EVALUATION OF THE STORMWATER MANAGEMENT STORMFILTER® TREATMENT SYSTEM

By

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DATA VALIDATION REPORT

AND

SUMMARY OF THE

TECHNICAL EVALUATION ENGINEERING REPORT

(TEER)

BY

STORMWATER MANAGEMENT, INC.

October 29, 2004

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Stormwater Management, Inc. (SMI) contracted with Resource Planning Associates, specifically Dr. Gary Minton (referred to as Consultant), to review the ability of the Stormwater Management StormFilter® (StormFilter) to meet "basic treatment" as defined by the Washington State Department of Ecology (Ecology, 2001).

The evaluation contained in this report is based on performance data recently collected by SMI of StormFilter systems located at two sites in the Pacific Northwest. A report prepared by SMI (SMI, 2004) presents in detail the data monitoring procedures and data, to which the reader is referred. The data were collected following a QAPP Plan (SMI, 2003), accepted by the Technical Review Committee of the Department of Ecology. The QAPP Plan was prepared using guidance of the Department of Ecology (Ecology, 2002) or Technology Assessment Protocol – Ecology (TAPE).

The Data Verification Report addresses two questions:

- Were the data collected consistent with the accepted QAPP protocol; and,
- Does the technology meet "basic" treatment as defined by the Department of Ecology (Ecology, 2001).

DESIGNATION SOUGHT BY STORMWATER MANAGEMENT, INC.

Stormwater Management, Inc. seeks ***General Use Level Designation (GULD)*** for Basic Treatment, for the following conditions: a nominal flow rate of 7.5 gallons per minute (gpm) per cartridge for the ZPG media. ZPG consists of three types of media: zeolite, perlite, and activated carbon.

Basic treatment is defined in the TAPE as: *"Ecology's basic treatment menu facility choices are intended to achieve a goal of 80 percent removal of total suspended solids for influent concentrations that are greater than 100 mg/L, but less than 200 mg/L. For influent concentrations greater than 200 mg/L, a higher treatment goal may be appropriate. For influent concentrations less than 100 mg/L, the facilities are intended to achieve an effluent goal of 20 mg/L total suspended solids. Flows in excess of the water quality design flow or volume can be bypassed around the facility. The performance goal applies:*

- *to stormwater with a typical particle size distribution;*
- *on an annual average basis to the entire discharge volume (treated plus bypassed); and,*
- *to the water quality design storm volume or flow rate. (Ecology, 2001-Ch.4, Vol.V)*

CONSULTANT'S RECOMMENDATION

Designation

It is recommended that the **GULD** be given to the StormFilter system for the specified media and the specified flow rate. Based upon the performance data reviewed in this report there is a reasonable expectation for the StormFilter system as specified will meet the definition of "basic treatment". The designation should be limited to the particular media, ZPG, and the flow rate of 7.5 gpm/cartridge. It is further recommended that Ecology allow the use of technology as specified herein for all urban land uses. It is recommended that SMI identify the general size distribution (upper and lower mesh) of the combined data mixture and that the GULD designation be limited to this size distribution or smaller.

Additional Testing

It is recommended that Stormwater Management determine through laboratory testing, the relationship between accumulated solids and flow rate through the cartridge containing the ZPG media.

CONSULTANT'S ROLE

As Defined by the TAPE

The TAPE specifies that the applicant is to hire an independent consultant stating "the following work must be performed by an independent professional:

1. Complete the data validation report.
2. Prepare a TEER summary, including a test results summary and conclusions compared with the supplier's performance claims.
3. Provide a recommendation of the appropriate technology use level.
4. Recommend relevant information to be posted on Ecology's website.
5. Provide additional testing recommendations, if needed."

Item 4 is not presented in this report. Information to be posted on the website can be generated subsequent to a decision by the Department of Ecology should it be favorable. SMI's TEER report consists of four documents (SMI, 2004a through d). The Consultant's report is in reference to these four reports.

Specific Tasks Defined by the QAPP

The Consultant's role as defined in the QAPP of SMI (SMI, 2004) was:

Pre-sampling Tasks

1. Review and approve the QAPP and certify that its objectives have been satisfied.
2. Visit each candidate test site and concur with those selected.
3. Inspect the equipment set-up at each site.

Tasks During the Sampling Period

1. Visit one site monitored by Taylor and Associates and one monitored by SMI to observe preparation of field blanks.
2. During one of the early storms and also midway through the sampling effort, visit one of the sites monitored by Taylor and one by SMI to observe retrieval of the samples and the preparation of the equipment for the next storm.
3. Early in the sampling period, review the field log and data sheets for completeness.
4. Review and inspect data as it is generated.

Data Analysis and Reporting

1. Complete a data validation report.
2. Review and edit final report for submittal to the TAPE committee.
3. Validate performance claims; provide a summary to the review committee.
4. Provide a recommendation as to the appropriate technology use level.
5. Provide recommendations for further testing.

OVERVIEW OF THE TECHNOLOGY

The StormFilter is a cartridge in which filter media is placed. A schematic of the cartridge is shown in Figure 1. Each cartridge treats a specified flow rate. To meet the design flow rate, the suitable number of cartridges are specified and placed in a vault like that shown in Figure 2.

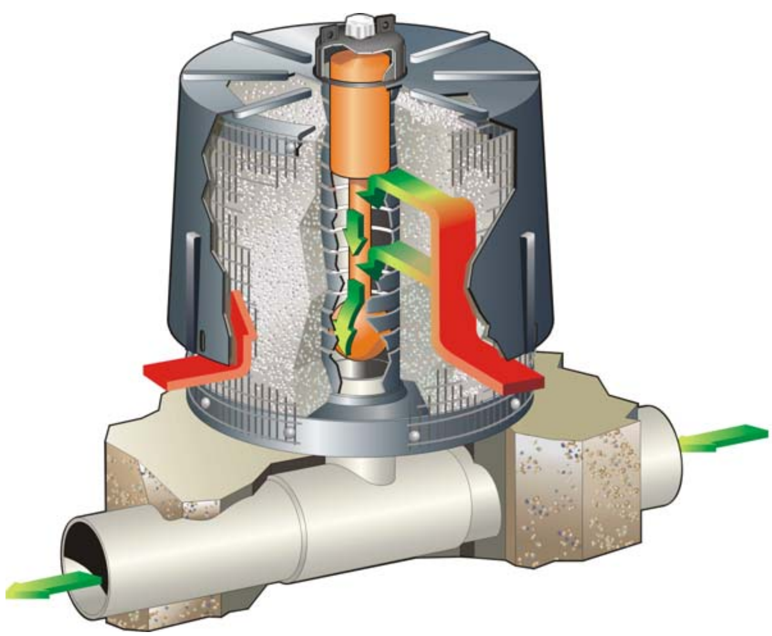

FIGURE 1 StormFilter Cartridge

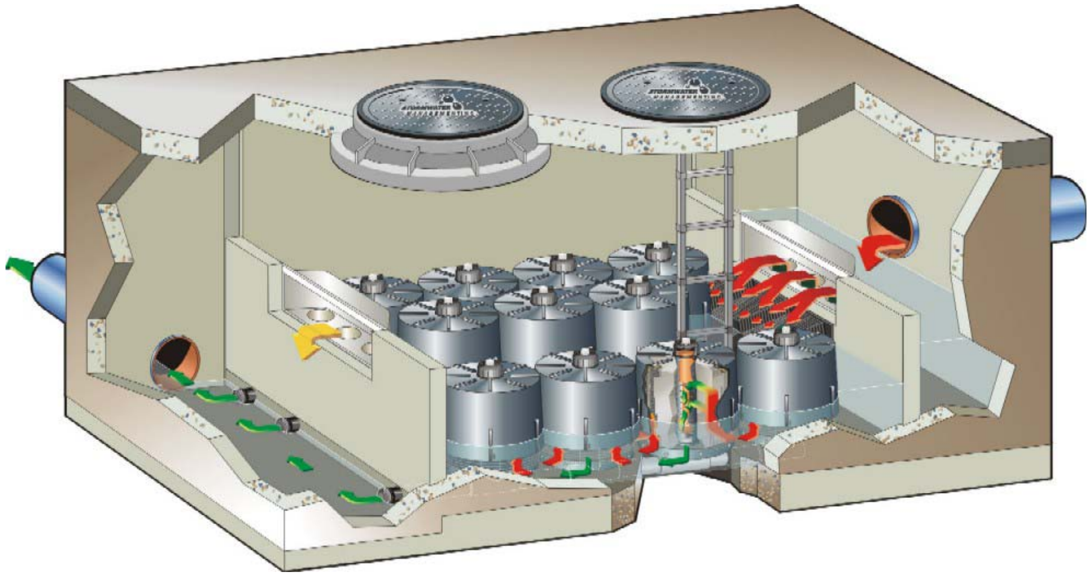

FIGURE 2 StormFilter Vault

Stormwater enters the cartridge horizontally (radial) through the media. It passes through the media to a centerwell within the cartridge, two inches in diameter. From the centerwell the treated stormwater moves downward to an underdrain system. The maximum flow rate (occurring with a clean cartridge) is controlled by means of an adjustable calibrated reducer disk located at the base of the cartridge. As solids accumulate in the filter media the flow rate gradually decreases. At some point of accumulation the partially clogged cartridge controls the flow rate. The cartridges are soon replaced and the control of the flow rate returns to the disk. Different media either singly or in combination are specified to meet the particular treatment objectives.

At the outset of a runoff event stormwater does not immediately pass through the cartridges. A passive vacuum system in each cartridge (the "float" in Figure 1) delays the filtration of stormwater until the level of stormwater rises just above the top of the cartridge. How this system works is best understood from Figure 3. Before a storm occurs, the float is located at the bottom of the center well, sealing entry to the underdrain system. As the water rises in the vault (Figure 3a), water fills the media and centerwell. However, stormwater does not pass into the underdrain because the float seals the entry point to the underdrains. As water fills the cartridge, air is forced through a one-way valve at the top of the centerwell (Figure 3b). Once the air is evacuated, the float moves upward allowing water to enter the underdrain system and treatment commences (Figure 3c). Note that as the water level drops with the termination of inflow, the water level within the hood remains at the top of the cartridge inside the hood (Figure 3c). The vacuum condition in the centerwell is maintained as long as the water level is above the lower lip of the hood. Once the water level in the vault drops below the lip of the hood, the seal is broken and the water level within the cartridge drops (Figure 3d). The downward movement of the water and air bubbles entering the space between the hood and the cartridge causes some solids on the surface of the media to dislodge and fall to the floor of the vault (Figures 3d and 3e). Residual water slowly drains from the bottom of the vault as the float seal is purposely designed to allow a minimum "trickle" flow.

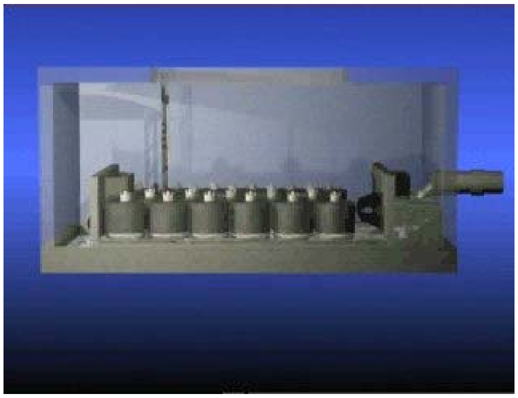

Figure 3a – cartridges in empty vault

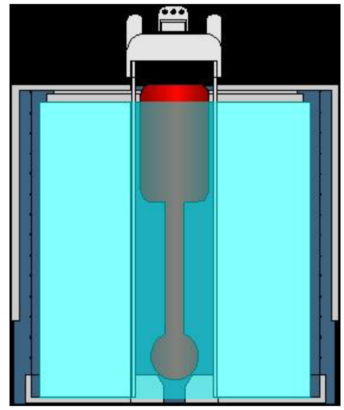

Figure 3b – water level at top, showing water In the cartridge but float not yet risen.

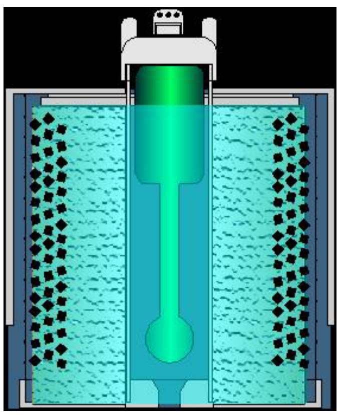

Figure 3c – float is up and water is passing into underdrain

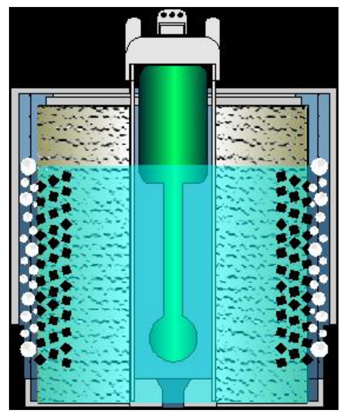

Figure 3d – water level has dropped in the vault to the bottom of the cartridge. Siphon begins to collapse, releasing air that scours the outside of the media within the cartridge.

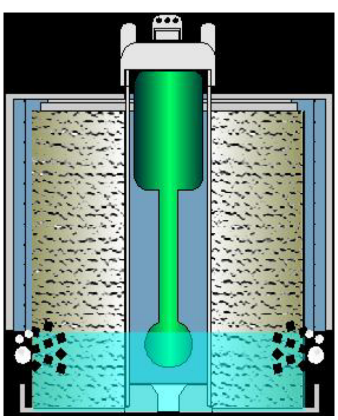

Figure 3e – sediment falling to the vault floor as the siphon finalizes its collapse.

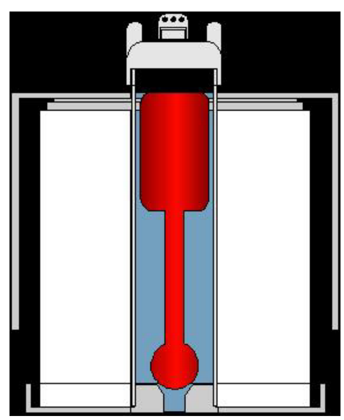

Figure 3f – Remaining water in the vault drains due to an imperfect seal at the base of the float.

The technical reason for the use of a vacuum system is to equalize vertically the flow through the cartridge. Absent this control, flow through a vertical media cylinder would be essentially zero at the top of the cartridge and maximum at the bottom. This is due the decrease in water head as one moves vertically upward on the filter surface. Two potential problems result from differential flow: decreased performance and more rapid clogging of the filter. Water moving more quickly through the bottom of the filter is treated less effectively than water that moves slowly through the upper part of the filter. Whether on average the same performance is achieved were the flow rate equal throughout the height of the filter is unknown. With more water passing through the bottom of the filter, differential clogging may occur; that is, with time the filter gradually clogs from the bottom upward rather than evenly. This may require that the cartridges be replaced more frequently than a system with even vertical flow. It is important to understand that equal flow is not achieved simply by maintaining the water level above the cartridge. Absent the vacuum, flow through the cartridge is not constant vertically.

An observation regarding maintenance: it has been the general experience that for most sites annual replacement of the cartridges is appropriate (SMI, 2004d). A small percentage of sites require maintenance more frequently; a significant percentage less frequently. This experience is based on the nominal flow rate of 15 gpm/cartridge. Reducing the flow to 7.5 gpm/cartridge should significantly extend the maintenance cycle. A cartridge experiencing only half the flow rate accumulates solids correspondingly at half the rate. Furthermore, more solids will accumulate in the cartridge before the cartridge, rather than the orifice plate, controls flow through the system.

The StormFilter vault has an internal bypass. Hence, some level of treatment is achieved at flow rates in excess of the combined capacity of the cartridges. Excess water passes over a weir at the far end of the vault (see Figure 2).

PRIOR STUDIES

There have been many field studies conducted prior to the field study upon which this report is based. Studies have been conducted by SMI as well as by the owners of installed systems. However, these data are not considered in this report because all of the studies were conducted with systems operating at a flow rate of 15 gpm, and not necessarily with ZPG media.

DESCRIPTION OF THE TEST PROGRAM

Test sites

The QAPP Plan (SMI, 2003) identified nine candidate test sites. After further inspection, the number of sites at which tests were performed was reduced to five:

- Parking lot of a shopping mall in Vancouver, Washington (Site A).
- Parking lot of a newspaper business in Olympia, Washington (Site B).

- Roadway surface and bridge in Lake Stevens, Washington (Site E).
- Parking lot of a Fred Meyers store in University Place, Washington (Site F)
- Parking lot of a shopping mall in Portland, Oregon (Site G).

The letter references are the site identifiers in the QAPP (SMI, 2003). The Consultant visited all nine sites and participated in the final decision on the five selected sites. However, only Sites A and E used the ZPG media. Therefore only these data are considered at this time. The data from Sites B and G are not considered in this report because the media used were perlite/leaf compost (CSF) and perlite, respectively. SMI may seek approval for these media at a future date (Lenhart, personal communication). The data from Site F are not included as the nominal flow rate per cartridge was kept at 15 gpm. Further description of the sites is presented in SMI (2004a).

Sampling structure

SMI reports (SMI, 2003, 2004a, 2004b) describe fully the sampling program. The particular aspect of interest to the Consultant is the sampler bottle selection strategy for compositing. SMI used the 24-bottle configuration in the ISCO samplers. Pacing volume was used to time the filling of bottles. Furthermore, the samplers were programmed to sample more frequently early in each storm. This was done should the storm have a relatively short duration. Typically, the first 12 bottles were programmed to sample every X volume (e.g. 1000 gallons) and the second 12 were programmed to receive a sample every 2X volume (e.g. 2000 gallons). If a storm extended into the second half of the sample program it was necessary to discard every other sample collected in the first half of the program. Also, on occasion two storms may have been sampled, one of which may have had to be discarded because it failed with respect to one or more of the TAPE criteria. The Consultant therefore examined the record regarding which bottles were composited and the rationale used by SMI staff to ensure no bias in selection.

TAPE STORM CRITERIA AND GUIDELINES

The TAPE provides several specifications, some that are minimum criteria that must be met while others are offered as guidelines. Upon careful consideration the Consultant modified the criteria and guideline because of the specific characteristics of the StormFilter, namely that it is essentially a "fill-and-draw" system without a standing wet pool. It is stressed that the modifications were not provided to SMI until after they had completed their field program. This was to assure that SMI would strive to the maximum extent possible to meet both the criteria and guidelines of TAPE.

The key consideration of the Consultant was "would the inclusion of storms that did not meet the strict TAPE criteria and/or the guidelines bias the analysis of performance to either favor or disfavor the technology. Would sampling more storms in attempt to strictly comply with both TAPE criteria and guidelines result in a different conclusion regarding the capability of the technology". The Consultants conclusion is that inclusion of storms meeting the Consultant's modified criteria and guidelines would not bias the conclusion, and that gathering additional storms would not provide any additional benefit.

TAPE criteria and guidelines

The minimum criteria relate to the characteristics of the sampled storms. They are:

- Minimum storm depth – 0.15 inches;
- Minimum storm runoff duration - one hour;
- Antecedent condition – not more than 0.06 inches during the 6 hours preceding the sampled storm;
- With respect to TSS, 12 to 35 events are sampled, the specific minimum number dependent upon the Coefficient of Variation observed at the test sites.

The guidelines are:

- For each sampled storm, at least 10 aliquots are retrieved to produce the flow-weighted composite sample;
- The aliquots are obtained over at least 75% of the volume of the sampled storm.

Modifications to the Minimum Criteria and Guidelines by the Consultant

The Consultant established for SMI a set of Criteria and Guidelines that differed somewhat from those specified in the TAPE. The modified set of Criteria and Guidelines are presented below. The modifications are in italics. The Consultant's rationale is provided for each modification.

- **Minimum storm depth – 0.15 inches**. *In the event that the storm depth is less than 0.15 inches, consider the average storm intensity. If it exceeds the average for western Washington (~0.03 inches/hour) include the storm in the analysis of efficiency. If the intensity is less than 0.03 inches/hour, consider the TSS concentration. If it is greater than 50 mg/L, include the storm. If not, exclude the storm.*

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Rationale: specification of a minimum storm depth is particularly relevant for treatment systems with dead storage (e.g. a manufactured wet vault). A secondary interest is ensuring there is sufficient runoff volume to obtain representative pollutant concentrations. However, the StormFilter does not have dead storage. Hence, the storm depth is essentially irrelevant. What is relevant is whether the runoff has concentrations that are within the range of what constitutes "typical". This is more likely to be achieved when considering the rainfall intensity (i.e. runoff rate) than the storm depth. Regardless, the inclusion of a storm with a relatively low influent TSS concentration only modestly affects aggregate performance based on loading reduction.

Note: Initially, SMI chose to relax this criterion only when considering each site individually, but not when pooling the data of the two sites. However, under the request of Mark Blosser and Ecology, SMI included in the analysis all storms with depths 0.10 inches or greater. The immediate objective was to include additional storms with influent TSS concentrations greater than 100 mg/L.

- **Minimum storm runoff duration - one hour**

- **Antecedent condition – no more than 0.06 inches during the 6 hours preceding the sampled storm**. *In the event that this condition is not met, consider the influent TSS concentration. If it exceeds 50 mg/L, include the storm in the analysis of efficiency.*

<u>Rationale:</u> an antecedent condition is established because of the concern that with insufficient time between storms there will be sufficient accumulation of pollutants in the catchment area. However, most storms do not result in a complete removal of all pollutants. Hence, if the TSS concentration of the influent is "typical", it is unreasonable to reject the storm. A value of 50 mg/L is specified reasonably represents the likely median concentration from most sites.

<u>Note: SMI chose not to relax this criterion initially, but was relaxed upon the request of Mark Blosser and Ecology. The immediate objective was to include additional storms with influent TSS concentrations greater than 100 mg/L.</u>

- For each sampled storm, at least 10 aliquots are retrieved to produce the flow-weighted composite sample. *Accept the storm if five aliquots are obtained*.

<u>Rationale:</u> At the time the TAPE was published there were no published studies of the relationship between the number of aliquots and the difference between the observed and true EMC. Most protocols specify ten aliquots like the TAPE. ETV specifies five. Roger Bannerman suggests that 20 are desirable (Bannerman, personal communication). A recent study (Stenstrom and M. Kayhanian, 2004) examines this question. The authors considered five sampling schemes, one of which is to take aliquots at a constant, specified incremental storm volume, the method used by SMI. Stenstrom et al. (2004) evaluated from ten to 100 aliquots. The analysis used computer generation of concentrations of COD based on a regression equation, which was derived from an extensive data base of one site. The conclusion of the authors was "The average error percentages for n (number of samples) are 23%, 16.6%, 12.0%, 9.7%, and 7.5%, respectively" for 10, 20, 40, 60, and 100 aliquots, respectively.

Note the word "average". The authors made multiple "runs" of data generation. Each average has a confidence bound that narrows with increasing aliquots. Unfortunately, an aliquot frequency of five was not considered. One might guesstimate an error on the order of 30%. This is not good. But it is not much worse than 23% at ten aliquots. That is the point: is it reasonable to disallow storms less than ten aliquots, given that requiring only ten appears involved the potential for considerable error.

Furthermore, there is an inherent conflict between trying to take as many aliquots as possible with the goal of sampling 75% of the storm. If the sampler program is set to assure that at least ten aliquots are taken, the specified trigger volume is reduced because of the short duration of many runoff events. However, if the storm is longer than anticipated, the sample bottles may be filled too early in the storm. However, if one wishes to meet the goal of sampling at least 75% of the storm volume, the trigger volume must be set so as to minimize the possibility that all the bottles will not be filled before the end of the storm. The result may be too few aliquots if the storm duration is less than anticipated. At the outset of the field study, SMI took the position that sampling 75% of the storm was the more important of the two objectives. The Consultant concurred with this decision. In retrospect, it would have been more appropriate to de-emphasize the volume capture requirement as the StormFilter is a fill-and-draw system.

- **The aliquots are obtained over at least 75% of the volume of the sampled storm.** *Reduce the minimum sampled volume to 50%.*

Rationale: Specifying a minimum percentage of each storm that is represented by the observed concentrations is relevant to systems with wet pools. For these systems the quality of the stormwater that initially exits the facility during each storm reflects treatment that has occurred before rather than during the particular storm that is sampled. It is therefore relevant to sample most of the storm volume. Gathering aliquots during as much as the storm volume as possible also compensates for the possibility that higher influent concentrations are occurring in the early period of the storm, i.e "first flush". These considerations are not important to a system that has no dead storage if the detention time in the system is relatively low. Such is the case for the StormFilter. The Consultant therefore reduced the requirement to 50%. As noted above, SMI decided to emphasize the goal of achieving 75%, and did for most storms. In hindsight it would have been preferable to emphasize the goal of 10 aliquots over the goal of 75% coverage.

DATA VALIDATION PROCESS

Compliance with the QAPP Plan

Those activities the Consultant carried out regarding the QAPP previously on Page 3 are repeated here for convenience.

QAPP compliance activities by the Consultant included:

1. Visit each candidate test site and concur with those selected.
2. Inspect the equipment set-up at each site.
3. Visit one site monitored by Taylor and Associates and one monitored by SMI to observe preparation of field blanks.
4. During one of the early storms and also midway through the sampling effort, visit one of the sites monitored by Taylor and one by SMI to observe retrieval of the samples and the preparation of the equipment for the next storm.
5. Early in the sampling period, review the field log and data sheets for completeness.
6. Review and inspect data as it is generated.

All of the above activities were accomplished. The Consultant visited all fives sites prior to commencement of storm sampling, and several of the sites during sample retrieval to inspect sample collection procedures. All field activities related to sample retrieval and preparation with respect to field blanks were conducted satisfactorily.

Questions Posed in the Examination and Validation of the Data

The Consultant considered the following questions:

- Did the storm meet the TAPE criteria
- Did the storm meet the modified guidelines
- Was the bottle selection valid
- Was the TSS value presented by SMI in their summary table consistent with the laboratory report
- Was the runoff volume for each storm presented in the summary table prepared by SMI consistent with their Individual Storm Report, and reasonable with respect to the observed storm depth
- Was the equipment rinsate blank procedure conducted at both sites
- Did the laboratory carry out its QA/QC protocol with respect to blanks
- Did the filter system function hydraulically as expected.

It is stressed that the Consultant considered not just those storms that SMI concluded met the TAPE criteria and modified guidelines. The Consultant also examined those storms rejected by SMI to be certain that the rejection was valid.

Reference is made above to the Individual Storm Report (ISR). This is a form developed by SMI to summarize pertinent information for each sampled storm. Completed ISRs are included in the two site reports (SMI 2004b, 2004c). The ISR summarizes key information on each sampled storm, including storm depth and duration, antecedent condition, runoff volume, and times of aliquot withdrawals. The information on these forms was checked against the criteria and guidelines, and for consistency with Table 3 in the summary report (SMI, 2004a). Additional rainfall gauge data was provided by SMI to the Consultant to check conclusions with respect to the antecedent condition. Evaluation of the antecedent condition was further confirmed by examining independent rainfall gauges. For the Lake Stevens site, the records of a gauge at the Alderwood Water District in southwest Snohomish County were examined. The gauge is located approximately 20 miles southwest of the Lake Stevens site. For the Heritage site, the records of a gauge at the Portland International Airport was examined, located approximately five miles southwest of the site.

Validation of bottle selection

Upon request, SMI provided the Consultant the protocol for bottle selection and the bottle selection rationale specific to each sampled event. Upon review the Consultant concluded that the bottle selection for each event was consistent with what was reported on the Individual Storm Reports. The bottle selection was also appropriate based on the rationale provided. This information can be provided to the TRC if requested.

Validation of TSS data

SMI examined its storm samples for total TSS and TSS prescreened to remove sediment greater than 500 microns. SMI used the later values to evaluate performance. The Consultant compared the TSS values identified in Table 3 of SMI's summary report (SMI, 2004a) against the respectively laboratory reports provided by the commercial laboratory. The values in the laboratory sheets were consistent with the values used by SMI in its performance analysis, with two anomalies described below.

At the Lake Stevens site for the storm of October 6, 2003, the TSS values identified by SMI were 83 and 22 mg/L for the influent and effluent, respectively. These values for TSS<500 mg/L were lower than for the unscreened TSS samples: 72 and 22 mg/L, respectively. It is reasonable to believe that the unscreened and prescreened TSS samples were reversed. However, SMI was unable to confirm this possibility. The only other parameter analyzed common to the unscreened and prescreen samples was volatile solids. However, it could not be ascertained from these data whether the samples had been inadvertently switched. SMI chose to accept the values as reported by the laboratory. The choice makes no difference in the performance analysis since in either case the influent samples were less than 100 mg/L, and the effluent samples were essentially the same. That is, either sample meets the Ecology performance goal of producing an effluent of 20 mg/L when the influent is less than 100 mg/L.

At the Heritage site for the storm of October 6, 2003, the TSS values identified by SMI for the influent and effluent were 117 and 41.1 mg/L, respectively. However, the laboratory report indicated the reverse, that is, the influent and effluent concentrations were 41.1 and 117 mg/L, respectively. But the results for TSS and all other parameters (metals, nutrients) for the unscreened sampled showed the reverse, influent concentrations greater than effluent concentrations. It was therefore reasonable for SMI to conclude that the influent and effluent samples for the prescreened samples had been reversed.

Validation of storm volumes

Frequently the volume observed by the flow meter appeared inconsistent with the rain gauge. This is not unexpected at low storm depths because the abstraction can vary significantly from storm-to-storm. However, even with this consideration in mind, the observed influent volumes appeared higher than would be expected given the observed rainfall depth for several of the storms. This occurred at both sites. Either the rain gauge or the inflow meter was in error. SMI opted to use the influent flow volumes when calculating the efficiency based on mass loading. It should be noted that storm volumes are only used to evaluate efficiency for those storms with influent TSS concentrations above 100 mg/L. Only three storms met this condition. Two of these had observed influent volumes that appeared high in comparison to the rainfall depth and the third had an observed influent volume that was low in comparison to the rainfall depth.

Validation of equipment rinsate blank procedure

SMI prepared field equipment rinsate blanks for the Heritage site on February 8, 2004, and at the Lake Stevens site on March 5 and October 7, 2003 and August 13, 2004. The Consultant witnessed the procedures at Lake Stevens on October 7th and August 13th.

Validation of laboratory QA/QC protocol with respect to blanks

The Consultant examined the laboratory record and concluded that it did carryout appropriate QA/QC testing.

Validation of hydraulic characteristics

Seven of 33 events experienced bypass. This implies excessive bypass and the potential to fail the requirement that 91% of the stormwater volume be treated over time. However, the original design criterion for the cartridges at the two sites was 15 gpm/cartridge. Restricting the flow to 7.5 gpm/cartridge resulted in the abnormal frequency of bypass. The occurrences are therefore an artifact of the experimental conditions. Examination of Figure 6 of the SMI performance report (SMI, 2004a) shows there was only one event in which the storm flows exceeded the original design capacity of 15 gpm/cartridge. This was the event at which the flow rate was 257% of the experimental capacity, which amounts to 128.5% of the original site design capacity. In other respects, the system appeared to function as expected.

VALIDATION RESULTS

Consideration of individual storms relative to criteria and guidelines

Table 1 lists all storms sampled at the two sites. The Consultant disqualified one storm (LSN120203) because the holding time for TSS was exceeded. However, upon review of the draft report (SMI, 2004a), Ecology requested that the storm be included in the analysis. The intent was to include an additional storm with an influent TSS concentration greater than 100 mg/L. The checkmarks indicate those storms that met the TAPE criteria and the modified guidelines. Table 2 lists the qualified storms. These tables were prepared by SMI in consultation with the Consultant. It was agreed that 22 of the 32 storms qualified. Fifteen of the storm samples had influent TSS concentrations less than 100 mg/L. The Coefficient of Variation (COV) for these 15 events was 0.60. Seven events had influent TSS concentrations above 100 mg/L. The Coefficient of Variation (COV) for these events was 0.65. According to the TAPE, only about six storms are needed for either set. The Consultant considered the COV separately for these two groups as this corresponds to the two components of the Ecology performance goal.

TABLE 1 SAMPLED STORMS BY SMI (2004a)

Event ID	Data Quality Objectives (DQOs)					Other Event Characteristics				
	Event Depth (in) [minimum 0.10]	Event Duration (hr) [minimum 1-hr]	Number of Aliquots [minimum of 5 (Inf:Eff)]	Average Event Coverage (%) [minimum of 50]	Qualified for Evaluation	Influent Volume (gal)	Peak Operating Rate** (%)	Antecedent Dry Period (hr)	Influent TSS-WA* EMC (mg/L)	Effluent TSS-WA* EMC (mg/L)
HMP050303	**0.26**	8	15:16	89	✓	21892	92	**103**	66.4	28.3
HMP050703	**0.19**	9	16:16	90	✓	26541	138^	**55**	519	23
LSN051503	0.18	14	5:6	93	✓	1332	76	4	120	29
HMP051603	0.10	5	3:9	63		11058	17	16	987	18.9
HMP090703	0.14	5	11:18	86	✓	7217	101	384	378	37.2
HMP090903	0.16	4	21:15	76	✓	12965	85	24	76.9	16
HMP091603A	0.05	3	8:4	79		4878	15	120	35.5	11.6
HMP091603B	0.10	2	17:15	96	✓	8744	96	10	96.9	31.2
LSN091603	0.30	15	5:5	97	✓	2591	81	60	99	21
HMP100603	0.27	5	21:21	58	✓	17335	257^	384	117	41.1
LSN100603	0.17	5	6:7	59	✓	2703	77	408	83	22
HMP100803	0.07	3	7:8	93		3866	31	36	43.4	19.9
HMP100903A	0.15	2	14:13	52	✓	13581	142^	18	83.6	40.4
HMP100903B	0.25	2	21:21	39		28521	228^	3	58.2	33.6
HMP101103	0.15	4	21:21	71	✓	15570	71	36	7.53	4.86
LSN101503	0.20	5	4:5	81		2836	71	48	23	10
LSN101603	0.17	5	4:5	80		2790	59	7	17	10
HMP102203	0.17	2	18:18	73	✓	14681	125	62	22.1	9.59
LSN102203	0.28	4	6:8	89	✓	3709	144^	31	95	11
HMP111003	0.14	4	14:17	83	✓	9193	97	264	30.6	22.3
LSN111003	0.97	15	21:21	85	✓	13080	137	48	26	10
HMP111503	0.23	6	18:18	74	✓	16901	96	96	6.85	6.16
HMP111903	**0.96**	7	18:18	12		104132	377^	**26**	29.4	27.8
HMP112103	0.08	4	11:9	86		8189	94	17	85.2	60.1
HMP120203	0.24	8	16:16	29		34988	412^	30	270	163
LSN120203	0.54	5	9:11	85	✓	5474	188	3	264	32.6
HMP120403	**1.10**	18	18:18	10		117340	104	**40**	35.9	20.3
HMP121003	**0.26**	7	13:16	79	✓	20814	78	**42**	28	17.2
HMP121603	0.22	5	10:8	54	✓	22981	79	22	45.9	18.8
LSN012204	0.39	10	6:6	77	✓	3475	87	86	54	46
LSN012904	0.69	8	10:13	68	✓	7007	120	32	170	48
LSN020304	0.19	9	5:4	76		2174	93	34	45	27
LSN030604	0.14	5	6:6	60	✓	2840	56	36	120	26

* 500-um pre-filtration, whole volume analysis
** expressed as percentage of effluent design Q
^ internal bypass confirmed by ODS
bold = off-site data used due to equipment error
inversion = analytical PQL substituted for ND value
shading = DQO met

TABLE 2 QUALIFYING STORMS BY SMI (2004a)

Qualifying Event ID	Normalized, Sampled Influent Volume (gal/cartridge)	TSS-WA EMCs by Category: All – Influent (mg/L)	All – Effluent (mg/L)	Inf. EMC < 100 – Influent (mg/L)	Inf. EMC < 100 – Effluent (mg/L)	Inf. EMC > 100 – Influent (mg/L)	Inf. EMC > 100 – Effluent (mg/L)
HMP050303	842	66.4	28.3	66.4	28.3	---	---
HMP050703	1033	519	23	---	---	519	23
LSN051503	123	120	29	---	---	120	29
HMP090703	270	378	37.2	---	---	378	37.2
HMP090903	428	76.9	16	76.9	16	---	---
HMP091603B	363	96.9	31.2	96.9	31.2	---	---
LSN091603	250	99	21	99	21	---	---
HMP100603	433	117	41.1	---	---	117	41.1
LSN100603	158	83	22	83	22	---	---
HMP100903A	307	83.6	40.4	83.6	40.4	---	---
HMP101103	481	7.53	4.86	7.53	4.86	---	---
HMP102203	463	22.1	9.59	22.1	9.59	---	---
LSN102203	330	95	11	95	11	---	---
HMP111003	332	30.6	22.3	30.6	22.3	---	---
LSN111003	1112	26	10	26	10	---	---
HMP111503	540	6.85	6.16	6.85	6.16	---	---
LSN120203	465	264	32.6	---	---	264	32.6
HMP121003	710	28	17.2	28	17.2	---	---
HMP121603	540	45.9	18.8	45.9	18.8	---	---
LSN012204	268	54	46	54	46	---	---
LSN012904	473	170	48	---	---	170	48
LSN030604	170	120	26	---	---	120	26
Average EMC (mg/L):		114	25	55	20	241	34
Aggreagate Pollutant Load Reduction (%):		82		61		89	

ANALYSIS OF THE VALIDATED DATA

TAPE protocol guidance

The TAPE protocol describes the expected performance goal, taken from the Department of Ecology's stormwater manual for Western Washington (2001).

"Ecology's basic treatment menu facility choices are intended to achieve a goal of 80 percent removal of total suspended solids for influent concentrations that are greater than 100 mg/L, but less than 200 mg/L. For influent concentrations greater than 200 mg/L, a higher treatment goal may be appropriate. For influent concentrations less than 100 mg/L, the facilities are intended to achieve an effluent goal of 20 mg/L total suspended solids. Flows in excess of the water quality design flow or volume can be bypassed around the facility. The performance goal applies:

- *to stormwater with a typical particle size distribution;*
- *on an annual average basis to the entire discharge volume (treated plus bypassed); and,*
- *to the water quality design storm volume or flow rate. (Ecology, 2001-Ch.4, Vol.V)*

The TAPE also makes reference to the expectation that 80% removal is to be achieved at the design hydraulic loading rate (Page 15), and the expectation that the device will be tested in the field "over a range of flow rates from 50-110%." Before proceeding further, the Consultant wishes to comment on these aspects as it affects the discussion from this point.

The Consultant believes that the expectation that a treatment device achieve 80% at the "design hydraulic loading rate" is ill conceived. These reasons are offered. First, the peak presumably occurs only once for a short period in the designated design event flow,based on the single event concept. Continuous simulation (WWHM) shows that this is simplistic. Nonethess, the peak rate-duration volume represents a very small portion of the volume of storms representing 91% of volume treated over time. As a consequence, the design hydraulic loading rate rarely occurs for most systems, whether volume or flow based. Secondly, the performance goals described above are based on actual performance data from public-domain treatment systems. The data of these systems are flow-weighted Event Mean Concentrations and therefore represent the summation of flow condition during each storm rather than a momentary peak. Thirdly, the Department of Ecology does not expect maximum performance of wastewater treatment plants. Flows vary substantially both diurnally and seasonally. Yet, Ecology does not require that the wastewater plant meet its discharge standard during each moment within a 24-hour period. The effluent samples are 24-hour composites. We do not expect such performance for wastewater treatment plants despite their sophistication and operator control. In contrast, stormwater systems are passive and without operator control. With respect to the StormFilter the outlet of the cartridges defines the treatment rate. Hence, the influent rate is irrelevant except with the question of bypass. Therefore in a sense the performance data provided by Stormwater Management are all at the capacity of the system.

The Consultant believes the expectation that a stormwater treatment device should achieve 80% removal <u>including bypass events</u> is ill conceived. Three reasons are offered. First, the expectation that a device must achieve 80% removal including bypass in effect states that absent bypass the treatment system must exceed 80% removal. This is not expected of public-domain systems, nor is it reflected in the performance data upon which the standard is based. Whether bypass occurred during any of the storms of any of the treatment systems represented in the data upon which the performance goals are based is unknown. Secondly, the effect of including bypass is to place no upper boundary on what constitutes the condition under which the performance goal does not apply. Is it expected that any treatment device, manufactured or in the public-domain, will meet the performance goal during a 25 or 100 year event? Not likely. Should the manufacturer throw out the data collected during extreme storms should they occur? If so, which extreme storms? What constitutes "extreme"? Third, we do not expect this performance of wastewater treatment plants. Considering the sophistication of such facilities with trained operators who can make adjustments under extreme conditions, the discharge permits allow reduced performance. Discharge permits for wastewater treatment plants are flexible in this regard. The definition of secondary treatment is "30/30": 30 mg/l of BOD and TSS, respectively. However, these are average values over any 30-day period: It is not required that they be met daily. Furthermore, the permits include the provision of a weekly average of 45 mg/L, as long as the average over 30 days is 30 mg/L or less. Hence, it seems that we are placing expectations on stormwater treatment systems that experience from wastewater treatment suggests is inappropriate.

Pooling the data

To outward appearances the two sites are quite different: the parking lot of a shopping mall and a bridge on a relatively lightly traveled road (likely less than 10,000 vehicles per day). Absent data, judgment suggests that the runoff from the bridge would have higher TSS concentrations and contain larger particles because it exhibits gutter flow. The metrics presented in Table 3 provide for comparison of the two sites. Concentrations are higher at the Lake Stevens site as expected. Although the percentage of TSS greater than 500 microns is the same for both sites, the fraction of sand in the vault sediment is greater at the Lake Stevens site. Using methods described in their report (SMI, 2004a), SMI determined the likely sediment distribution of the influent. They were: Heritage, 10% sand, 89% silt, and 1% clay; Lake Stevens, 33% sand, 65% silt, and 2% clay. These findings are consistent with the analysis of the sediment in the respective vaults. As expected, influent sediment at the Lake Stevens site is much coarser. However, it is the Lake Stevens site that is likely more representative of "typical" stormwater. A study by the City of Bellevue (Pitt and Bissonette, 1984) of stormwater from a mixed commercial residential area found that 35% of the sediment was fine sand or larger, the remainder silt and clay. The Heritage site likely has a lower concentration of coarse sediments as water moves as sheet flow across the pavement. Hence, including the Heritage site in the analysis is conservative.

TABLE 3 COMPARISON OF THE TWO SITES

	LAKE STEVENS	HERITAGE
Sediment %> 100 microns	35%	12%
Sediment % > 500 microns	15%	4%
TSS % > 500 microns[a]	10%	11%
TSS median[a]	89 mg/L	52 mg/L

a. Of all sampled storms

Analysis of performance

The TAPE identifies four methods to calculate efficiency.

Method #1: Individual storm reduction in pollutant concentration.
The reduction in pollutant concentration during each individual storm calculated as:

100 (flow-weighted influent concentration – flow-weighted effluent concentration)/ flow weighted influent concentration

Method #2: Aggregate pollutant loading reduction.
Calculate the aggregate pollutant loading removal for all storms sampled as follows:

100(A-B)/A

Where:
A= (Storm 1 influent concentration) * (Storm 1 volume) + (Storm 2 influent concentration) * (Storm 2 volume) +…(Storm N influent concentration) * (Storm N volume)

B = (Storm 1 effluent concentration) * (Storm 1 volume) + (Storm 2 effluent concentration) +…(Storm N effluent concentration) * (volume of Storm N)

Concentrations are flow-weighted, and flow = average storm flow or total storm volume (vendor's choice)

Method #3: Individual storm reduction in pollutant loading.

100(A-B)/A

Where:
A= (Storm 1 influent concentration) * (Storm 1 volume)
B= (Storm 1 effluent concentration) * (Storm 1 volume)

Method #4:
Method #1 applied to partial-storm data (EvTEC approach), comparing influent and effluent discrete flow composites for relatively steady-state flow periods within storms to evaluate removal efficiency versus flow rate.

Method #1 was the most common method used early in the evolution of system comparison. It has fallen from favor as it gives undue weight to events of high efficiency, in particular given that with some technologies high efficiencies tend to occur with small events that are far below the capacity of the system. High efficiencies also tend to occur with high influent concentrations, which are uncommon. These considerations have lead to the use of Method 2. Method 3 is simply a subset of Method 2. Method 4 is not applicable to the StormFilter, given the diluting effect of the vault.

It will be noted that none of methods provides for consideration of the performance goal at influent concentrations less than 100 mg/L. The simple approach is to ascertain how many storms with influent concentrations less than 100 mg/L had effluent concentrations at or near or below 20 mg/L. Method 2 is applicable to storms with influent concentrations above 100 mg/L. SMI considered these approaches, summarized in Table 4 of their summary report (SMI, 2004a), repeated below. This Consultant checked and agrees with the content of Table 4. There were thirteen events with influent concentrations less than 100 mg/L but greater than 20 mg/L. Of these, nine had effluent concentrations near or less than 20 mg/L. Three events had effluent concentrations significantly above 20 mg/L; that is, greater than 30 mg/L.

TABLE 4 EFFICIENCY CALCULATIONS BY SMI (2004a)

Influent TSS-WA EMC (mg/L)	
< 100	***> 100***
Approximately 70% of the qualifying events fall into this category. Of these, approximately half demonstrate effluent EMCs less than 20 mg/L. An arithmetic average of effluent EMCs under this category yields an *annual average effluent TSS-WA EMC of 20 mg/L (n=15).*	***Only the aggregate pollutant loading reduction calculation (Method #2) recommended by WADOE (2002) produces a singular performance value on an annual average basis. The resulting performance for this category is an*** *annual average removal of 89% (n=7).*

Further consideration of events with TSS over 100 mg/L

It is appropriate that Ecology distinguishes events over 100 mg/L from those less than this value. It is well recognized that efficiency begins to drop at influent concentrations less than about 100 mg/L because, roughly, the lowest effluent concentration that is likely for public-domain treatment systems is about 20 mg/L. But having established the demarcation of 100 mg/L, its significance should not be overstated. Both Nationally and for the maritime climate region of the Pacific Northwest, the median concentration for TSS for all land uses is only about 50 mg/L (Pitt, 2004). Furthermore, analysis of the National data base indicates no relationship between storm depth and TSS concentration (Pitt, 2004). Concentrations are totally random with respect to storm depth and concentration.

REFERENCES

Bannerman, Roger, personal communication, Wisconsin Department of Natural Resources.

Ecology (Washington Department of), 2002, Guidance for Evaluating Emerging Stormwater Treatment Technologies Technology Assessment Protocol – Ecology (TAPE), October 2002 (Revised October 2003) Publication Number 02-10-037

Ecology (Washington Department of), 2001, Stormwater Management Manual for Western Washington, Publications Numbers 99-11 through 99-15.

Lenhart, James, personal communication, Stormwater Management, Inc.

Pitt, et al., 2004, Research Project Report, Findings from the National Stormwater Quality Data Base (NSQD), University of Alabama, Tuscaloosa, Alabama.

Pitt, R.E., and P. Bissonette, 1984, Bellevue urban runoff program: summary report, Bellevue, Washington.

Stenstrom, M. and M. Kayhanian, 2004, Sampling Issues: Composites versus Grabs, Presented at StormCon2004, July 26-29, 2004, Palm Desert, California.

Stormwater Management Inc., 2003, StormFilter® Quality Assurance Project Plan.

Stormwater Management Inc (SMI), 2004a (September 28), Final Draft Performance of the Stormwater Management StormFilter® Relative to Ecology Performance Goals for Basic Treatment

SMI, 2004b (October 1), Final Draft, Lake Stevens North Field Evaluation: Stormwater Management StormFilter® with ZPG™ Media

SMI, 2004c (September 28), Final Draft, Heritage Marketplace Field Evaluation: Stormwater Management StormFilter® with ZPG™ Media

SMI., 2004d, (October 11) Factors Other Than Treatment Performance

