Field Testing Guidelines for Certification of Manufactured Stormwater BMPs: Part II

John Sansalone[1], Jeff Benty, Ernie Carrasco, John Gulliver, Jon Hathaway, Bill Hunt, Masoud Kayhanian, Uday Khambhammettu, Robert M. Roseen, Betty Rushton, Tim Williams

John Sansalone, University of Florida, Environmental Engineering Sciences, 218 Black Hall, Gainesville, FL 32611 (email: jsansal@ufl.edu) for Field Verification Sub-Committee

ABSTRACT

Guidance from information and field testing concepts examined by the ASCE/EWRI Subcommittee on Field Testing is presented. Field-testing of manufactured treatment devices requires critical planning and implementation through all steps of the verification process from watershed/catchment selection, to testing and analytical protocols, to data evaluation and quality assurance and control measures, to data reporting guidelines. Ultimately the goal of field testing is to provide verification of analytical or numerical models for BMPs that have been developed through scaled or full-scale controlled physical model testing. The desired goals and outcomes must be known and designed into the entire verification process. Ultimately, the entire process leads to a defensible model that represents a quantitative yardstick for both deterministic and probabilistic evaluations of a BMP for stakeholders across a range of regional conditions.

This committee is focused on field verification of a BMP for separation of particulate matter (PM) from rainfall-runoff and snowmelt. Towards this goal, the entire gradation of PM requires characterization for a BMP field evaluation, in particular the suspended fraction because of the mobility and acute bio-availability of this finer fraction. On the other hand, the coarse sediment fraction is of particular importance because this coarse fraction fills many BMPs and is most labile. A fundamental, transferable and defensible methodology is considered which includes particle size distributions (PSD) combined with gravimetric index tests for PM: total suspended solids (TSS) and suspended sediment concentration (SSC). TSS by definition is the PM fraction remaining suspended in an Imhoff Cone after one hour, although current methods utilize sub-sampling generate controversy as to the meaning of the measurement. However TSS remains in use because of ubiquitous usage, regulatory significance and as an important index of treatability. In contrast, SSC provides a gravimetric analysis of the entire sample and therefore limited bias, and outstanding reliability and repeatability. Quality assurance and feedback protocol are a necessary part of the testing protocol. We must recognize the range of challenges and collect sufficient representative data within an event and across events so that the role of such uniqueness can be quantified for the specific BMP or BMPs tested.

The committee is developing a multi-tiered approach to field testing predicated on the intended utilization and rigor required for the defensible and transferable examination of BMP behavior; thereby removing BMPs from the category of "black-boxes". Testing protocols with a basis of scientific knowledge are needed because the complexity for field testing of uncontrolled and episodic events is significant. This complexity extends to watershed characteristics, rainfall-runoff event characteristics, operation and maintenance requirements, system sizing tied to hydrologic and PM loadings, testing methodologies including mass balances and the non-stationary behavior of the BMP. A testing protocol must dictate methods to minimize bias, such that system performance can be effectively evaluated within a defensible level of statistical confidence. Additionally, such testing must ensure that valid comparisons between BMPs can be

conducted and that the protocols and results for such BMP testing are provided in a transparent and available format. The dataset provided should be sufficiently populated with an event and between events that defensible models can be developed from the results of the BMP testing and comparisons between BMPs can be made with statistically significant inferences.

As the committee moves forward, major technology protocols and reports will be reviewed. Guidance documentation will also be compared with TARP (Technology Acceptance Reciprocity Partnership) and TAPE (Technology Assessment Protocol- Ecology's) considerations. Field Testing guidance are developed as part of the ASCE/EWRI Committee on Guidelines for Certification of Manufactured Stormwater BMPs.

KEYWORDS

Best Management Practices, Unit Operations, Unit Processes, Stormwater, Rainfall-Runoff, Mass Balances, Watersheds, Hydrology, Particulate Matter, Particle Size Distributions

INTRODUCTION: Transferability of Hydrologic and PM Loadings

Controlled or uncontrolled field-testing of manufactured BMPs (unit operations and processes) still relies to a large extent on measurements of hydrologic loadings and particulate matter (PM). The most common measurements include TSS and SSC, both gravimetric indices as well as turbidity. A focus on PM has a fundamental rationale. While the dissolved fraction must be addressed and is bio-available; pollutants can partition to and from PM in many watershed and BMP conditions. PM measurements are coupled with hydrologic loadings from the watershed and hydraulic measurements in the BMP. In general, while watershed processes can be categorized and modeled, each watershed is different and unique with respect to BMP loadings of hydrologic, chemical, biological and PM quantities. Climates are different across the USA. However, despite such differences small watershed that commonly load manufactured BMPs can exhibit similar loading behaviors for different climates. For example, Figure 1 compares Trenton NJ to Gainesville, FL and Figure 2 summarizes the frequency distribution of events for each locations.

Annual average	Gainesville, FL	Trenton, NJ
Temperature	68.4 °F / 20.2 °C	54.8 °F / 12.7 °C
Humidity	78.2%	65.0%
Mean PDD*	3.1	2.3
# of events / yr	117	159
Precipitation	45.7 in / 1116 mm	41.6 in / 1057 mm

*: Previous dry days

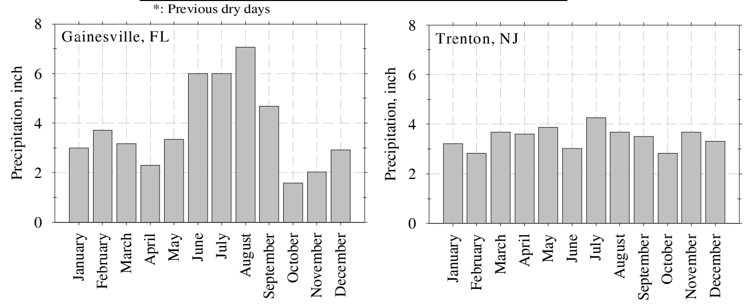

Figure 1. Comparison of the annual average and monthly average climate data for Gainesville, FL and Trenton, NJ.

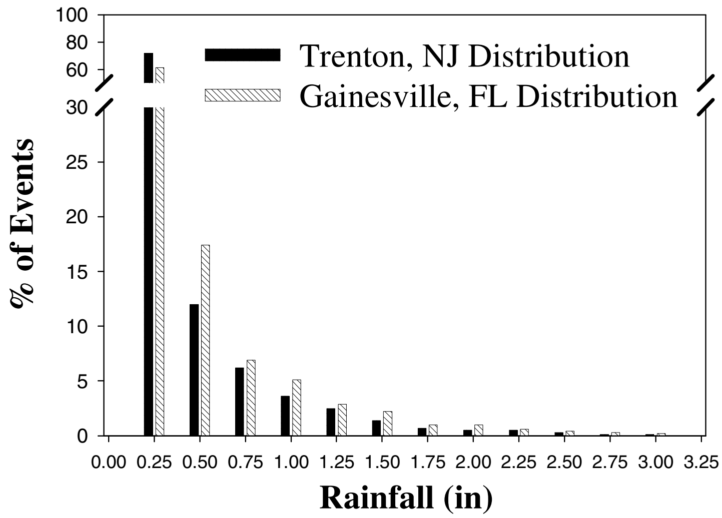

Figure 2. Frequency distribution of rainfall depths based on 30+ years of data from NOAA for both localities.

Despite specific climate differences, the two locations on the eastern seaboard of the USA have many rainfall frequency similarities with similar total annual rainfall depths. We can recognize these differences and similarities and collect sufficient representative data so that the role of such uniqueness can be quantified for the specific BMP or BMPs tested. What is more challenging than minor differences in climate are the very disparate methodologies of PM protocols that range from gravimetric index tests such as the traditional total suspended solids (TSS) method adopted from wastewater treatment evaluations, or the more recent suspended sediment concentration (SSC) method, index tests such as turbidity testing, to more fundamental methods of particle size distributions (PSDs). Each index method provides an indication of BMP performance with respect to PM; however a more fundamental, transferable and defensible methodology includes PSD (and specific gravity) and turbidity testing that are paired with a representative gravimetric index test for PM. In other words, SSC and PSD must be paired to provide a complete gravimetric description of the gradation. Field testing is predicated on the intended utilization and the rigor required for the defensible and transferable application of BMP performance results between localities of reasonably similar hydrologic loadings. Differences can be addressed through collecting a sufficient number of events to provide a distribution of hydrologic loadings that are comparable across regions. In addition to hydrologic loadings, knowledge of PM loadings is important. While both the fine suspended fraction and coarse sediment fraction are each important for BMP field testing, field testing requires the transport of a hetero-disperse PSD so that the BMP can be tested and examined across the gradation. This committee has the benefit of protocols such as TAPE and TARP that can be used as examples. The guidance that each protocol provides, while not universal is instructive when considering PM and the BMP separation of PM and building further guidance. It should be recognized that the entire gradation of PM should be representatively characterized for a BMP, in particular the suspended fraction, because of the mobility and acute bio-availability of this finer fraction. Figure 3 illustrates an example of an event mean PSD for a small watershed in Gainesville, FL. This urban catchment on the University of Florida campus is loaded by biogenic and anthropogenic PM loadings. The event mean PSD illustrated is compared to that of the NJCAT gradation. Again, despite the differences between New Jersey and Gainesville, Florida, the similarity between PSDs is striking. It should be noted however that there is variability around the event mean; as there would be for any constituent.

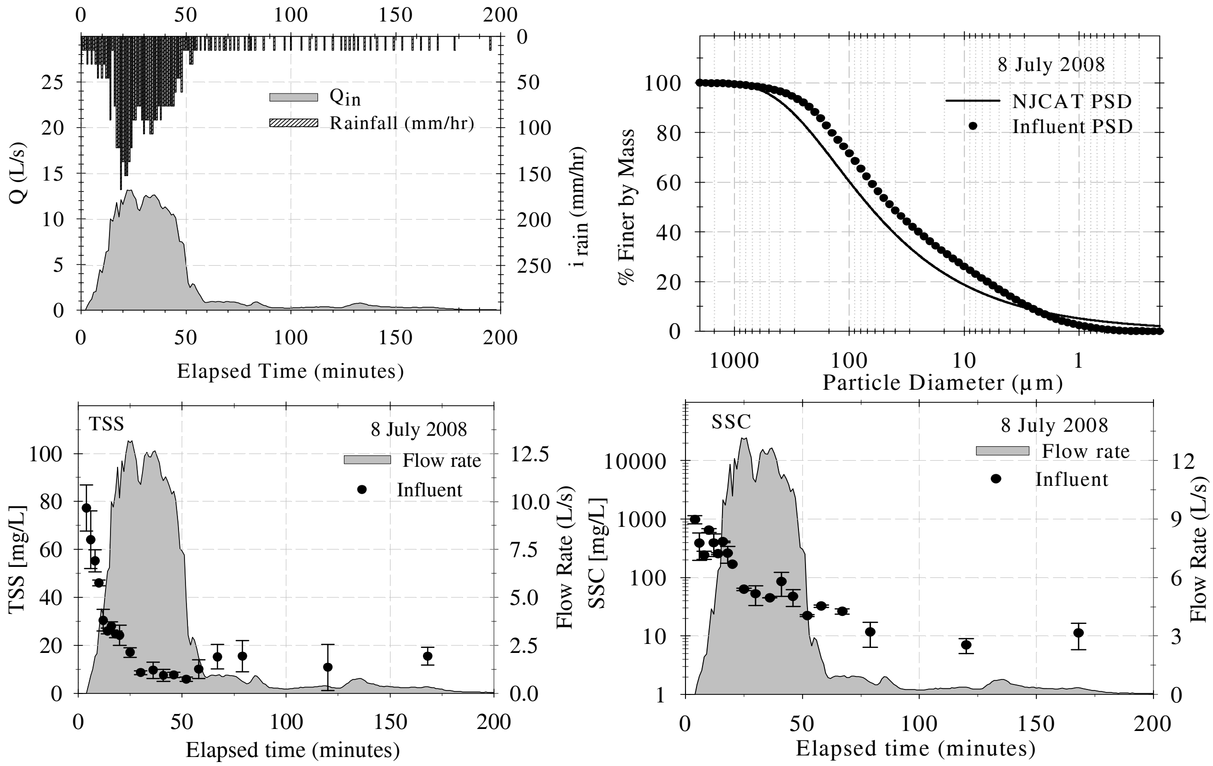

Figure 3. Coupling of hydrologic loads with PM measurements. The PSD illustrated is the event mean PSD.

Figure 3 illustrates a number of important phenomena that the committee is addressing. First, the highly unsteady nature of the hydrologic phenomena provides a far more challenging testing environment for a BMP and for the evaluators. The temporal hydrologic behavior is not known a-priori nor is the arrival of the event. Certainly, representative hydrologic measurements and sampling are challenging with such unsteady behavior. BMP behavior is directly impacted by such unsteady behavior that is not represented by controlled testing. However, such uncontrolled testing is not as readily amenable to model development or parametric analysis. Despite such unsteady behavior the event mean PSD is very similar, albeit slightly finer than an NJCAT gradation. The event-mean PSD and NJCAT are equally hetero-disperse. Such results suggest that a hetero-disperse NJCAT gradation for regulatory testing not only has the attributes of a defensible testing gradation, the NJCAT gradation has a reasonable granulometric resemblance to real gradations, albeit an event mean PSDs. If we step back and examine aggregate gravimetric indices such as TSS (PM < ~ 25 μm) there are a number of important observations. First, there is a clear mass-limited behavior between flow and TSS concentration that is driven by hydrology. The function of a BMP will be driven by this relationship between hydrology and load, with the caveat that such behavior is not known a-priori. When comparing TSS to SSC, it can be observed that TSS for this catchment is a small fraction of SSC. This is a result of the small watershed and source area configuration of the watershed. The high levels of SSC early in the event are biogenic and larger anthropogenic sediment (> 75 μm) that are transported but not replenished during the event. This SSC material was generated between events and washed off during the rising limb of the runoff hydrograph. Early in the event the BMP (and the field sampling) is challenged by high flows, neutrally-buoyant biogenic material and coarse (> 75 μm) anthropogenic PM. SSC follows a more attenuated mass-limited behavior. Given the hetero-disperse nature of the PSD, representative automated sampling is challenging.

GENERAL DESCRIPTION OF BMP FIELD VERIFICATION AND MODELING

The basis of transport and fate of PM and other pollutants in natural and engineered BMPs, at the most rigorous macroscopic level of description, are the Navier-Stokes (NS) equations. Derivation of the NS equations to examine fate and mitigation strategies starts with the basic laws of conservation of mass, momentum and energy which apply to all natural and engineered BMP systems. The resulting equations would be the Navier-Stokes (NS) system of non-linear partial differential equations (PDEs) for multi-phase hydrodynamics and the fate (separation) of entrained pollutants (for example, particles) and the partitioning to these particles. While such a defensible analysis of field BMP performance is rare it is important to recognize that BMPs are amenable to such rigorous analysis whether the BMP is a simple batch settling tank or a screened hydrodynamic separator. The transport and fate of particles and pollutants (such as phosphorus that partition and distribute to particles) with such a defensible methodology for a BMP requires the following components.

Field Verification Components (with general BMP assessment needs)

1. **Geometric data component**: These are the data which geometrically define the domain of the BMP, essentially the BMP control volume (overall dimensions of the BMP system). For example the BMP system could be a wet vault, a hydrodynamic separator pre-treatment device or a combination of multiple unit operations and processes (UOPs) such as a wet vault followed by a cartridge filter. The geometric data are commonly generated by as-built drawings, as-built surveying data, manufacturer's drawings/specifications and surveying data for inflow and outflow geometries (pipe dia., slope, material, outflow geometry, soil cover, elevations, etc.). In modeling efforts, a Computer Aided Design (CAD) module is used to generate and modify (in the case of design or retrofits) the geometry of the BMP system. The data inputs are:
    a. A three dimensional description of BMP system through detailed CAD drawings or engineered drawing, including all inflow and outflow conveyance geometries. From such data, stage-storage, stage-outflow, inflow-storage functions are developed.
    b. This should be a common and conventional requirement for urban drainage and BMP system design/construction. Those who are carrying out the modeling, the CAD tasks, and those gathering field data and geometric data inputs should have the background and experience for such tasks.
    c. This is not significantly different than conventional as-built data, but with the need for standardization across protocols.

2. **Boundary-initial conditions data component:** These are the data that define the "quantity" and "quality" parameters at the BMP system boundaries. These parameters are classified as:

- **Hydrologic** (rainfall, previous dry hours, wind, air temperature, relative humidity, infiltration, evaporation, watershed storage, watershed characteristics),
- **Hydraulics** (flow rate, velocity, cross-sectional flow area, wetted perimeter, roughness, shear stress, hydrodynamic regime, temperature, degree of saturation, residence time distributions, RTD as developed from tracer studies),
- **Chemistry** (chemical species concentrations, temperature, turbidity, dissolved gas concentrations, partitioning, kinetics, pH-redox couples), and
- **Particulate** (particle size distributions, PSDs, particulate matter measured as suspended sediment concentration - SSC, suspended solids measured as TSS, trash, floatables, constituent distribution on PSDs, specific gravity, surface area, surface charge, solubility, exchange capacity, leaching, sludge and sediment properties including depth, density and cohesive-frictional properties)
- **Porous medium, soil or filter matrix** (porosity, pore size distribution, media or soil size distribution, tortuosity, effective porosity, surface area, exchange capacity, mineralogy, aquifer dynamics, equilibria, kinetics, breakthrough, hydrodynamics, moisture content – hydraulic conductivity relationships and head loss, leaching)
- **Vegetation** (species, hydraulic and friction properties, uptake and release equilibria, growth and uptake kinetics, leaching, specific gravity, flexural properties)
- **Microbiological** (species, size, charge, number, specific gravity, growth kinetics, uptake rates, hydrodynamic selection criteria and washout)

These parameters apply to the inflows, the BMP system and outflows. Even this list of parameters provided herein is not exhaustive and it should be recognized that the scope of this committee is most directly towards PM separation. However, these are coupled phenomena, and as such the role of vegetation (such as in an infrastructure-constrained bio-detention cell), microbiology and chemistry are important for the fate of PM across a BMP. It is readily apparent that such boundary and initial condition data requirements are significant and many are significantly different as compared to conventional data collection practices, as can be seen from the list of parameters in each category. Therefore, at this point in time, three levels of boundary/initial conditions field verification requirements are proposed. These field verification requirements will be defined in three levels:

- "***Level 1***" field verification requirements are for event-based BMP examinations. ***"Level 2"*** field verification requirements are more detailed, are appropriate for monitoring and modeling event-based BMP examinations, and require temporal input and output data, as well as event-based system data.
- "***Level 3***" requirements are research or specialized datasets for BMP examinations examining specific pollutants beyond PM, nutrients or metals, for example, microbiological, that is combined with modeling and water chemistry examinations such as charge, volume and mass balances.

Commensurate with the available length of the paper, the following is a draft summary of the field verification requirements for a BMP under a detailed Level 1 requirement.

Number of Events Monitored: (12 calibration, 3 verification events for modeling)

a. A minimum of 12 calibration and 3 verification events are required for a BMP system. Events should occur in a one year period, and event rainfall depth should be at least 0.25 inches. There should be at least 24 previous dry hours. This is similar to other BMP testing protocols around North America. Event mean flows should be reasonably distributed between 25 and 75 % of the BMP design flow rate.

Hydrologic: (initial storage depth required for CFD)

a. A ***watershed delineation*** so that a rainfall-runoff model can translate rainfall loadings to runoff loadings at the BMP system location for the watershed of interest. This is a hydrologic modeling input and should be a current and conventional requirement for BMP systems in any protocol.
b. A ***frequency distribution of the historical rainfall record*** for the watershed or locality. The maximum time increment between rainfall depth measurements during the event should be no greater than the time of concentration for the watershed. This is a hydrologic modeling input and should be a current and conventional requirement for BMP systems in any protocol.
c. A ***watershed-based and event-based temporal rainfall record*** for storm events captured. Representative rainfall depths should be recorded in increments of 0.01 inches or in time at increments no greater than 5 minutes for the watershed. This is a hydrologic modeling and should be a current and conventional requirement for BMP systems in any protocol.
d. A measurement of ***previous dry hours (pdh), wind speed and direction, air temperature, evaporation indices, and relative humidity*** for the watershed or locality on an event-basis. These data are readily available from a number of sites around most MS4s and do not require a weather station for the watershed where the BMP system is located.
e. A measurement of ***initial runoff storage depth and sludge depth*** should be made in the BMP.

Hydraulic:

a. ***Flow depths and velocities*** at increments no greater than 5 minute intervals for the entire inflow and outflow duration for each inflow and each outflow of the BMP system. These are direct BMP verification inputs and should be a current and conventional on-line measurement requirement for BMP systems.
b. ***Temperature***, for simplicity at increments to match hydraulic flow measurements for the entire inflow and outflow duration for each inflow and each outflow of the BMP system, as well as initial storage and final storage temperatures. These are indirect BMP inputs (to specify aqueous viscosity and density), and should be conventional on-line measurement requirement for BMP systems.
c. A ***temporal RTD*** for a high-flow calibration event and a lower-flow calibration event using a conservative tracer. This is carried with a known mass input of conservative tracer in the influent and temporal automated sampling of effluent with temporal discrete samples (not composited).
d. ***Pressure measurements*** should be made as a function of volume treated for BMP systems that contain a porous media including in-situ soil filters, taken on-line just upstream and downstream of filter. This is a critical need for porous media systems.
e. A ***calibration curve*** should be provided for each hydraulic measurement for each event. This should be required in any quality assurance plan.

Chemistry:

a. ***Constituent species and phases*** are analyzed from duplicated composite samples to provide event mean concentrations (EMCs). Recognizing that automated samplers cannot reproduce a representative PM; but to avoid endless debate over this topic, this methodology will nominally refer to "sampling" but not a method. These duplicate composited samples for an event will be composited by representative samplers for the entire duration of influent and effluent flow. The sampler is setup to house 4, 4 L (minimum composite volume) samples, unless larger volumes (i.e. 6 L composite samples) are possible. This additional volume is important for effluent samples. It is fully recognized that EMCs eliminate any temporal understanding of influent and effluent transport, and automated samplers cannot representatively sample influent and effluent flows (particularly influent particulate matter (PM) larger than approximately 75 μm and neutrally-buoyant material). However, for the sub-75 μm PM and the operationally-dissolved fraction of constituents such index methods will have to suffice until more representative measurements become more viable for common "Level 1" applications. Constituent selection is dependent on the receiving water impairments, BMP system and watershed. Calcium and alkalinity are also important measurements. An event-mean analysis of rainfall should be conducted.

b. All ***constituent analyses are conducted on fractionated (filtered) samples***; creating a dissolved fraction and a particulate fraction, operationally-separated using a 0.45 μm membrane filter. As with automated sampling and EMCs this masks the continuum of partitioning, but is a Standard Method, recognized by most laboratories, and will have to suffice. A digestion process is utilized to examine the constituent concentration associated with the dry PM (as TSS) retained on the membrane filter after the dry filter with dried TSS is weighed and the dry filter weight subtracted. The exact volume filtered to generate the TSS is also recorded along with the dry TSS mass retained on the membrane filter. It is noted that this fractionation occurs after the sample is pre-screened by passing each composite sample separately through a #200 (75 μm) stainless steel or nylon sieve (discussed in the particulate section).

c. A ***sample holding time of less than 24 hours***. No sample shall be held for more than 24 hours before analysis between the time the sample was taken and fractionation between dissolved and particulate-bound fractions, even under refrigerated conditions. While partitioning occurs at much shorter time intervals, within hours, there is currently no practical method to fractionate rapidly without on-site personnel.

d. ***On-line temporal chemistry measurements*** should include pH, redox (hydrogen-based offset provided), temperature, turbidity, total dissolved solids – TDS and conductivity for influent and effluent. The on-line measurement technology has advanced to the point that these are commonly deployed applications for BMP systems.

e. A ***calibration curve*** should be provided for each chemistry measurement for each event. This should be required in any quality assurance plan.

Particulate:

a. A ***measured volume for each duplicated composite sample*** should be determined to the nearest 10 mL. Duplicated 4-L (or larger if possible) and 20-L composite sample should be prepared with the exact volumes recorded. The 4-L duplicated influent and effluent composite samples will be used for obtaining datasets d, e and f. The 20-L influent and effluent composite samples will be used for obtaining datasets b, c and h.

b. ***A pre-screening through a #200 (75 μm) stainless steel or nylon sieve*** of each duplicated 4 L composite sample and 20 L composite sample should be first carried out before fractionation at the 0.45 μm level by passing the entire volume that is free of any holes or grid weighed and gently disaggregated. This dried material will then be dry-sieved through the standard (#50) 300 μm, (#80) 180 μm, (#100) 150 μm and (#140) 106 μm sieves. A mass balance shall be made by summing the mass components on each sieve allowing no greater than a 5% mass balance error from the original dry weight.

c. A ***determination of constituen Tc 0.0vss i11(s)ter224(i11bu)1(nti)1((n)10(a(s)(a( )-15of)11tu)1***

e aopari11 ae ehrord(ig)14(e)17(s)8teoesfror(e)17(ac( )15ph)14()13(r)11tel sie.h is82(i(s)22( )]TJ-0.1066 T

l(r nna)40(y)1-7(s6(es0 .(a)-327(a(5)6(s(m61)n)1)29(g)24(e)64(r290 ta(c)1575 Tw23(<)0TJC20T j1/ TT10 Tc

Microbiological:

a. An ***identification of the redox conditions and microbial consortium*** and their numbers in the water column or media (or soil) column should be approximated.

CONCLUSIONS

While field verification of manufactured BMPs is more complex and uncertain than controlled,
scaled f93(u)13(l)43(l)43-Pscale BMP2-4((e)16stl)14inguoed f93huoer92(i)-(scal)14a (93(a)16nd)90(m63 c
a2(m)7(e)17(tr215(c (e)17 v)13a(l)15(cat)15(io)13(p)-2 s)7, or(co)13((tr)10(o)13(l)15(l)15(e)17(pte)17(r
ritifioctinofn
u-idncbefrrfrid
rere;tlltr226(a)2(te)17dxh(e)76(r)11(e)76ind.

m86bp
adlvnfr96co
m86corellege
cr-14
ddt(n)15(fa)u-eio(s)75torb(u-)5(tio)-4(oi)15(n)(s)75,ctte(s)75
e15laotnsdnn(n)18(tn)116ohn.o
ve(n)116,toool(s)75

.
u-dp-entda
abofBMMP92ssenhh

be,175
ees veff(f)17cor BMMPh eh(e)76trm86iot