologic* B
*Runoff class:* low
*Potential frost* moderate

*Representative soil profile:*

| Horizon -- | Depth (inches) | Texture | Ksat | pH | Salinity (mmhos/cm) | SAR |
|---|---|---|---|---|---|---|
| Oi -- | 0 to 1 | Slightly decomposed plant | 56.7 | | 0 - 0 | 0 - 0 |
| A -- | 1 to 7 | Coarse sandy loam | 12.8 | 5.1 to 6.5 | 0 - 0 | 0 - 0 |
| Bt1 -- | 7 to 21 | Coarse sandy loam | 4.0 | 5.1 to 6.5 | 0 - 0 | 0 - 0 |
| Bt2 -- | 21 to 46 | Gravelly coarse sandy loam | 4.0 | 5.1 to 6.5 | 0 - 0 | 0 - 0 |
| Bx -- | 46 to 67 | Coarse sandy loam | 0.1 | 5.1 to 6.5 | 0 - 0 | 0 - 0 |
| C -- | 67 to 73 | Stratified fine sandy loam to silty | 4.0 | 5.1 to 6.5 | 0 - 0 | 0 - 0 |
| Cd -- | 73 to 101 | Coarse sandy loam | 0.1 | 5.1 to 6.5 | 0 - 0 | 0 - 0 |

*Ecological class(es):* NRCS Forestland Site - Pinus jeffreyi-Abies concolor/Ceanothus cordulatus-Ceanothus prostratus/Pedicularis semibarbata-Kelloggia

## 7471 - Marla loamy coarse sand, 0 to 5 percent slopes

***Composition***

- Marla and similar soils: 80 percent of the unit
- Christopher, Loamy coarse sand and similar soils: 4 percent of the unit
- Gefo, gravelly loamy coarse sand and similar soils: 4 percent of the unit
- Tahoe, silt loam and similar soils: 4 percent of the unit
- Ubaj and similar soils: 4 percent of the unit
- Watah and similar soils: 4 percent of the unit

***Setting***

*Landform(s)* mountains, outwash terraces, valley flats
*Elevatio* 6217 to 6496 feet
*Precipitatio* 23 to 49 inches
*Slope* 0 to 5 percent
*Air temperature:* 41 to 46 ºF
*Frost-free* 20 to 75 days

***Characteristics of Marla and similar soils***

*Average total avail. water in top five feet* 7.9
*Available water capacity* Moderate
*Parent* alluvium derived from granodiorite
*Restrictive* none
*Depth to Water* 20 to 59 inches
*Drainage* poorly drained
*Flooding* rare
*Ponding* frequent
*Soil loss tolerance (T* 5
*Wind erodibility group* 8
*Wind erodibility index* 0
*Land capability class, irrigated:*
*Land capability class, non-* 6w
*Hydric soil:* yes
*Hydrologic* B/D
*Runoff class:* very high
*Potential frost* moderate

*Saturated hydraulic conductivity* Moderately High

*Representative soil profile:*

| Horizon -- | Depth (inches) | Texture | Ksat | pH | Salinity (mmhos/cm) | SAR |
|---|---|---|---|---|---|---|
| Oi -- | 0 to 3 | Slightly decomposed plant | 56.7 | | 0 - 0 | 0 - 0 |
| A -- | 3 to 14 | Loamy coarse sand | 4.0 | 5.1 to 6.5 | 0 - 0 | 0 - 0 |
| C -- | 14 to 47 | Loamy coarse sand | 4.0 | 5.6 to 6.5 | 0 - 0 | 0 - 0 |
| 2Cg1 -- | 47 to 59 | Clay loam | 0.6 | 5.6 to 6.5 | 0 - 0 | 0 - 0 |
| 2Cg2 -- | 59 to 68 | Stratified sandy loam to fine sandy | 2.8 | 6.1 to 7.3 | 0 - 0 | 0 - 0 |

*Ecological class(es):* NRCS Forestland Site - Pinus contorta var. murrayana/Salix lemmonii

# APPENDIX C – Fabricating MPDs

<u>Two-piece MPD Materials</u>:

1. Clear 4" thinwall UV Rated PVC. 16" length
2. 4" diameter x 2.75" Stainless T-304 schedule 10 pipe. 2.75" length. 60* beveled edge.
3. 4.5" diameter x 3" Silicone Coupler. Cut to 45mm length.
4. 4.5" hose clamps (2 needed)
5. Adhesive Metric Scale
6. Silicone sealant

| Item | Cost ($) | Supplier |
|---|---|---|
| 4" clear thinwall PVC | 20.00/ft. @ 1.3 ft. = 26.00 | FlexPVC.com |
| 4" dia x 2.75" Stainless T-304 sch 10 pipe | 15.74 | OnlineMetals.com |
| 4" Silicone Coupler | 11.86 | Racinginnovationandsupply.com |
| 4.5" hose clamps | 2 @ 1.85 ea = 3.98 | Home Depot |
| Adhesive Metric Scale | N/A | NTCD |
| Silicone Sealant | N/A | NTCD |
| TOTAL: | $57.58 | Includes shipping costs and sales tax (NV 7.5%) |

<u>Directions:</u>

1. Bevel 4" Steel Ring at 60* angle
2. Cut silicone coupler to 45mm height with razor
3. Apply small bead of silicone sealant to inside edge of coupler
4. Slide sealant edge of silicone coupler onto 4" tube so that 51mm of beveled end of steel ring is exposed.
5. Install and tighten hose clamps around the silicone coupler (one at bottom of coupler; other at top of 4" steel ring)
6. Double check to ensure 51 mm of beveled pipe is exposed.
7. Cut 16" length of thinwall clear PVC and deburr ends with 120 grit sandpaper.
8. Apply measure tape to outside of clear PVC so 0 reading on scale aligns w/ 51mm of beveled pipe (soil surface, when installed). Trim tape as needed to seat flush with silicone coupler and top of PVC.

<u>Installation Tool Materials:</u>

1. 4.5" hole saw and arbor
2. Scrap 2x6 piece

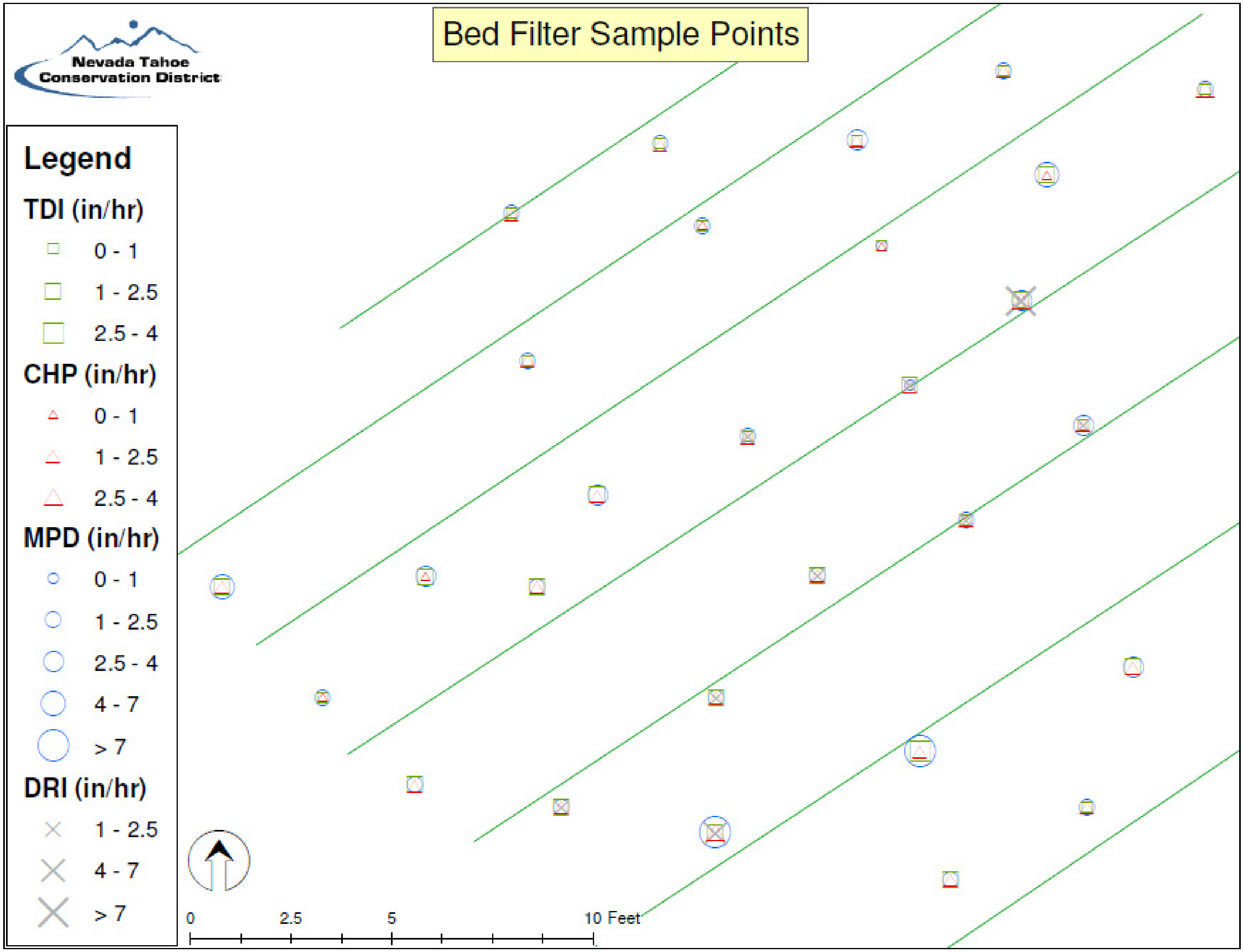
| Item | Cost ($) | Supplier |
|---|---|---|
| 4.5" hole saw and arbor | 49.94 | Home Depot |
| Scrap 2x6 lumber piece | N/A | NTCD |
| TOTAL: | $49.94 | |

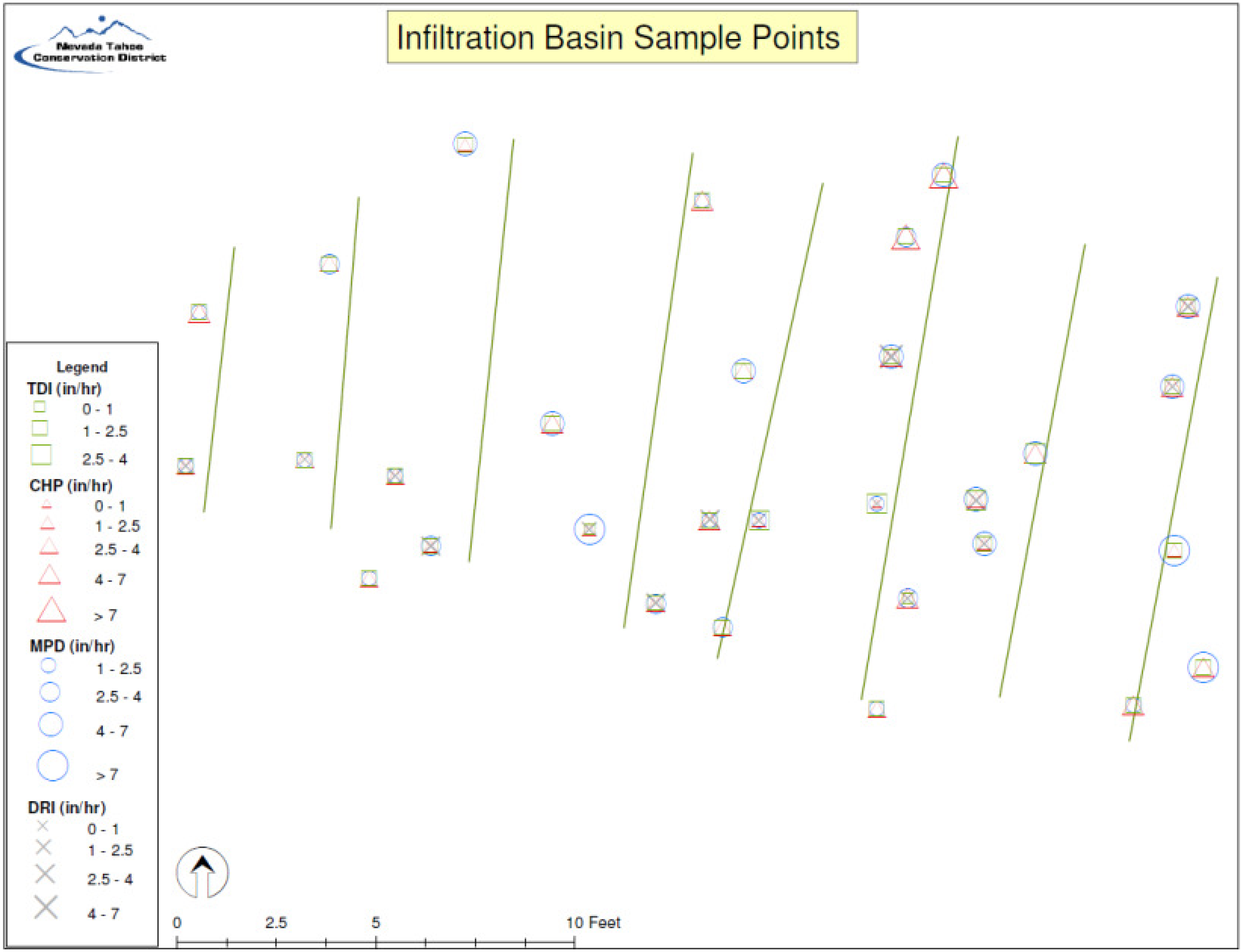
<u>Directions:</u>

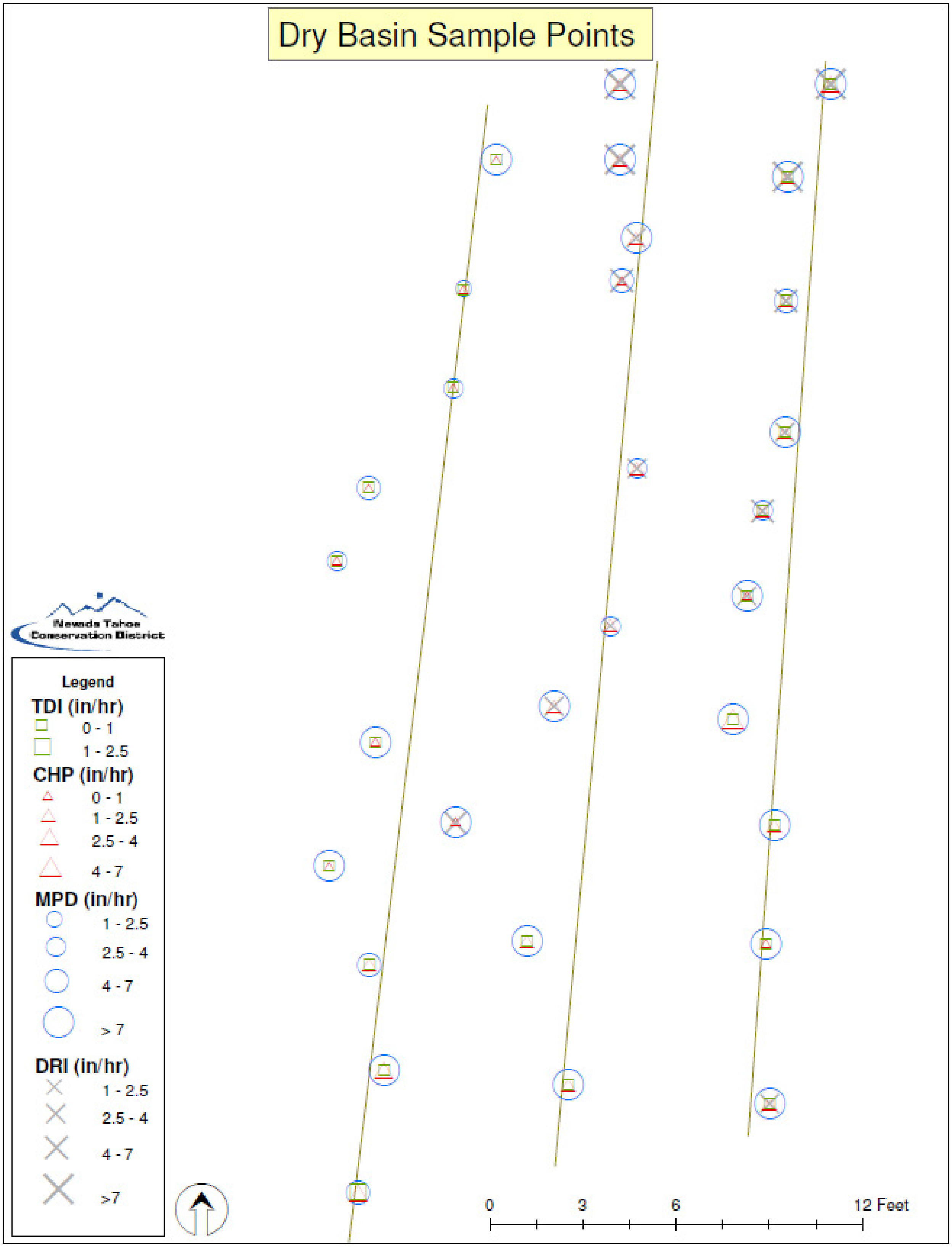
1. Drill through a scrap piece of 2x6" with a 4 ½" hole saw.
2. Remove wooden circle from drill bit and smooth rough edges.

This wooden insert will snugly fit inside the base of a two-piece style MPD and will allow insertion of the base into the soil with repeated mallet blows to the wooden insert.

## APPENDIX D – Sample Data Maps




Infiltration Basin Sample Points
Nevada Tahoe Conservation District
Legend
TDI (in/hr)
0 - 1
1 - 2.5
2.5 - 4
CHP (in/hr)
0 - 1
1 - 2.5
2.5 - 4
4 - 7
> 7
MPD (in/hr)
1 - 2.5
2.5 - 4
4 - 7
> 7
DRI (in/hr)
0 - 1
1 - 2.5
2.5 - 4
4 - 7
0
2.5
5
10 Feet


Dry Basin Sample Points
Nevada Tahoe Conservation District
Legend
TDI (in/hr)
0 - 1
1 - 2.5
CHP (in/hr)
0 - 1
1 - 2.5
2.5 - 4
4 - 7
MPD (in/hr)
1 - 2.5
2.5 - 4
4 - 7
> 7
DRI (in/hr)
1 - 2.5
2.5 - 4
4 - 7
>7
0
3
6
12 Feet

# APPENDIX E – Raw Field Data

| BMP | Sample Point | MPD Ksat (in/hr) | CHP Ksat (in/hr) | DRI Ksat (in/hr) | TDI Kp (in/hr) |
|---|---|---|---|---|---|
| BF | 1 | 2.35433198 | 2.167 | | 1.37 |
| BF | 2 | 1.25196918 | 1.250 | | 0.69 |
| BF | 3 | 0.61811057 | 1.600 | | 2.08 |
| BF | 4 | 3.25984428 | 1.600 | | 2.08 |
| BF | 5 | 2.94882049 | 1.600 | | 2.08 |
| BF | 6 | 8.7795323 | 2.167 | | 2.63 |
| BF | 7 | 8.97244579 | 2.500 | 6.779869252 | 1.37 |
| BF | 8 | 3.29134036 | 1.625 | 1.613847971 | 0.69 |
| BF | 9 | 1.23622114 | 1.375 | 1.272292844 | 0.69 |
| BF | 10 | 1.50393782 | 1.333 | 1.946864218 | 1.37 |
| BF | 11 | 2.33858394 | 1.333 | 2.433580273 | 2.08 |
| BF | 12 | 2.43307218 | 1.333 | 1.729122826 | 1.37 |
| BF | 13 | 3.24803325 | 2.667 | 9.700165579 | 1.31 |
| BF | 14 | 0.28740173 | 2.167 | 1.793164412 | 1.31 |
| BF | 15 | 1.12204785 | 1.833 | 1.852936559 | 0.69 |
| BF | 16 | 2.62598567 | 2.000 | | 1.37 |
| BF | 17 | 2.31496188 | 2.200 | | 1.37 |
| BF | 18 | 2.35433198 | 1.800 | | 1.37 |
| BF | 19 | 2.15354447 | 1.000 | | 0.69 |
| BF | 20 | 3.43307272 | 1.000 | | 2.08 |
| BF | 21 | 2.16929251 | 1.400 | | 0.69 |
| BF | 22 | 1.95275696 | 1.000 | | 0.69 |
| BF | 23 | 0.02362206 | 0.500 | | 0.69 |
| BF | 24 | 4.01968721 | 0.500 | | 1.37 |
| BF | 25 | 1.93700892 | 2.625 | | 0.69 |
| BF | 26 | 1.22441011 | 2.125 | | 0.69 |
| BF | 27 | 3.42126169 | 1.750 | | 0.69 |
| BF | 28 | 1.72441038 | 1.500 | | 0.69 |
| BF | 29 | 1.61023709 | 1.250 | | 0.69 |
| BF | 30 | 5.90945201 | 1.750 | | 1.37 |

| BMP | Sample Point | MPD Ksat (in/hr) | CHP Ksat (in/hr) | DRI Ksat (in/hr) | TDI Kp (in/hr) |
|---|---|---|---|---|---|
| IB | 1 | 1.76378048 | 3.000 | | 1.31 |
| IB | 2 | 0 | 4.400 | | 1.97 |
| IB | 3 | 9.51181616 | 4.500 | | 1.97 |
| IB | 4 | 11.82284103 | 1.200 | | 1.97 |
| IB | 5 | 4.51968748 | 2.429 | 2.062139073 | 1.97 |
| IB | 6 | 2.68897783 | 5.000 | 2.35673037 | 0.66 |
| IB | 7 | 2.62598567 | 2.667 | | 1.97 |
| IB | 8 | 2.62992268 | 3.400 | 3.752836947 | 1.31 |
| IB | 9 | 4.9212625 | 5.143 | | 2.63 |
| IB | 10 | 4.00787618 | 3.500 | 2.689746618 | 2.63 |
| IB | 11 | 2.43307218 | 0.750 | 0.794115668 | 2.63 |
| IB | 12 | 2.18504055 | 2.000 | 1.088706964 | 2.63 |
| IB | 13 | 1.72441038 | 4.286 | 2.638513349 | 1.31 |
| IB | 14 | 7.5590592 | 2.000 | 1.203981819 | 0.33 |
| IB | 15 | 3.79921465 | 2.375 | 2.536046811 | 1.31 |
| IB | 16 | 1.35039443 | 2.500 | | 1.97 |
| IB | 17 | 5.09055393 | 6.625 | 3.157250196 | 1.97 |
| IB | 18 | 4.83071127 | 5.286 | 2.12618066 | 1.97 |
| IB | 19 | 4.9212625 | 5.143 | 4.491449907 | 1.97 |
| IB | 20 | 4.33464801 | 3.500 | | 1.97 |
| IB | 21 | 4.91338848 | 4.857 | | 1.31 |
| IB | 22 | 1.48425277 | 3.714 | 1.818781046 | 1.31 |
| IB | 23 | 1.61023709 | 3.875 | 0.768499034 | 1.97 |
| IB | 24 | 2.01574912 | 2.500 | 1.767547777 | 1.31 |
| IB | 25 | 4.06299432 | 8.571 | | 1.97 |
| IB | 26 | 2.78740308 | 10.429 | | 1.31 |
| IB | 27 | 1.12992187 | 5.000 | | 1.31 |
| IB | 28 | 4.82677426 | 2.375 | | 1.31 |
| IB | 29 | 2.68110381 | 3.000 | | 1.31 |
| IB | 30 | 1.97637902 | 4.250 | | 1.31 |

| BMP | Sample Point | MPD Ksat (in/hr) | CHP Ksat (in/hr) | DRI Ksat (in/hr) | TDI Kp (in/hr) |
|---|---|---|---|---|---|
| DB | 1 | 64.05908971 | 3.000 | 14.43497351 | 0.16 |
| DB | 2 | 27.42914867 | 2.375 | 7.62094875 | 0.06 |
| DB | 3 | 6.11023952 | 2.125 | 5.328259966 | 0.33 |
| DB | 4 | 8.62598891 | 1.125 | 3.663178727 | 0.33 |
| DB | 5 | 3.83071073 | 1.625 | 5.084901939 | 0.16 |
| DB | 6 | 7.68898053 | 0.625 | 3.13803772 | 0.22 |
| DB | 7 | 15.63780372 | 4.125 | | 0.33 |
| DB | 8 | 10.14173776 | 2.125 | | 0.16 |
| DB | 9 | 11.70473073 | 0.429 | | 0.33 |
| DB | 10 | 15.4330792 | 1.125 | 3.97057834 | 0.22 |
| DB | 11 | 22.54725627 | 1.375 | 7.147041012 | |
| DB | 12 | 25.55513191 | 1.875 | 10.83583637 | |
| DB | 13 | 28.35040901 | 2.000 | 3.983386657 | |
| DB | 14 | 6.36614517 | 0.750 | 4.316402905 | |
| DB | 15 | 2.53937145 | 1.375 | 3.061187817 | |
| DB | 16 | 3.3070884 | 1.875 | 2.279880466 | |
| DB | 17 | 7.35433468 | 1.625 | 3.368587431 | |
| DB | 18 | 17.93308055 | 0.875 | 6.865258033 | |
| DB | 19 | 11.2204785 | 1.250 | | 0.66 |
| DB | 20 | 11.32677777 | 2.250 | | 0.66 |
| DB | 21 | 6.57086969 | 3.625 | | 1.31 |
| DB | 22 | 7.77559475 | 2.750 | | 0.66 |
| DB | 23 | 5.68504244 | 1.500 | | 0.33 |
| DB | 24 | 7.14961016 | 0.875 | | 0.33 |
| DB | 25 | 9.01968991 | 0.375 | | 0.33 |
| DB | 26 | 2.79921411 | 0.625 | | 0.22 |
| DB | 27 | 5.69291646 | 0.625 | | 0.33 |
| DB | 28 | 3.01968667 | 0.500 | | 0.33 |
| DB | 29 | 1.72834739 | 0.375 | | 0.66 |
| DB | 30 | 7.76378372 | 0.625 | | 0.66 |

Yellow Highlighted Cells = Outliers removed before analysis

# APPENDIX F – Peer Review Comments

| MPD Testing Peer Review Comments | | | | |
|---|---|---|---|---|
| # | Page # | Comment | Response | Action |
| 1 | 14 | This section needs to be re-organized for readability and flow of thought. Start with a summary of the data like Table 3, then what probability distribution you applied or used, the transformation that was required (if any) and then a summary table of the means & variances of the transformed data from each test method followed by the appropriate z or f and p-values. | NTCD followed organization and layout used in other similar published studies. We believe the suggested approach would create more of a "summary report". The Final Report as written would still be necessary for those interested in the complete information thus creating a duplication of effort. | |
| 2 | 14 | This is good to explain your criteria for removing outliers and is expected. We usually also try to offer possible explanations as to why the particular values were outliers from the field notes perhaps, and speculate on how they might have affected the results. Often, interesting information may be contained in the outliers that are true values and not associated with experimental problems… | | Added sentence on pg 14 on additional criteria used, but citing of Stedinger 1992 and Rousseeuw 1990 should be sufficient to direct reader to outlier detection and removal methods followed. Added sentence on page 14 on speculation of more outliers with infiltrometers than permeameters. |
| 3 | 15 | Ye; this is always true in the field. Entrapped air alone of 5-10% by volume results in K = 0.5 Ksat | The reviewer suggests a correction factor of 2 be applied to TDI data to compensate for the application under tension similar to findings in "Pore size distributions and infiltration", Grismer 1986. We have not been able to obtain the source paper to determine applicability to this study and have found no other studies that have suggested the need for a correction factor to TDI data in order to estimate $K_{sat}$. | |
| 4 | 18 | Is there not a 3x4 matrix of comparisons for each site that get back to your original hypotheses? You expected MPD results to compare well with those from TDI and DRI and likely differ from those obtained using the CHP. | Table 6 presents the findings of the statistical comparison of the results from one method to another. The CHP is expected to be statistically different from the other methods because it measures $K_{sat}$ at depth in the soil profile, versus at the surface that is recorded by the other methods. | |
| 5 | 18 | So then if both MPD and CHP don't differ from DRI, then likely MPD does not differ from CHP, no? | No. DRI data lies between the MPD values and CHP values. The MPD and CHP are close enough to the DRI but aren't close to one another. | |
| 6 | 19 | Making the coarse assumption that TDI Ksat measured values are likely <0.5 times Ksat of any of the other wet methods, then at least for the bed filter and infiltration basin, these comparisons are only marginally different if at all. | NTCD did not apply a correction factor to the TDI values, but they are within an order of magnitude. Assuming a 50% difference in measured values is indeed a "coarse assumption" and would vary depending upon pore size distribution of the matrix which was not measured. | |
| 7 | 19 | Based on this figure, the four methods yielded equivalent Ksat results | Yes. Within an order of magnitude. | |
| 8 | 20 | Possibly… may I suggest that variability of the DRI results is less than that of the other two methods (though only half as many samples); perhaps due to a ;larger sampling area per test? I suggest that all TDI estimated Ksat values be at least doubled and then analyzed again. | DRI variablity is less than other methods, but likely due to n=~10 vs n=~30 for other methods. Sampling area of DRI is the same as MPD and about half of TDI. The reviewer suggests correction factor of 2 be applied to TDI data to compensate for the application under tension similar to findings in "Pore size distributions and infiltration", Grismer 1986. We have not been able to obtain the source paper to determine applicability to this study and have found no other studies that have suggested the need for a correction factor to TDI data in order to estimate actual $K_{sat}$. | |
| 9 | 22 | OK, but the MPD method resulted in the greatest variability and difficulty in reproducing results… | True. Variability may be explained by fact that DRI had a fewer number of samples obtained. TDI measured Ksat under tension which results in less variability than methods which do not(MPD, DRI, CHP). CHP measures Ksat in the soil profile, whereas the MPD measures at the soil surface, which is inherently more variable. | |
| 10 | 23 | Rather than a bar chart, this would be better presented as a correlation comparison asking the question of how well does the TDI method yield results that map onto those from the MPD. Similar comparisons should be made between the other methods and described in the stats analysis section. | This comparsion considered data points directly on top of each other (one after the other), versus in the same proximity, as the majority of the sample collection. Removing the noted outlier from the MPD data set, the comparison of the MDP and DRI points yields a regression equation of y = 0.4653x + 0.9313, r2=.474. A comparison of the MPD and TDI data points has essentially no correlation, as all of the TDI data points are 1.314 in/hr at the 6 locations, whereas the MPD measurements ranged from 1.12 to 4.8 in/hr. | Swapped bar chart on page 23 for two regression graphs. And added discussion pertaining to regression analysis between methods at same location. |
| 11 | 23 | This number comes from assuming a Gaussian distribution for the sample population, something unknown in this case. | | Removed two sentences referring to sample size and variability. |
| 12 | 25 | Move this section and the one following to the end of the Discussion. All of the supporting information sections about bulk density and soil moisture etc should be here and used to better describe the statistical results/conclusions. For example, greater bulk densities at the near surface should result in lower average Ksat values from the DRI and TDI as compared to the MPD and CHP and so on. | | Section has been moved as recommended. BD and Porosity sections were combined. |
| 13 | 25 | OK, so use of MPD is problematic in the field and a pain. Using your data from the BF and IB, map CHP onto MPD and determine the correlation (if any) as described above so you can better buttress your arguments while offering a possible alternative. | Regression Analysis results indicated that the strongest correlation was between the MPD and DRI data at the DB site, suggesting that the MPD is an appropriate tool for quantifying soil surface Ksat at that location. Overall, little correlation was found between the test methods using Regression Analysis. I don't think there is enough findings to warrant inclusion in the Final Report. Appendix D contains maps of testing method results. | Drafted Regression Analysis section, but findings suggest that it does not warrant inclusion in final report. It is more appropriate left in response to comments document. Appendix D contains visual comparision of geolocated data. |

| | | | | |
|---|---|---|---|---|
| 14 | 27 | This section (surface caking)needs more support and should be just after the stats section as this is another of the major components of study hypotheses. While I agree that the level of caking to ~1" does not seem to be a factor, further testing is required, or an analysis of the "cake" materials directly. | Measurement of surface caking was difficult at the IB and DB sites. Dr. Miller and I dug test pits to determine change in soil color and texture. Caking at the IB and DB sites was apparent in spots where vegetation was absent, but not as defined an extent or depth as at BF. Project scope did not allow for analysis of caking materials. | A sentence or two was added to the Surface Caking section. |
| 15 | 31 | Not really | We believe that the fact that the CHP does not measure soil surface Ksat of SWT BMPs leads to at least an intuitive support for any method (MPD) which does. | |
| 16 | 31 | By what measure – certainly not variances or range? | Of the tested methods, the MPD had the smallest percent change (2.3%) in Ksat measurements between pre-storm and post-storm data, while the CHP exhibited a 23.8% change and the TDI a 100% change in Ksat measurements. | Added this sentence to pg 22. |
| 17 | 32 | Hate to rain on your parade, but your results do not support this conclusion. It seems that the MPD is a much easier(?) field method provided you don't need to measure soil moisture, but its variability is greater. What about basic DRI msmts? Can you use your data to correlate the various msmt results and better support which method to deploy when combined with arguments about relative ease of use and expense in the field? | I think the data does support the conclusions. The data shows that the MPD is comparable to the DRI method for measuring Ksat at soil surface. It is not uncommon for testing equipment or procedures to be modified to gain ease of use. Modifications typically result in a justifiable sacrifice to accuracy. The study employed two such modifications by following modified procedures for the DRI and the CHP is itsef a modified tool and testing procedure created to rapidly obtain Ksat measurements. I think it possible to modify the MDP to create a RAM tool. | I rewrote the Field Operations section to include evaluation of each method based on 5 ranking criteria. That section will need review with a critical eye. |
| 18 | 0 | What is a RAM tool? Please define for those of us not familiar with Tahoe lingo | | Added definition to Executive Summary. |
| 19 | 13 | Was particle density measured? | No. Assumed value of 2.65 g/cm3 was used to represent a sandy soil. | Added sentence to reflect this. |
| 20 | 14 | And DRI measures macropore flow and TDI does not! They should not | This comment was brought up in peer review of the SAP. Dr. Miller's reply, "The TDI can be used to characterize hydraulic conductivity of a matrix at near saturation; albeit an unsaturated state. Infiltration under 1-3 cm of tension does, however, eliminate macropore infiltration that would be present under conditions of ponded infiltration. Note that based on the literature, all these techniques likely measure some degree of unsaturated hydraulic conductivity with the difference being that the TDI excludes the effects of macropores if present, and the other techniques provide measurements over a deeper profile. " How well the TDI measurements compare with other methods is thus dependent on the presence or absence of macropores and/or the variability of pore size distribution. | |
| 21 | 14 | What about a simple regression? | Because of the high spatial variability in the field measurements, it is impossible to compare point to point values, and that is why you take a number of values using each method at many sample locations, and compare the means or medians to evaluate changes in Ksat. The various other papers cited in the study conducted their field testing and analysis in this manner as well. Another reason you cannot compare point to point values is because measurements were not carried out on the same volume across the different methods. Here we are not trying to determine Ksat of the basin; we are trying to compare the results obtained from each method for effectiveness – how close the means and/or medians of the field measurements are among the testing methods. All of the devices produced results similar considering order of magnitude by which Ksat values can vary in the field, as well as whether the results were greater than- or less than- the 1 in/hr that is the standard assumption of effectiveness of a BMP for the BMP RAM tool. | SImple regression analysis was conducted in Excel, and a summary sheet is included herein (Regr resutls), as well as the figures produced showing the trendlines. Drafted a brief section on Regression Analysis results. There is not much to report there, but is included in Final Report |
| 22 | 14 | I agree with JK8: we find so-called outliers all the time. Not all of them can be assumed to be mistakes. I suggest analyzing the data with and without the outliers. | Because we are trying to compare means or medians of different methods, not assess true saturated hydraulic conductivity across the basin, we feel it is appropriate to remove the outliers from the dataset for this comparison, similar to that which was done for other similar studies comparing different methods (Munoz-Carpena et al., Nestingen, etc.). Although some of these outliers were likely caused by experimental error such as equipment malfunction, the majority were likely due to the presence of root zones or macropores that are important when determining the true Ksat for designing a basin at a particular site, but not appropriate in comparing Ksat values across different testing methods. An additional report published by the USGS (OFR 01-65) describes removing outliers from an infiltration rate study to fit a regression curve. | |
| 23 | 14 | But, but but! These macropore sites are real and may well be the most important feature of the hydrologic properties of the soil! The DRI will certainly be strongly affected by them. | We are not trying to calculate the infiltration rate of the BMPs, but see if there is statistical significance among the different methods. | |
| 24 | 15 | All of which is very real and should not be discarded from the data! | We followed the methods and statistical analysis of similar studies comparing methods of infiltration rate, which recommend that the means or medians of datasets be compared, not point to point comparison, due to such data variations. | |
| 25 | 16 | Was this done after the so-called outliers were removed? | Poor correlation was found, hence trying to remove the outliers for better fit. Similar to USGS OFR 01-65 | |

| | | | | |
|---|---|---|---|---|
| 26 | 16 | Looks like preferential flow areas had strong effects on both DRI and MPD – not surprising. I think both are real. | True. More variability at the soil surface is expected than within soil profile. Again we were not trying to measure Ksat of basin but compare testing instruments within the basin. Root holes preferential flow are likely real. No dispute there. But in this study where we are comparing test methods, you cannot compare results that suggest root holes or prefential flow to ones which do not. | |
| 27 | 19 | I really don't see that comparing the means tells us much about the utility of these various methods. How do they compare on the edges, where for example, the most problematic Ksat values will occur? I think a regression analysis would be far better. | The methods used in this study were in the peer-reviewed SAP, and no prior suggestions of regression analysis were raised. The analysis used in this study was based on similar peer-reviewed studies; see Munoz-Carpena, Gupta. | Nonetheless, a simple Regression Analysis was performed and the results included in the Final Report |
| 28 | 22 | Statistical significance? | There was only one storm event, therefore only a few data points to review, so an average was calculated just to see if there was any type of similarity. Storm event wasn't part of the original study nor included in the SAP; it was additional analysis due to the occurrence of the storm. | |