A Review On Pollution Control And Ecology Water Pollution Control Permit: Effluent Limitations And Monitoring Requirements

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ABSTRACT

The purpose of this study is to review the effluent limitations and monitoring requirements authorized by the Arkansas Department of Pollution Control and Ecology and proposes recomendations to enhance the improvement of the present requirements. The study is done at the city of Fayetteville and it concentrates on three main issues:

1. Sampling methods: Grab Versus Composite Sampling
2. Cost of the Sampling methods
3. Distinction between a fixed monthly average and a moving average.

Explanations and suggestions made are based on information from relevant literatures compiled with respect to monitoring of water quality. With the recomendations forwarded, it is hoped to aid the Arkansas Department of Pollution Control and Ecology to better understand the advantages and disadvantages of the Grab and Composite Sampling, realizing the cost involved and the distinction between using a fixed monthly average and a moving average measurement on the discharge limitation.

INTRODUCTION

Purpose

The purpose of this study is to review the effluent limitations and monitoring requirements authorized by the Arkansas of Pollution Department Control and Ecology to Fayettevile Municipal Pollution Control Facility. The study addresses the differences between Composite and Grab sampling methods, costs involved in both methods and the distinction between a monthly average.

Problem

In compliance with the provision of Arkansas Water and Air Pollution Control Act, Fayetteville Municipal Pollution Control Facility is authorized to contruct and operate a facility in accordance with the plans and specifications as approved by the Department of Pollution Control and Ecology. The facility is located immediately west of the White River, one mile of Lake Sequoyah in Section 7 and 8, Township 16 Noth, Range 28 west of Washington county.

Any discharge shall be to the receiving stream named: 50 percent of effluent flow to White River, Segment 4K of the White River Basin, and 50 per cent of effluent flow to unnamed tributary of Mud Creek, Segment 3J of the Arkansas River Basin. Refer to Table 1 for an example of the effluent limitations and monitoring requirements.

Table 1: An example of the Discharge limitation and Monitoring requirements

Effluent Characteristic	**Discharge Limitations**		
	Mass kg/day (lbs/day) 30-day Avg.	Other Units (Specify) 30-day Avg.	7-Day Avg.
	December 1 through March 31		
Flow-(MGD)	N/A	*	*
Carbonaceus Biochemical Oxygen Demand (5-Day)	235(517)	10mg/L	15 mg.L
Total Suspended Solids	352(776)	15 mg/L	22 mg/L
Ammonia Nitrogen	117(259)	5 mg/L	7 mg/L
Total Phosphorus	23(52)	1 mg/L	2 mg/L
Total Residual Chlorine	N/A	N/A	0.05 mg/L
Fecal Coliform Bacteria	N/A	1000/100 ml	2000/100 ml
Dissolved Oxygen	N/A	7.8 mg/L**	N/A

Effluent Characteristic	Monitoring Requirements	
	Measurement Frequency	Sample Type
Flow-(MGD)	Continuous	Indicate/Totalize/Record
Carbonaceous Biochemical Oxygen Demand (5-Day)		
Total Suspended Solids	One/Day	Composite
Ammonia Nitrogen	One/Day	Composite
Total Phosphorus	One/Day	Composite
Total Phosphorus	One/Day	Composite
Total Residual Chlorine	One/Day	Grab
Fecal Coliform Bacteria	One/Day	Grab
Dissolved Oxygen	One/Day	Grab

* Flow is not an effluent limitation, but flow monitoring and reporting are required
** Minimum

SAMPLE TYPE

Grab and Composite

Water samples can be broadly classified as "Grab" or "Composite." Grab samples represent the composition of the flow at a given instant in time, irrespective of the flow volume. Composite samples represent an average composition in the flow over time (usually 24 hours) and may or may not be proportional to flow[1]

Comments

Looking through the Arkansas Department of Pollution Control and Ecology Water Pollution Control Permit, the monitoring requirements reflect preference to Composite Sampling. Grab Sampling is used only when Composite Sampling is not applicable.

Monitoring by Grab Sampling is an acceptable alternative strategy and for some is the recommended one – for regularity and compliance purposes. One reason that it is not so considered is the wide spread belief that Composites are "better" than Grabs. The primary retionale for preferring Composite samples over random Grabs appears to be economics. However, as the data in Table 12 of Fulk et. al. (1979)[2] shows the economics savings in analytical costs due to compositing are rapidly overcome by the costs of taking the Composite sample.

GRAB VERSUS COMPOSITE

Compositing Before Analysis is Equivalent to Averaging Separate Sample

It is believed that compositing before analysis is equivalent to averaging separate sample results after analysis. The validity of the technical arguments is addressed below.

The fundamental assumption which is made can be expressed mathematically as

$$X = \Sigma C_t/n = X_c \qquad \text{Eqn. 1}$$

where X_c is the analytical value of the Composite, the C_t's are the analytical values of the individual subsampless comprising the Composites and X is the average value of C_t.

If X_c and X are equivalent (not just numerically equal), it may be more economical to take a single Composite sample rather than n Grabs, since analytical cost are reduced.

The misconception is expressed in Equation (1), however, is that compositing prior to analysis is equivalent to averaging separate results. In compositing, volumes of sample containing unknown weight solute are combined, with subsequent loss of their individuality. In averaging, concentration are combined without destruction of individual values. While the numerical values resulting from compositing (Xc) and averaging (X) may be the same for any given sample, the results – conceptual and statistical – are not equal.

Thus in taking a Composite, all information about process variability during the sampling period is lost, and uncertaintly in X_c as estimate of process variability is infinite (regardless of analytical accuracy) since the variance of a single value is undefined. In contrast, the variance of X is

$$\text{Var}(X) = [\Sigma C_t^2 - (\Sigma C_t)^2/n]/(n^2 - n) \qquad \text{Eqn. 2}$$

Here, we have information on the range and variability of the process from the individual C_t values, as well as the stability of the daily sample averages from Equation (2). Thus, regardless of the equality of numerical values of X_c and X given by Equation (1), the two are not equivalent estimators of process, since only X tells us something about process variability.

Gain in Compositing Relative to Grab Sampling Decreases as Variance Increases

Prior to the work of Rohde (1976)[3], Janardan and Shaeffer (1977)[4], and Janardan (1978)[5], no comprehensive theoretical study of Grab and Composite effluent sampling was available. These workers considered the statistical properties of a single Grab and of a single Composite which composes of n subsamples.

From the references above, we can conclude that a single Composite can provide as much information as the average n Grabs. However, the actual gain obtained is sensitive to the variability of the compositing process itself. In practise, it is difficult to attain the n-fold gain that is theorectically possible.

We can also conclude that the long-term (monthly) mean of a series of Grab samples will be statistically the same as the mean of a series of Composites, as found in field study by the United States Environmental Protection Agency (1974)[6]

PHYSICAL SIGNIFICANCE DIFFERENCE OF SAMPLE TYPE

In order to examine the physical significance of these differences, operating data and parameters for several facilities were assembled from the files of Illinois Environmental Protection Agency. Prior to a detailed analysis of the sampling properties of these data, the raw data mean, standard deviation and variances, skewness, kurtosis and shape of distribution were determined according to the Pearson System (Hahn 1967)[7]. These statistics were used as population parameter to drive a simulator which produced Grab and Composite samples of the proper distribution.

Table 2: Summary Statistics for Grab and Composite Samples

Sample	Obtained mean	Sample variance	Corrected variance	Su	Relative Information (C/G)	Distribution Shape
A. BOD(mg/l)						Normal
Grab	18.52	70.83	71.74			
Composite	18.19	4.34	6.13	7.18 E-4	11.71	
Monthly mean grab	18.52	3.06	3.59			
Monthly mean composite	18.18	0.16	4.42		0.81	
B. BOD (mg/l)						Lognormal
Grab	2.30	1.29	1.22			
Composite	2.33	7.77 E-2	1.01 E-1	5.19 E-4	12.05	
Monthly mean grab	2.30	5.73 E-2	6.08 E-2			
Monthly mean composite	2.33	3.31 E-3	7.89 E-2		0.77	
C. Industrial BOD (mg/l)						Gamma
Grab	74.35	3315.61	2570.49			
Composite	77.52	167.71	218.76	5.29 E-4	11.75	
Monthly mean grab	74.01	69.33	128.53			
Monthly mean composite	77.52	8.07	170.26		0.77	
D. Lagoon BOD (mg/l)						Gamma
Grab	28.89	822.14	834.5			
Composite	27.36	37.59	52.05	6.68 E-4	16.03	
Monthly mean grab	28.49	28.59	41.73			
Monthly mean composite	27.36	1.51	38.31		1.09	
E. Lagoon Suspended Solid (mg/l)						Gamma
Grab	33.92	627.55	603.23			
Composite	35.62	38.68	62.83	1.08 E-4	9.6	
Montly mean grab	33.92	39.53	30.16			
Monthly mean composite	35.62	3.09	39.89		0.76	
F Industrial zinc. mg/l						Beta
Grab	0.22	1.73 E-2	1.73 E-2			
Composite	0.22	1.73 E-3	1.22 E-2	4.30 E-4	14.15	
Monthly mean grab	0.22	1.73 E-3	8.65 E-2			
Monthly mean composite	0.22	1.73 E-5	9.92 E-2		0.87	

a Fore daily sample means n = 720; for montly means n = 36.

b Sample variance was obtained from the individual orservation Var (X) = [nΣX – {ΣX]/(n – n).

Refer to Table 2. It is interesting to find out that the simulated results strengthens the validity of the theoretical expectations.

1. All Grab Samples returned the name shapes. Similarly, all Composite runs returned about the same means as Grabs Samples.
2. The Composite samples show the expected loss of information relative to Grabs.

Table 2 summarizes the results for several parameters – biochemical oxygen demand (BOD), zinc, suspended solids, etc. The data in Parts C and D of Table 2 are of particular interest, since the former represent data from an industrial facility operating in variance from a BOD standard of 30 mg/l, where as the latter are from a lagoon system meeting a monthly average of 30 mg/l. Thus, in Part C, the mean Grabs is somewhat smaller that of Composites, while in Part D this is reversed. This illustrates that the numerically smaller value can result from either Composites or Grabs, and that there is no basis that the latter must always be larger.

For these data, the numerical differences are small, so the realized means of Composites or Grabs are equally good predictors of the true (population) mean.

Despite small values of the volume variability SW^2 (about 6×10^{-4}), the realized estimates of the variance are inflated for the Composites relative to the usual variance estimates, which are computed from the raw Composite data using Equation (2). This variance inflation reduces the expected 24-fold gain of a single Composite over a single Grab as an estimator of process performance by 50% and 33% respectively.

Real losses, however, occur in forming the monthly means, making Grabs better estimators in the industrial facility, and at least as good in monitoring the longterm performance of the laggon. A similar Grab superiority is found in the remainder of the table.

Comments

These results cleary show that although individual Composites appear to be more stable than individual Grabs, this advantage is lost when averages are taken. Furthermore, while a single Composite may be a better estimator of average daily performance than is a single Grab, the monthly averages are nearly the same and so are the ranges of the means.

In light of this findings, it is reasonable to argue that monitoring by Grab Sampling is an acceptable alternative stategy – or the recommended one – for regulatory and compliance purposes. Furthermore, according to David J. Shaeffer[8], through his study on "Composite Samples Overestimate Waste Loads" stated that regulatory monitoring data obtained from Composite Samples must be view with suspicion.

COSTS

Fulk et al.[3] (1979) present data on the costs for composite sampling, grab sampling, travel, and laboratory analyses. From the data, it is found that the cost of samples collections and analysis of two Grab samples is the same as one Composite. Grab sampling is more economical if we include the cost of purchasing and maintaining an automatic composite sampler for composite sampling. According to Wallin and Schaeffer[9] (1977), cost per station increased 3 to 5 times, without any quality improved if it changed from an ambient water quality monitoring network based on Grab sampling to one based largely on cross-sectional, depth-integrated composites.

In collecting samples for trace analysis, it is found that the cost of analyzing a sample is more than $1500. This is a 24-hour Composite with the attendance of an engineer.

An interesting finding by the Illinois Environmental Protection Agency is in its industrial monitoring, 10 grabs samples from separate locations, one Composite sample from a single facility, can be collected in a man day (Ken Rogers, pers, comm., 1979). In their study, they experience no difference in analytical costs, thus sampling cost becomes the important factor in determining which type of sampling will be done. The Agency concludes that its monitoring requirements are best met by Grab sampling which provides more information and is less expensive.

FIXED MONTHLY AVERAGE VERSUS MOVING AVERAGE

According to the information given, the Environmental Protection Agency requires a fixed monthly average measurement on the discharge limitations whereas the state of Arkansas law requires a moving average measurement. To satisfy both requirements, both ways of measurement are carried out.

A moving average is calculated by computing the average [Equation (1)] of a list of items, where the earliest observation in sequence is dropped from the list as each new item is added.

From our previous discussion above, it is cleary understood that individual samples in a given average are completely distinct from those in subsequent one. The effect of a moving average is similar to that which is obtained if the subsamples forming the composite are not independent but correlated. In these situations, additional terms which account for the lack of independence in the samples of subsamples become important. Each moving average contains very little new information. Many cases are examined and the result indicates that the change is 5% a day for a 30-day moving average with 20 working days per month. Thus, an exceptionally low value will reduced the average each day for 30 days, while a high value could drive the legal limit for the same period.

For example, in simulating data from an extreme value distribution [exp (exp (z)), where z is a normaly distributed variable] with mean of about 15, one "Grab" with a value of 70,000 + was obtained, this yields a Composite Sample over 3000, and a Composite mean of over 300. In physical terms, this "plant" had a momentary upset. Used in moving averages, these chance values would totally misrepresent the plant's long-term performance. Obviously, the slow rate of change, and the opportunity for substantially under or overestimating the long-term performance, making "moving averages" undesirable standards. The use of nonoveralapping calendar periods to specify reporting periods eliminates moving-average problems since successive reported average are now independent of each other.

RECOMMENDATIONS

In reviewing the effluent limitations and monitoring requirements, below are suggestions which hopefully can benefit the department.

1. From the previous discussion regarding "Grab versus Composite", it is recommended to use Grab sampling for the 30-day average measurement in meeting the discharge limitations. When taking averages for 30 days, Grab sampling schedule can be set up at a time which is of more convenience. It also provides more information and reduces cost if cost of analyzing is the same for both Grab and Composite. However, for daily sampling. composite is more preferable since a single Composite provides more and better information.
2. As stated previously, that both measurement (Fixed monthly average and Moving average), are carried out Refering to the discussion on "Fixed monthly average versus Moving average", we can conclude that using Fixed monthly average is better and a more practical representation of a plant's long-term performance. Thus it is more cost and time effective to carry out only the Fixed monthly average measurement.
3. The time and cost that are reduced in carrying out suggestion 1 and 2 should be spent on further study and research regarding sampling methods which can be used to achieve a balance between gains due to sampling and their associated costs.

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