

FIELD PERFORMANCE OF ADVANCED WASTEWATER PRETREATMENT SYSTEMS – INFERENCES FROM NORTH CAROLINA’S EXPERIENCE

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ABSTRACT

A growing number of single and multi-family homes in North Carolina rely on advanced wastewater pretreatment systems (AWPS) prior to subsurface dispersal, especially in the State’s Coastal resort communities. Use of two models of peat media systems and more recently textile media systems has become widespread. All systems are required to have an operator, whom inspects systems at least semiannually, and currently collects influent and effluent samples at least annually. The local health departments also routinely inspect the systems, in addition to responding to failures and nuisance complaints. North Carolina’s recently established influent and effluent performance standards for AWPS are described, and the results of data collected during 2006 from three types of systems at over 400 sites are presented. Field results are compared to comparable influent data from bench test sites where AWPS receive certification. Influent concentrations of TKN are nearly twice as strong as for wastewater used at existing bench-test sites (NSF, ETV), indicating a need for new or modified testing sites to be more representative of individual home flows. Field data are evaluated against multiple performance measures (mean, 95-percent confidence intervals, percent exceedence), as well as based on a visual inspection protocol. Reasons for compliance excursions are discussed. Finally, an analysis is presented to evaluate the number of grab samples needed to reach accurate and replicable conclusions about AWPS compliance with established standards. Twenty randomly-sampled sites is too few but results from 60 sites did not appear to add much improvement to results from 40 sites, in comparison to conclusions drawn by sampling all sites.

KEYWORDS. Wastewater Treatment, Peat Systems, Textile Systems, Media Filters, Sampling protocol, Performance Standards

INTRODUCTION

Advanced Wastewater Pretreatment Systems (AWPS) beyond the septic tank remain the exception, rather than the rule, in North Carolina, where 50% of the homes are served by on-site systems and 40-50,000 systems are installed annually. Their extent of use, however, was jump-started as an integral component of systems installed in conjunction with the rebuilding of beachfront homes after the Hurricanes of the mid 1990’s devastated large portions of North Carolina’s Coastal resort communities. Predominantly used to allow a reduction in the size of the final dispersal field by 50 percent or greater, more recently systems are now also being promoted which additionally meet higher standards for reductions of Total Nitrogen (TN) and fecal coliforms.

Peat filters were the first AWPS to achieve widespread use, due to the ability they afford for reduced system sizing by allowing the treatment units to be placed directly over the drainfield dispersal beds. There are currently over 500 individual peat systems operational in the state,

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with use now extending from the coast westward to our Piedmont and Mountains, where increasing numbers of sites require advanced pretreatment to allow for their effective use. Two companies are active with their approved systems, with competition keeping systems cost competitive. Interest in these and other AWPS has stimulated the state to develop improved AWPS regulations, including upgrading the approval process and provisions for assuring comprehensive life-cycle management, establishing detailed system siting, sizing, design, installation, operation and maintenance, and performance monitoring criteria.

As recognition of the potential benefits and markets for individual advanced pretreatment in the state has grown, so has the variety of systems and manufacturers seeking approval through the State's Innovative and Experimental approval program. A textile filter system has become the next most popularly installed product, again predominantly in the Coastal region, but also increasingly throughout the remainder of the State. Its advantages include a smaller treatment "footprint," non-degradable treatment media, and the added potential for nitrogen reduction and for fecal reduction when used in conjunction with a UV disinfection system.

The basis for use of AWPS is their ability to achieve reduced levels of various wastewater constituents prior to final on-site effluent dispersal. Furthermore, the use of such systems highlights the need to have an effective life-cycle management system in place. A number of questions surround the use of individual AWPS in North Carolina and elsewhere:

- To what extent should system approval be tied to prior evaluation in accordance with nationally recognized protocols and certification/listing under nationally recognized standards (e.g., NSF Standard 40 for Residential Wastewater Treatment Systems)?
- What (if any) sampling should be required for individual systems?
- If sampling is required, how will sample results be used for assessing individual site performance, and overall system performance?
- How should system performance be otherwise evaluated, instead of or in addition to effluent sampling?
- What levels of operation and maintenance are needed and what role should the system manufacturer have in assuring necessary operation and maintenance measures are followed?

North Carolina's on-site program has evolved to address these issues, as the interest in AWPS has grown. During the past two years, rules have been adopted to refine the approval and system management process for systems compliant with NSF Standard 40 and for systems designed to achieve higher levels of treatment [see Rules .1957(c) and .1969, NC Administrative Code, 2006]. A new comprehensive AWPS rule (Rule .1970, NC Administrative Code, 2006) was also adopted, establishing influent and three effluent performance standards; uniform siting and sizing requirements for ground absorption systems that are preceded by treatment systems complying with the various performance standards; generic system design, installation and operation requirements; and criteria for evaluating compliance for individual sites and types of systems.

INFLUENT AND EFFLUENT PERFORMANCE STANDARDS

Individual AWPS in North Carolina are routinely designed to receive “typical” domestic strength effluent, with pretreatment to the unit as provided by a septic tank. During the AWPS rule development process, it became evident that influent waste strength where the majority of the systems are currently used (Coastal resort communities) appears to be much “stronger” than previously reported. Table 1 shows the maximum expected influent quality parameters established by Rule.

Table 1. Influent Quality Standards for APWS.

Parameter	Influent Not to Exceed (mg/l)*
Biochemical Oxygen Demand (BOD)	350
Total Suspended Solids (TSS)	200
Total Kjeldahl Nitrogen (TKN)	100
Fats, Grease and Oil (FOG)	30

*mg/l is milligrams per liter

To account for influent strength concerns, while an individual site may be considered in violation if influent standards are exceeded, the effluent data from such sites (if exceeding effluent standards) will not “count” when determining aggregate performance countywide or state-wide of an AWPS. Results from 2006 influent sampling for BOD and TKN are shown in Figures 1a and 1b, including comparisons made to influent data for the same systems as reported in their NSF Standard 40 bench testing reports (NSF, 2006, 2005, 2002), and with influent data at the Massachusetts NSF/ETV test site (NSF/ETV, 2003).

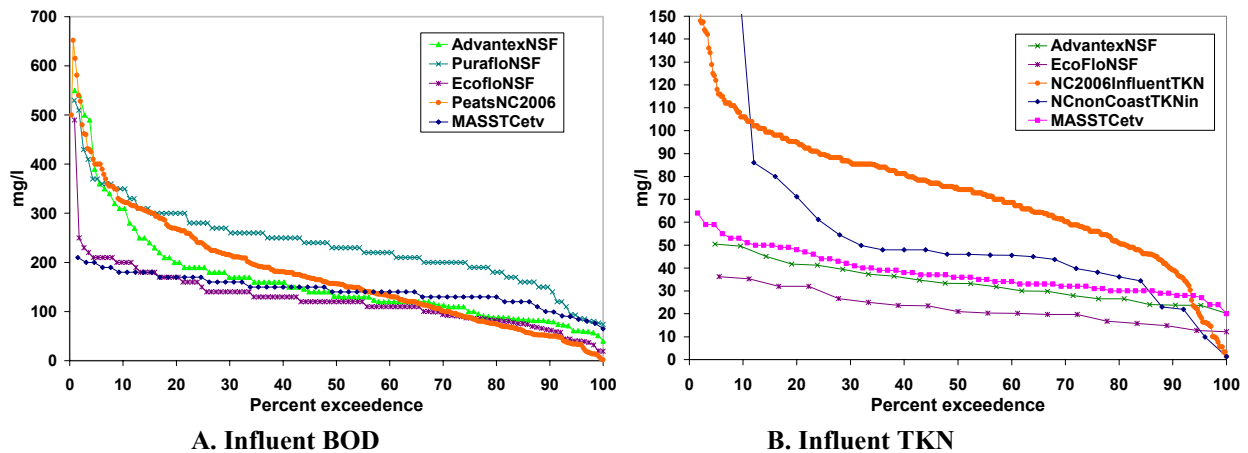


Figure 1. Influent Wastewater Quality, NSF/ETV Test Sites and NC Sampled Sites.

The variability of influent quality at NSF test sites is reflected by the BOD influent data. Waste strength appears much higher at the Waco test site for one of the Peat systems tested, compared to the other Peat system tested at the same site. The Massachusetts test site strength is also on the “low” end, and the British Columbia NSF test site strength in between the others. Influent BOD at the North Carolina monitored sites is less than at the Waco test site when one of the Peat systems was tested, but generally greater than influent BOD reported for the other Waco test and

for other test sites. The TKN data comparison highlights concerns about the extent to which the NSF test sites currently in use adequately reflect expected wastewater strength for influent Nitrogen, especially for sites similar to the coastal North Carolina resort communities, where AWPS demand is greatest. The medium (50% exceedence) TKN value in the NC data set is over twice the median TKN value reported from the NSF/ETV test sites. The TKN levels at North Carolina monitored sites outside of the Coastal resort counties are closer to the test-site data, though still comparatively elevated.

There remain no nationally recognized comprehensive effluent standards for AWPS, other than NSF Standard 40 (CBOD, TSS), and the more recently adopted NSF Standard 245 for Nitrogen reduction. Thus, many states have developed their own AWPS effluent performance standards. Table 2 presents the three levels of effluent water quality now recognized in North Carolina's subsurface Rules.

Table 2: Effluent Quality Standards for APWS.

Parameter	NSF-40	TS-I	TS-II
Carbonaceous Biochemical Oxygen Demand (CBOD)	<25 (mg/l)*	<15 (mg/l)	<10 (mg/l)
Total Suspended Solids (TSS)	<30 (mg/l)	<15 (mg/l)	<10 (mg/l)
Ammonium Nitrogen (NH ₄ -N)		<10 (mg/l)	<10 (mg/l)
Total Nitrogen (TN) (TN is Total Kjeldahl Nitrogen plus Nitrate+Nitrite Nitrogen)			<20 mg/l or >60% removal
Fecal Coliform		<10,000 (colonies/100 ml)	<1,000 (colonies/100 ml)

*mg/l is milligrams per liter

Criteria for site and system compliance are outlined in Table 3.

Table 3: Criteria for Site and System Compliance for AWPS.

Site Compliance
<ul style="list-style-type: none"> • Passes annual visual inspection • Flow criteria <ul style="list-style-type: none"> ○ 7-day flow \leq 1.3 x design daily wastewater flow, and ○ 30-day \leq design daily wastewater flow • Influent wastewater doesn't exceed threshold (grab sample) • Effluent sample criteria (grab sample) <ul style="list-style-type: none"> ○ No parameter value $>$ 2 x standard (2.5 x for fecals) ○ Mean \leq standard for when 4 or more samples collected annually
System Compliance
<ul style="list-style-type: none"> • Mean of all data \leq designated standard • Less than 20 percent of sites exceed standard for one or more parameters • Less than 10 percent of sites exceed 2 x standard for one or more parameters

North Carolina’s criteria for site and system compliance takes into account a number of factors which have been found to be of critical importance. This includes recognition that both influent flow rate and influent wastewater characteristics have an overriding influence on system treatment capability and hydraulic performance. Sampling protocols incorporate an expectation that a single annual grab sample has limited value as a measure of an individual system performance at a given site. Hence, a site isn’t considered out of compliance unless the grab sample results exceed two times the standard (2.5 times for fecal coliforms). Yet also reflected in these the criteria is the expectation that a robust pretreatment system should be expected to achieve effluent performance standards the majority of the time ($\leq 20\%$ exceedence of standard allowed by NC Rules, and $\leq 10\%$ of sites allowed to exceed two times the standard). Also recognized is the importance of manufacturer assurance of proper system operation, and a comprehensive annual visual inspection. The believe is that a trained operator will typically glean as much or more about long-term system performance and maintenance needs from visual inspection than afforded just by reviewing the single grab sample results. In some instances, the system can be treating the effluent passing through it quite well, but during a visual inspection is found to be hydraulically malfunctioning and discharging untreated effluent directly to the drainfield or ground surface, perhaps even bypassing an effluent sampling port. Rules now also allow for the annual sampling of each site to be replaced by a statistically-valid system audit (to replace sampling only – not the annual assessment of water usage and the annual visual inspection).

EFFLUENT QUALITY FROM THREE NORTH CAROLINA AWPS

Results for three North Carolina AWPS from the 2006 monitoring season are presented in Tables 4a and 4b, and 5a and 5b.

Table 4: North Carolina APWS Effluent Data, 2006.

a. Peat Media Systems

Measure	Model # 1		Model # 2	
	BOD	NH3	BOD	NH3
Mean (mg/l)	12.4 (222)*	8.0 (216)	14 (116)	10 (113)
SD	17.5	10.6	23	12
95% conf.	+/- 2.3	+/- 1.4	+/- 4.0	+/- 2.3
10% exceedence	30	22	30	25
20% exceedence	17	13	17	16
50% exceedence	6	3.6	8	5.9

*Number in (parentheses) is number of samples

b. Textile Media Systems

Measure	BOD	NH3	TSS	FECAL	TN
Mean (mg/l) (fecal: geomean, cols./100 ml)	4.7(73)*	6.2 (77)	6.7(67)	79(74)	23.8(64)
SD	4.3	11.8	7.1		12.1
95% conf.	+/- 1.0	+/- 2.8	+/- 1.6	+/- 2.3	3.2
10% exceedence	11	14	16	6000	45
20% exceedence	7.5	6.95	9.6	2200	31
50% exceedence	2.8	2.2	4.3	79	20

*Number in (parentheses) is number of samples

Table 5. Media Systems Site/System Compliance Summary, 2006.

a. Based on Effluent Performance-vs.-Standards, Statewide Data

Type of System	1 x Standard		2 x Standard	
	Pass	Fail	Pass	Fail
Peat (# 1)*	123	74 (38%)	162	38 (19%)
Peat (# 2)*	60	37 (38%)	88	14 (14 %)
Textile**	34	17 (33%)	44	8 (15%)

*Based upon site's compliance with TS-I Standards (see Table 2) for one or more parameters

**Based upon site's compliance with TS-II Standards (see Table 2)

b. Based on Visual Inspection Protocol* (data from single county only)

System Type	System Age	Compliant	Non-Compliant
Peat (# 1)	All	61	18 (23%)
	1-2 yrs. old	19	0
	3 yrs. old	11	0
	4 yrs. old	13	2 (13%)
	5 yrs. old	6	4 (40%)
	6+ yrs. old	12	12 (50%)
Peat (# 2)	All	92	19 (17%)
	1-2 yrs. old	43	6 (12%)
	3 yrs. old	20	7 (35%)
	4 yrs. old	10	2 (17%)
	5 yrs. old	13	3 (19%)

*Failure based on significant observed ponding and/or severe media surface degradation

Compliance success has been variable. In all cases, the quality of effluent far exceeds the quality of the septic tank influent for the parameters these TS-I and TS-II systems are designed to handle. Samples from the peat systems were compliant based upon the means of all sampled parameters, and the 95% confidence range was generally at or below standard levels (with the exception of the BOD and NH3 95% confidence range for Model # 2 peat). The 20% exceedence parameters, however, generally were not in compliance with the established standards (and 10% exceedence standard for NH3 exceeded for both models). Also, as indicated in Tables 5a and 5b, the percentage of sites exceeding standards for one or more parameters, and the number of sites non-compliant based upon visual inspection were greater than allowed for in North Carolina's performance standards. The visual inspection performance data are from a single NC county containing the greatest number of systems. Results on compliance of the

textile media system were similarly variable. This system is intended to comply with the more stringent TS-II standards, and does so quite well based on all parameters with the exception of Total Nitrogen (and Nitrogen reduction), which accounts almost exclusively for its compliance excursions.

ANALYSIS OF COMPLIANCE ISSUES

Multiple reasons have been identified for instances of the systems' non-compliance. In accordance with North Carolina requirements, effluent data have been excluded for the analyses presented from sites where influent exceeds the BOD or TKN standards (Table 1). Data have not yet been excluded, however, from sites where influent flow rates may be excessive, since the mechanism has just recently been put in place for this information to be accurately assembled simultaneously with effluent sample collection. Previous flow studies (Curran, 2007) documented excessive water usage well beyond system design flows in Coastal resort communities where the majority of AWPS have thus far been utilized. A comparison between effluent data for systems designed for 480 gallons per day or less (4 bedrooms or less), compared with larger systems provides some indirect evidence that excessive flows remain an important non-compliance explanatory factor (see Figures 2a and 2b).

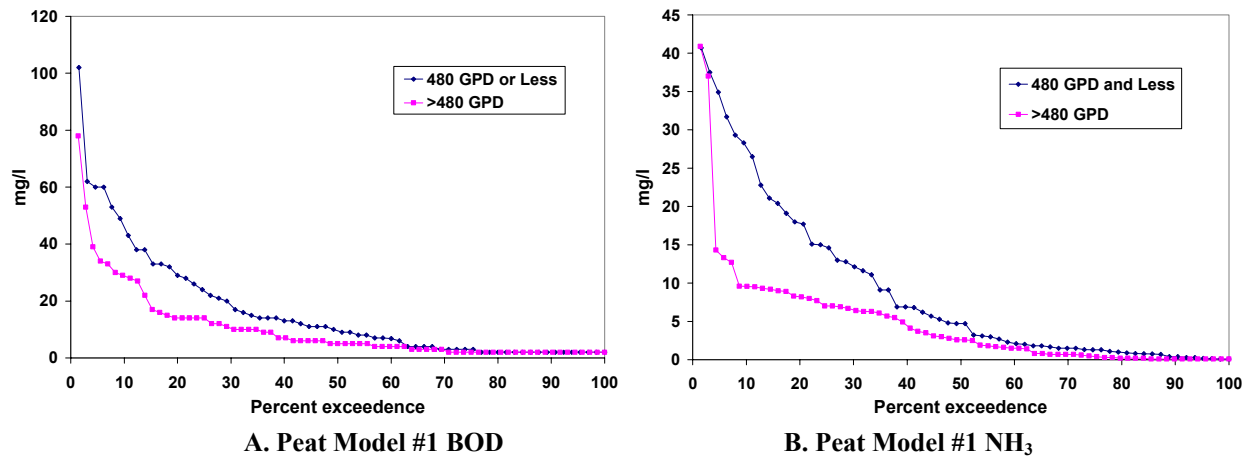


Figure 2. Performance of Peat Systems, as Influenced by System Size.

The sites with a greater design flow have typically been much less susceptible to abuse/overuse, compared to the three and four-bedroom rentals. While system size is clearly evident as a performance factor for the Model # 1 Peat system, there wasn't found to be a similar significant correspondence between Total Nitrogen levels and system size for the textile media system.

Another factor considered was age of the system, with enough systems of varying ages to evaluate for the two models of peat media systems. These analyses are presented in Figures 3a and 3b for the parameters which appeared to exhibit a clear age-relationship.

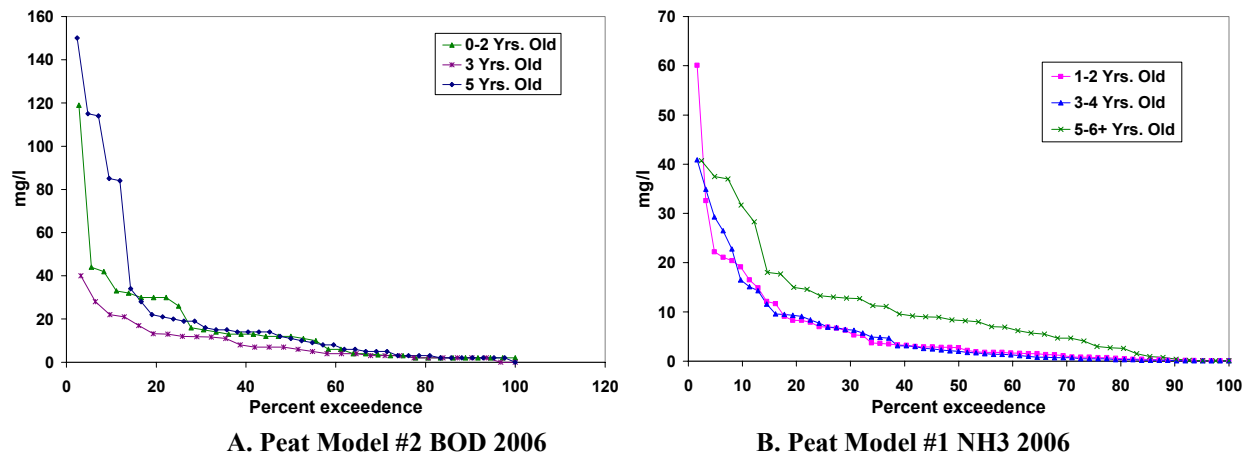


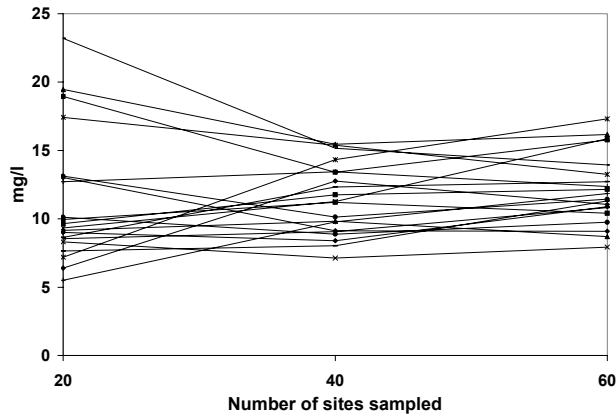
Figure 3. Performance of Peat Systems as Influenced by System Age.

The BOD values for the Model # 2 peat system show an improvement, comparing 3-year old versus 0-2 year old systems, but a degradation in quality for the 5 year old systems. For the Model # 1 peat system, degradation of NH3 becomes evident with the systems over 5 years old, compared with younger systems.

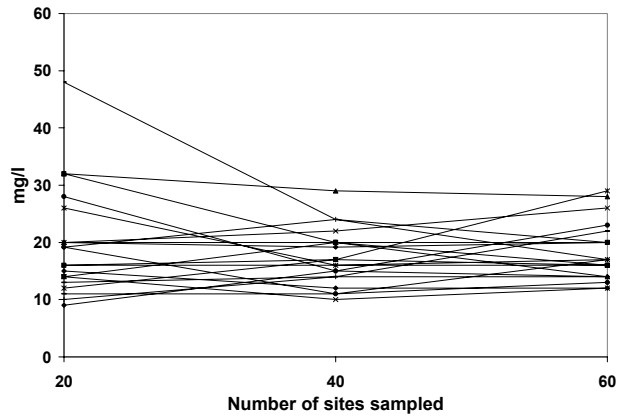
INFERENCES ON SAMPLING PROTOCOLS FROM NORTH CAROLINA AWPS DATA

There has been much discussion in the on-site community about sampling protocols, the extent to which bench testing can be relied upon, and the type and extent of sampling needed to achieve meaningful results about sites and different types of systems (Converse and Nordheim, 2004; Groves, et al, 2005). With the available North Carolina data sets, some analyses could be done to at least partially address some of these issues. Data collected and reported herein (predominantly single grab samples from separate sites) were from over 200 sites using Model # 1 peat systems, over 100 sites using Model # 2 peat systems, and from about 75 textile media sites. We looked at randomized effluent data sets for BOD and NH3 from all three types of systems, and for TN at the textile media system sites. Twenty randomized sets were compiled, using 20, 40 and 60 randomly-selected sites for each parameter, for each type of system. From these data sets it could be visualized the degree to which increasing the number of sites is necessary in order to reach accurate (and replicable) conclusions about the AWPS compliance with established pretreatment standards. The most “robust” system should allow for conclusions about compliance status to be drawn based upon a relatively small number of sites sampled.

Examples of the results of these analyses are presented in Figures 4 through 7, and all results are summarized in Table 6.

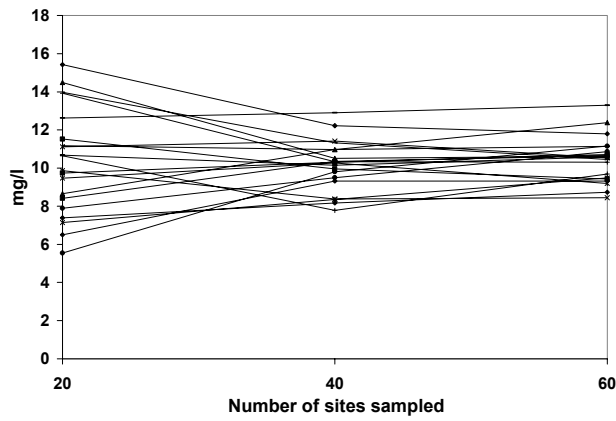


A. Measure: Sample Mean

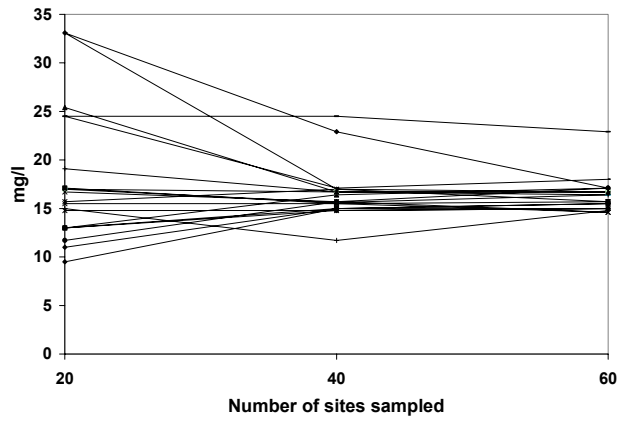


B. Measure: 20% Exceedence Level

Figure 4. Randomized Data Sets, Peat Model #1, BOD.

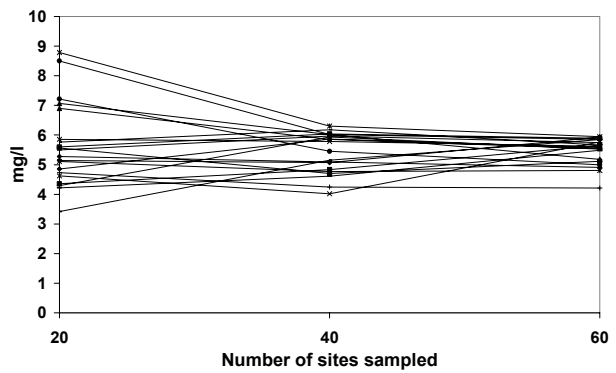


A. Measure: Sample Mean

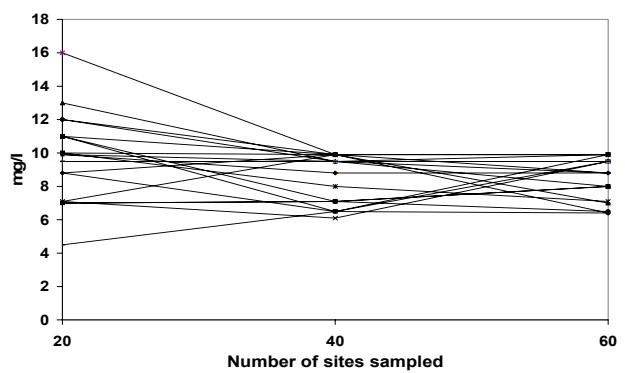


B. Measure: 20% Exceedence Level

Figure 5. Randomized Data Sets, Peat Model #2, NH₃.



A. Measure: Sample Mean



B. Measure: 20% Exceedence Level

Figure 6. Randomized Data Sets, Textile, BOD.

Table 6: Analysis of Number of Sites to Sample to Determine Standard Compliance

Type of System	Parameter	Number of Sites Sampled					
		20		40		60	
		Measure Evaluated					
		Mean	20% exc	Mean	20% exc	Mean	20% exc
range in parameter values in 20 randomized data sets							
Peat Model # 1	BOD [p,f]**	5.5-23 (80%)*	9-48 (40%)	7.1-15 (85%)	10-29 (35%)	7.9-17 (80%)	12-29 (30%)
	NH3 [p,f]	3.8-12 (100%)	5.5-28 (25%)	5.2-11 (100%)	9.2-17 (30%)	5.9-9.9 (100%)	9.5-18 (15%)
Peat Model # 2	BOD [p,f]	6.6-23 (80%)	10-42 (30%)	9.3-19 (70%)	14-28 (25%)	11-17 (60%)	15-26 (10%)
	NH3 [p,f]	5.5-15 (95%)	9.5-33 (5%)	7.8-13 (100%)	12-25 (0%)	8.4-13 (100%)	15-23 (0%)
Textile	BOD [p,p]	3.4-8.5 (100%)	4.5-16 (70%)	4.0-6.3 (100%)	6.1-9.9 (100%)	4.2-5.9 (100%)	6.4-9.9 (100%)
	NH3 [p,p]	2.7-12 (85%)	4.7-24 (50%)	5.0-9.2 (100%)	6.3-14 (60%)	5.1-7.9 (100%)	7.1-11 (70%)
	TN [f,f]	20-30 (5%)	31-52 (0%)	22-29 (0%)	30-45 (0%)	24-26 (0%)	31-37 (0%)

*Number in (parentheses) is percent of 20 randomized data sets in compliance for the specified parameter based on TS-I (Peat systems) or TS-II (Textile system) standards.

**Letters in [brackets] indicate whether system “p” = passed or “f” = failed to meet “mean” and “20% exceedence” standards, respectively, based upon complete data sets.

The conclusion drawn from this analysis is that while 20 sites generally appears to be too few, there was little additional accuracy of system compliance assessment when 60 sites are sampled, instead of just 40, in comparison to conclusions drawn by sampling all sites.

CONCLUSIONS

Advanced Wastewater Pretreatment Systems (AWPS) will continue to play an increasing role in the on-site programs in North Carolina and elsewhere. Rules are in place and under further review and development to deal with the approval of products in a highly competitive industry and to assure long-term performance of these systems. There is a critical need for further development of widely recognized AWPS performance standards and for National bench test sites to be selected or modified to achieve better correspondence between influent waste streams and the expected field conditions where the demand for these systems is greatest. The need for nationally recognized sampling and performance monitoring/verification protocols is also critical. Until this occurs, field performance measurements must be incorporated in the States’ management programs.

Based on North Carolina’s experience, a management/surveillance system incorporating routine flow measurement and comprehensive visual inspection of all systems is needed to assure individual site compliance. Additionally, a limited sampling regime (of 40 to 50 sites) appears to be adequate to assess ongoing performance of a particular technology on a statewide basis.

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