Task 1: Monroe County detailed study of diurnal and seasonal variability of performance of advanced systems

Final Report

for

DEP Agreement G0239
Department of Health Assessment of Water Quality Protection by Advanced Onsite Sewage Treatment and Disposal Systems: Performance, Management, Monitoring Project

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Executive Summary

This study reports on samples from aerated onsite sewage treatment systems in the Florida Keys. Over the course of the study between February 2007 and June 2009 we obtained grab and composite samples from 40 treatment systems in Monroe County at different frequencies. The samples were analyzed for carbonaceous biochemical oxygen demand (cBOD5), total suspended solids (TSS), total nitrogen (TN), total phosphorus (TP), less frequently for total alkalinity, and occasionally for fecal coliforms and by some screening tests. The objectives of this task were to validate a sampling protocol for use in Task 4 of this grant agreement by characterizing the variability of grab samples over the course of a day, to compare grab sample results to time-composite sample results, and to assess longer term or seasonal variability. A secondary objective was to gather data on the influent and effluent concentrations of treatment systems to begin assessing the performance of such treatment systems. Experiences and conclusions from this study can be categorized into two groups: (1) Validation of a sampling protocol and (2) Preliminary assessments on the treatment effectiveness of treatment systems based on the sampling protocol.

Validation of a Sampling Protocol

- Occasional spurious high concentrations were reported, in many cases for one analyte but not for others in the same sample. While this may influence means, median concentration results are less impacted by this and appear generally reliable. Review of sample results on the background of typical results and communication with the laboratory appear to be a way to resolve some of these. The conditions for such interaction were much improved for Task 4.
- Relative to target concentrations, results from analysis of blanks indicated that the approach to sampling using peristaltic pumps was successful. For Task 4, flushing volumes were increased in an attempt to further reduce TN in equipment blanks, which had been detected most frequently.
- TSS appeared to be the most variable parameter in replicate samples from an intermediate container with a median relative standard deviation of 12%, but for cBOD5, TN, and TP this measure was 3% and less. Concerns about samples obtained from intermediate containers are thus less warranted for nutrient analyses than for TSS analyses.
- Detailed characterization of the treatment systems and sampling locations are very important. Particularly in treatment systems with multiple treatment steps, “influent” and “effluent” need further qualification, and may be ambiguous to a sampler encountering the treatment system or to a data analyst. In the present study this required some reclassification during data analysis from “influent” to “intermediate”. For Task 4, data fields for sample location description were more extensive, and a screen for the validity of “influent” samples was developed.
- The operational and maintenance conditions of a treatment system need to be better characterized if one wants to distinguish between technical limitations of treatment and shortcomings due to operator error or lack of maintenance. The assessment protocol for Task 4 included a more detailed assessment, including characterization if the power was on, observation of problems and the dissolved oxygen concentration as a measure of aeration.
- Assessments of variability between grab samples during each event showed that TSS had the highest variability, while TP and total alkalinity had the least, followed by TN. The first grab sample of a sampling event tended to be about 20% higher in TSS and 10% in cBOD5 than subsequent grab samples. This difference did not exist for nutrient species. Given that the emphasis of the project is on nutrient treatment effectiveness, grab sampling appeared appropriate for Task 4.
- There was no overall bias found between the effluent composite and average of grab samples during the same event, even though for any event there could be differences. These differences were the least for total alkalinity, TP, TN and nitrate, with more than 50% of events showing a relative difference of less that 10%.

- The between event variability as expressed by relative standard deviations, is at least twice as large as the within event variability for all parameters, except for TSS.
- Analysis for differences by weekday showed no consistent results. Flow measurements for a subset of systems, but not for all measurements, appeared to decrease from Monday through Thursday. Grab but not composite effluent sample results for TSS and cBOD5 indicated a decrease from Sunday through Thursday, but this was at least partly due to differences in the occurrence of first grab samples on each day.
- Differences in concentrations between the wet/hot and dry/cold seasons were not significant.
- Visual/olfactory assessments appeared to be able to discriminate a threshold-value of TSS (visual) and possibly TSS, ammonia, and TKN (olfactory). During Task 4, the assessment protocol was refined to use more standardized terminology.
- The Hach DR/890 colorimeter showed good agreement with laboratory nitrate and ammonia measurements and less so for ortho-phosphate compared to total phosphorus. In all cases there was an indication of between study-phase variability. To address these issues the recording forms for Task 4 were revised to better capture dilution and conversion factors.
- Taylor kits provided good agreement with laboratory measurements for total alkalinity. Task 4 relied largely on Taylor kits for this measurement, with some additional laboratory measurements for confirmation. Chlorine measurements by Taylor kit could not be independently assessed. They were utilized occasionally during the implementation of Task 4 to assess the effectiveness of chlorination devices.

Preliminary Assessment of Treatment Systems

- Maintenance and operation of treatment systems appear to be important variables that were not systematically characterized in this study. Both the sampling results of processes that require replenishment of materials and anecdotes by the samplers indicated that this is an important, but not quantified, element of performance variability.
- Typical influent concentrations of cBOD5 and TSS were consistent with domestic sewage, and total phosphorus slightly elevated. TN concentrations were about twice as high as concentrations during a study that established the feasibility of current treatment standards and as the septic tank effluent concentrations provided in Florida performance-based treatment system regulations as point of comparison. Overall, 50% of influent composite samples showed a TN concentration between 47 and 94 mg/L, compared to 15 and 43 mg/L for the effluent.
- Overall, the addition of a phosphorus reduction treatment step, usually a media filter, improved treatment for TSS, cBOD5, nitrite-nitrogen, and total phosphorus. Systems without that treatment step had median concentration results similar to an earlier survey of ATUs in the Keys.
- Among the phosphorus treatment approaches sampled there were significant differences in effluent concentrations. While overall, total phosphorus was significantly reduced, the Keys treatment standard was not met in most cases, even for the better performing approaches.
- Within the treatment systems sampled, nitrification appeared to be a limiting step to nitrogen reduction. The sampling events with the most nitrified effluent achieved typically about a 75% reduction compared to their influents, while the events with the least nitrified effluent only achieved a typical TN-reduction of about 28% and did not eliminate cBOD5. Events with intermediate nitrification showed intermediate TN-reduction and some indications of occasional alkalinity limitation.
- 25% of the obtained fecal coliform samples exceeded the secondary grab sample standard of 400 cfu/100 mL. Nearly half of the obtained chlorine measurements did not meet the system-required chlorine residual. Such observations confirm that aerobic treatment alone is not sufficient to meet secondary fecal coliform standards. The chlorine measurements also point to the need for monitoring the effectiveness of chlorination units.

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1 INTRODUCTION

Grab samples are commonly used to assess treatment results of onsite sewage treatment and disposal systems (OSTDS) in the field. Testing of installed systems in the field is usually done by taking a few individual grab samples over a time period that can extend for years. Compilations of field sampling results (e.g. Groves et al., 2005; Roeder and Brookman, 2006) have indicated that the variability of field data is much larger than variability of standardized test center results. The most common testing standards for aerated onsite sewage treatment systems are NSF-40 for cBOD5 and TSS removal and NSF-245 for nitrogen reduction. These utilize frequent 24-hour flow composite samples from treatment systems installed at a test center and loaded for six months under defined conditions (NSF International, 2000; 2007). One question is if the difference between grab samples and composite samples is important relative to other sources of field variability. The Florida Department of Health (FDOH) and Monroe County Health Department (MCHD) initiated a study to measure treatment results of a sample of aerated treatment units. The field work of the study was completed in three phases from early 2007 to mid-2009. The objectives of the part of the study described here were to characterize the variability of grab samples over the course of a day, to compare grab sample results to time-composite sample results, and to assess the variability of sampling results between repeat visits at the same treatment unit. A secondary objective was to gather data on the influent and effluent concentrations of treatment systems. Preliminary results of this study have been presented previously (Roeder and Brookman, 2008, 2009 on data from the first phase of the study; Roeder and Brookman, 2010 on aspects of nitrogen reduction assessment). This report expands on these previous summaries and discusses the complete results of the study.

1.1 Acknowledgements

This study benefited from the cooperation of many people. Particularly appreciated here are the cooperation of the participating owners, the implementation of the study by William Brookman, the sampling efforts by Joe Aretz, Deborah Chesna, Gary Lichtler, Jane Parthemore, Mark Terrill, and Pam Weeks, the assistance with data entry and quality control by Elke Ursin, Susan Polangin, and Debra Roberts, and the direction of the Onsite Sewage Research Review and Advisory Committee. Funding was from the Florida Onsite Sewage Research Fund and Monroe County Health Department as a matching contribution to DEP Agreement G0239: Department of Health Assessment of Water Quality Protection by Advanced Onsite Sewage Treatment and Disposal Systems: Performance, Management, Monitoring Project.

2 METHODOLOGY

2.1 Phases of the Study

The study included three phases. In the first phase, from February 2007 through mid-October 2007, samples were analyzed for cBOD5, TSS, nitrate, nitrite, ammonia, total Kjeldahl nitrogen, and total phosphorus; during the second phase from mid-October 2007 through May 2008, total alkalinity and occasional fecal coliform and enterococci analyses were added. The third phase, January through June 2009, added treatment systems, dropped the microbiological analyses early in the phase, and added more replicates and blanks. Additional details on sampling procedures were documented in a sampling protocol document.

2.2 System Selection

The study included samples from volunteer owners for two permitting classes of aerated onsite treatment units installed in the Florida Keys: onsite wastewater nutrient reduction systems (OWNRS) and interim systems. Interim systems are aerobic treatment units approved in Florida based on certification by NSF. They are intended to serve as interim wastewater treatment option until central sewer is extended to the property. OWNRS are a type of performance-based treatment system; engineer-designed systems that usually include an aerobic treatment unit and a separate media filter to remove phosphorus, and are intended as a long-term wastewater solution. In the following, all systems that only include an aerated treatment step are categorized as (“I”) for interim systems. All systems that included a phosphorus reduction step are categorized as (“P”) for performance-based. Limitations in the access of sampling points resulted in some performance-based treatment systems being sampled before the phosphorus treatment step.

During the first two phases of this project, all systems sampled served single family residences (“R”). These systems had to be serving residences inhabited by permanent residents (homestead exemption) and possess a current maintenance contract, which is required by Florida regulations. System selection was based on volunteers who responded to a request from MCHD to all OWNRS-owners and a random sample of interim system owners whose systems fulfilled these requirements. Some owners lost interest during the study period and declined continuing participation. During the third phase, in 2009, additional single family residences and commercial establishments (“C”) were recruited by MCHD to increase the number of systems and types of facilities on which data were gathered. System characterizations based on permit records and field observations are contained in Appendix A. Monthly water billing records were obtained from the water utility for the year 2007 to estimate water use.

The system selection ensured that systems were maintained according to regulatory requirements. That is, owners had contracts with a maintenance entity to maintain their systems, and an operating permit existed for each system, which is the main mechanism for the health department to track maintenance and operation of a system. Data on the extent and quality of maintenance and inspections actually performed by the maintenance were not directly gathered during this study.

2.3 Sampling

Sampling occurred from February 2007 to June 2009. Effluent sampling points were in most cases pump compartments or modified P-traps. The Florida Department of Health has suggested these as a suitable location for a sampling port (FDOH, 2000). Influent samples were obtained from the most upstream accessible tank or compartment. This included some compartments that subsequent analysis indicated were influenced by the aeration. 24-hour time-composite samples in one-hour intervals were obtained by an auto-sampler for effluents and, where accessible, influents. Grab samples were obtained at the same location using another auto-sampler with peristaltic pump several times during staff working hours separated by at least one hour and typically two hours to represent possible monitoring grab samples.

The following types of blank samples were taken: field blanks were taken with grocery-bought distilled water and with tap water. The tap water samples, while not strictly blanks, were aimed at measuring the background concentrations of the water supply feeding the sewage treatment systems. Field equipment blanks with distilled water were taken during the second half of the third phase, starting in May 2009.

Over the course of the project replicates were taken. During the initial two phases of study, replicates were taken occasionally, about once a week. During the third phase, replicates were taken both of the composite effluent sample and of the first effluent grab sample. The replicates were taken in the following manner: the peristaltic pump collected sufficient samples in an intermediate container for two sets of samples. The intermediate container was inverted several times. Then the sample containers were filled. The two sets of samples were sent to the lab with the same shipment. Replicates amounted to about 10% of samples.

Samples were stored in ice, and shipped by courier service to a NELAP-accredited laboratory. The laboratory returned a copy of the chain of custody with the sampling results to Monroe County Health Department.

2.4 Analysis

The laboratory analyzed the samples for the following parameters: total alkalinity, (EPA310.1) (only in Phase 2 and 3), carbonaceous biochemical oxygen demand after 5 days ($cBOD_5$) (SM5210B), total suspended solids (TSS) (EPA160.2), ammonia nitrogen (EPA350.1), total Kjeldahl nitrogen (TKN) (EPA351.2), nitrate nitrogen and nitrite nitrogen (SM4500 NO3-F, or EPA300.0), total nitrogen (TN) (calculated), and total phosphorus (TP) (EPA365.4). During Phase 2 and the first part of Phase 3, some samples, generally the last grab sample of an event, were analyzed by a local NELAP-accredited lab for fecal coliform and enterococci.

To assess the feasibility of alternative methods of analysis, two approaches to screening tests were evaluated: field testing kits, and visual/olfactory assessment. Field testing kits included a field colorimeter (Hach DR/890) that allowed analyses for nitrate-nitrogen (high range, Test'n'Tube, Chromotrophic Acid Method), ammonia-nitrogen (High Range, Test'n'Tube, Salicylate method) and reactive or ortho-phosphorus (EPA Method 365.2), a Taylor-kit that was used as additional screening test for alkalinity, free chlorine, and pH, and, for a brief period of time, an indicator strip. Visual/olfactory assessments included assessments of clarity and color, and of smell. These analyses were performed less frequently than the laboratory analysis, usually on a replicate of one sample per sampling event.

The laboratory provided lab reports, which were entered manually into a project database (MS-ACCESS) that also was used to gather system information. Except for consistency checks between analytes, the laboratory data were accepted as provided. A person different from who had entered the data performed quality control of the entered data. Further processing and data analyses were performed in MS-ACCESS, MS-EXCEL, and SPSS 17.0.

For the purposes of analysis, the value of the detection limit was generally used in the following for results that were below the detection limit. The differences between duplicate and original results and between time-composite and grab samples were characterized by the relative deviation. The variability of grab samples over the course of a day and of multiple samples over the course of the study was characterized by the relative standard deviation. Results were characterized in two ways: relative difference (2^{nd} sample-1^{st} sample)/(0.5*(2^{nd} sample + 1^{st} sample); and relative standard deviation (standard deviation/average, or for two samples, abs(relative difference/sqrt(2)). The distribution of relative differences allows an assessment if systematically the first sample results in lower or higher measurements than the second sample. The relative standard deviation provides an indication how close together the two values are.

To assess qualitatively if concentrations of different analytes were related, Pearson correlation coefficients between the ranks of analytical results or deviation measures were determined. Such a correlation indicates if relatively large values (high rankings) of one parameter are associated with relatively large values of another parameter. Additionally, graphing and linear correlations in Excel were employed to screen for relationships between parameters. Two aspects of the variability of grab samples were assessed: how variable are grab samples over the course of a day, and how different is the average of grab samples from the time-composite sample obtained over the 24-hour time period?

3 VARIABILITY ASSESSMENTS

3.1 Blanks

Table 1 shows the results of blank analyses, grouped by equipment blanks with DI water, field blanks with DI water, and field blanks with tap water. Equipment blanks showed in all cases below detection limit for TSS and nitrite-nitrogen. In most cases, cBOD5 (92%), nitrate-nitrogen (69%) and total phosphorus (69%), and total alkalinity (62%) were below the detection limits as well. In contrast, most samples contained quantifiable amounts of ammonia (54%), TKN (69%), and total nitrogen (85%). While quantifiable, the concentrations were in most cases much below one mg/L. Of note is that the first three equipment blanks showed the highest concentrations for nitrogen and phosphorus species, with total nitrogen up to about four mg/L and total phosphorus up to 0.8 mg/L. Two explanations appear plausible: the initial equipment blanks were obtained using tap or drinking water instead of distilled water; or the samplers improved the cleaning and sampling procedures after the first three equipment blanks. An argument for the first explanation is that results are fairly consistent with the results for tap water (see below). An argument against the second explanation is that sampling results of the first equipment blanks were only received three weeks after sampling, two weeks after subsequent equipment blanks, therefore no information on high concentration results was available when the improvement would have occurred.

While not all five field blanks using distilled water achieved results below detection limit, the nitrate/nitrite species in addition to cBOD5 and TSS were all below detection limit, all total phosphorus results were below the PQL, but TKN was detected three times, in amounts up to 0.66 mg/L.

Tap water field blanks were mostly free of detectable levels of TSS (58%), nitrite (56%) and total phosphorus (56%). Usually samples were close to about 2 mg/L for cBOD5 and TSS. Median nitrate-nitrogen, TKN, total nitrogen concentrations, and total alkalinity were 2.7, 0.8, 3.5 and 45 mg/L, respectively. One observation that the large number of samples allowed was how frequently unusually large concentration results are returned from the lab. The occurrence of large concentrations of five times the median or more occurred occasionally (>5%) for cBOD5 and nitrite-nitrogen, and rarely (<5%) for TKN, total nitrogen, total phosphorus, and TSS.

The highest rank order Pearson correlation coefficients were 0.66 between nitrate-nitrogen and total nitrogen, 0.52 between TP and TSS, followed by 0.48 between ammonia-nitrogen and TKN and 0.44 between TKN and total nitrogen. The correlations between nitrogen species are plausible, given that total nitrogen is a value calculated from nitrate, nitrite, and TKN, ammonia is part of TKN, and nitrate-nitrogen in the tap water samples is usually present at the highest concentration of the three. The second correlation suggests a joint appearance of some TSS and TP, such as suspended solids containing phosphorus, in tap water. The lack of strong correlations otherwise suggests that occasional or rare spikes in concentration results occur largely independent from each other and represent noise in the obtained data.

Table 1. Statistics of blanks (concentrations in mg/L)

	CBOD5	TSS	AMMONIA-N	NITRATE-N	NITRITE-N	TKN	TOTAL NITROGEN	TOTAL PHOSPHORUS	TOTAL ALKALINITY (CaCO3)
Equipment Blanks									
Count	13	13	13	13	13	13	13	13	13
Max	2.61	2	0.59	3	0.026	2.02	4.19	0.79	47
Fraction with "I"	0.00	0.00	0.15	0.15	0.00	0.08	0.00	0.00	0.00
Fraction with "U"	0.92	1.00	0.31	0.69	1.00	0.23	0.15	0.69	0.62
Median	2.00	2.00	0.10	0.05	0.03	0.19	0.19	0.04	5.00
75-percentile	2.00	2.00	0.22	0.10	0.03	0.55	0.55	0.15	10.00
Distilled Water Field Blanks									
Count	4	5	5	5	5	5	5	5	3
Max	4.6	2	0.05	0.05	0.053	0.66	0.66	0.19	62
Fraction with "I"	0.00	0.00	0.40	0.00	0.00	0.20	0.20	0.40	0.00
Fraction with "U"	0.75	1.00	0.60	1.00	1.00	0.40	0.40	0.60	0.00
Median	2.00	1.00	0.04	0.05	0.04	0.26	0.12	0.04	46.00
Tap Water Blanks									
Count	92	93	93	93	93	93	93	91	61
Max	39	10	1.6	12[(1)]	2.64	8.8	12	5.1	66
Fraction with "I"	0.00	0.00	0.04	0.00	0.17	0.02	0.01	0.18	0.00
Fraction with "U"	0.38	0.58	0.08	0.12	0.56	0.09	0.04	0.56	0.00
Average	4.67	1.70	0.48	2.51	0.14	1.04	3.50	0.19	45.49
25-percentile	2.00	1.00	0.28	2.3	0.03	0.49	3.00	0.035	41.00
Median	2.00	2.00	0.50	2.66	0.05	0.82	3.50	0.08	45.00
75-percentile	2.88	2.00	0.65	2.89	0.09	1.00	3.84	0.14	47.00
95-percentile	20.00	2.80	0.92	3.58	0.57	2.71	4.90	0.33	61.00

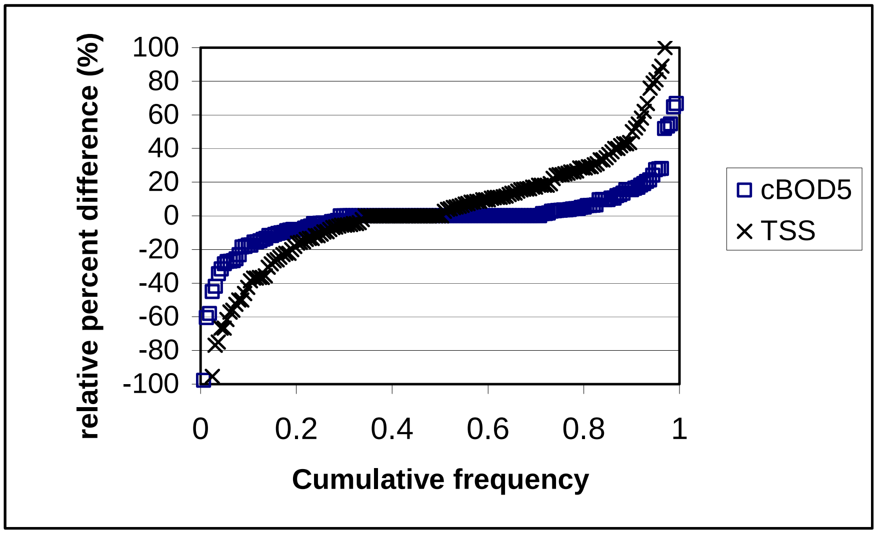
[(1)] This result was associated with a lab report of TN=2.6 mg/L, indicating an inconsistency of reported results

3.2 Replicates

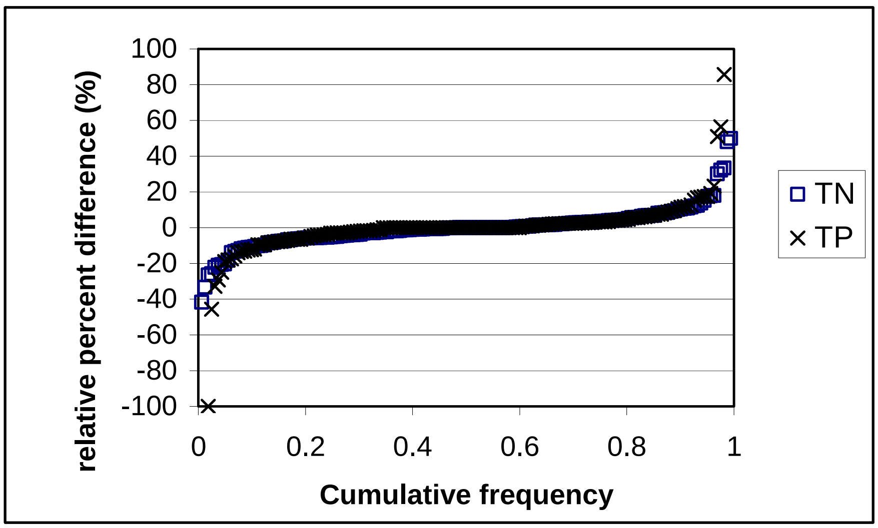
Comparisons of analytical results between samples and their replicates showed that TSS had the highest variability, while nutrient samples had very low variability. Figure 1 shows the cumulative distribution of relative percent differences for cBOD5, TSS, TN, and TP. Table 2 shows characteristics of both the relative percent difference and the relative standard deviation for the analytes. For these analyses, it was assumed that the difference between two samples qualified as “U” was zero, even though the numerical value associated with the “U” may have been different, e.g. due to different dilution factors in the analysis.

The average relative percent difference is close to zero relative to the standard deviation of these differences and the median difference as a typical value is zero for all analytes. Therefore, no bias in measurements is apparent. The relative standard deviations show that the average for nitrite, nitrate, total nitrogen and total alkalinity is less than five percent. For cBOD5 and TP the average relative standard deviation is less than 10%, while for TSS, ammonia and TKN it is between 13 and about 20%. It is interesting to note that the variability of TN appears to be much less than the variability of ammonia and TKN, even though TKN is a component of TN and therefore the two could be expected to vary together. Differences in the distribution of large deviations become apparent when considering the fraction of samples that had a relative standard deviation of 20% or less. This fraction is for total alkalinity: 100%; TN: 96%; nitrite-N: 95%; nitrate-N: 95%; TP: 94%; cBOD5: 92%; TKN: 82%; ammonia-N: 81%; and TSS: 65%.

A Pearson regression analysis of ranks of relative percent differences deviations of each analyte against the ranks of relative percent differences of other analytes and against the date of sampling was performed to assess if there was a pattern in deviations. The only large correlation was between TKN and total nitrogen (0.72) and the second highest was between nitrate-nitrogen and total nitrogen (0.43) (see Table 3). Such a correlation is not unexpected as TKN and nitrate-nitrogen are components of total nitrogen. The lack of strong correlations between any of the other analytes indicates that the relative deviations for analytes are independent of each other. The difference between the observed association between TP and TSS for tap water blanks and the lack of such an association between replicate samples suggests that the fraction of TSS that causes the high variability between replicates does not contain noticeable amounts of TP.



a)



b)

Figure 1. Cumulative distribution of relative percent differences between samples and their replicates for a) cBOD5 and TSS, and b) TN and TP.

Table 2. Statistics of deviations between replicate samples

	CBOD5	TSS	AMMONIA-N	NITRATE-N	NITRITE-N	TKN	TN	TP	TOTAL ALK.
Count	160	162	161	162	162	161	161	161	149
Relative % difference									
Average	-0.7	5.2	-7.1	-0.9	-1.8	-1.8	-0.1	0.0	-0.6
standard deviation	18.6	44.1	43.2	20.1	21.0	37.9	11.2	25.9	6.5
5-percentile	-27.2	-61.3	-100.0	-10.5	-12.5	-40.2	-18.4	-18.2	-9.5
25-percentile	-4.5	-10.5	-6.3	-1.1	0.0	-8.2	-5.0	-3.0	-1.7
Median	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
75-percentile	3.2	24.3	4.3	0.9	0.0	7.7	3.4	3.2	0.0
95-percentile	24.2	78.6	26.1	8.1	7.4	41.0	15.2	17.4	7.2
Relative standard deviation (%)									
Average	6.9	20.1	14.8	4.5	4.3	13.7	4.9	7.3	2.3
standard deviation	11.1	24.1	27.2	13.5	14.3	23.1	6.2	16.8	3.9
5-percentile	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25-percentile	0.0	4.1	1.2	0.0	0.0	1.7	1.0	0.0	0.0
Median	2.5	12.1	3.8	0.8	0.0	5.7	3.0	2.2	0.4
75-percentile	9.4	26.2	10.0	2.9	1.7	14.6	6.0	6.0	2.9
95-percentile	32.1	67.2	83.9	14.9	20.1	69.1	18.2	32.3	12.7

Table 3. Pearson correlation coefficients between ranks of relative percent differences between replicates for analytes, and between the ranks and date

	CBOD5	TSS	AMMONIA-N	NITRATE-N	NITRITE-N	TKN	TN	TP	TOTAL ALK.	Date
CBOD5	1.00	0.03	-0.01	-0.06	0.01	0.10	-0.04	0.09	-0.04	0.09
TSS	0.03	1.00	-0.04	-0.08	0.03	0.13	0.00	-0.11	-0.06	0.15
AMMONIA-N	-0.01	-0.04	1.00	0.09	-0.04	0.03	0.07	0.06	0.01	0.01
NITRATE-N	-0.06	-0.08	0.09	1.00	0.05	0.06	0.43	-0.06	-0.04	0.02
NITRITE-N	0.01	0.03	-0.04	0.05	1.00	0.01	0.09	0.01	-0.07	0.08
TKN	0.10	0.13	0.03	0.06	0.01	1.00	0.72	0.21	0.06	-0.07
TOTAL_NITROGEN	-0.04	0.00	0.07	0.43	0.09	0.72	1.00	0.31	0.10	-0.08
TOTAL_PHOSPHORUS	0.09	-0.11	0.06	-0.06	0.01	0.21	0.31	1.00	-0.03	-0.18
TOTAL ALK.	-0.04	-0.06	0.01	-0.04	-0.07	0.06	0.10	-0.03	1.00	-0.03

3.3 Overall Distribution of Influent and Effluent Concentrations

This section describes the concentration results of the obtained samples. Sample locations were categorized into influent; intermediate, or effluent. The intermediate category was created to address samples that did not represent untreated septic sewage, based on two criteria: system construction did not include a pretreatment tank, or high levels of nitrate were found in a sample otherwise consistent with sewage. The analysis for most samples included cBOD5, TSS, nitrogen species, total phosphorus, and total alkalinity. Analysis of bacteriological samples occurred rarely, only twenty times, and a separate subsection will discuss these results.

3.3.1 Influent Composite Samples

Initial review of the obtained influent samples indicated the need for further screening according to the following criteria: For systems where the construction records indicated that there was no pretreatment tank present, “influent” samples were reclassified as an “intermediate” sample, regardless of concentrations; Samples that showed total nitrogen above 10 mg/L and nitrate and nitrite above 3 mg/L indicated some aerobic treatment influence and were also reclassified as “intermediate” samples, for four systems this resulted in some influent samples being included and some reclassified as intermediate samples. The systems for which these occurred were tanks with an aerobic treatment insert, which may or may not have included a baffle wall to separate a pretreatment compartment from the aeration compartment.

Other noteworthy special considerations were the following: The laboratory had analyzed the first influent sample with a cBOD5 reporting limit of 300 mg/L and the result was less than this value. For this result an exception was made from the convention to use the reporting limit as measured effluent concentration and it was excluded from the statistics. Two samples showed above 5 mg/L nitrate but low TKN and TP, which indicated that the influent was very close to pure tap water, these samples were included as influent sample.

In the following, only time composite influent samples, without considerations of grab samples or replicates, are summarized. There were only three influent grab samples, for two of those influent composite samples were also obtained during the same event.

Summary statistics of influent samples are shown in Table 4. Several observations are of note:
TSS and nitrate have a standard deviation much larger than the mean and a mean that is much larger than the median. In both cases this stems from a few samples with very high concentrations. For TSS, an explanation of this could consist of the sample containing scum or sludge, that is, material that is present but that is usually not sampled and retained by the primary treatment compartment. For nitrate, the two samples with the outlying high concentrations were associated with low TKN and TP concentrations and indicative of a high fraction of tap water.

cBOD5, nitrite, and TP show standard deviations on the same order as the mean and means that are about 50-100% higher than the median. For cBOD5, the two highest concentrations are associated with samples that also have very high TSS concentrations. cBOD5 distribution is also influenced by the laboratory’s use of a detection limit of 60 mg/L for most samples, which more than a quarter of the samples did not exceed. Total phosphorus variability is influenced by a few high values that are associated in three of seven cases with high TSS-values, and two low values that are associated with samples similar to tap water. Nitrite variability was caused largely by variations in the detection limit due to differences in dilution of samples

Ammonia, TKN, total nitrogen, and total alkalinity show standard deviations smaller than the mean and a mean that is within 20% of the median. This indicates a limited effect of particularly high concentrations.

The effect of removing a few samples with very high concentrations can be seen in Table 4b: By excluding three samples with very high solids content (TSS>1000 mg/L), which may represent difficulties in sampling from the clear zone, two samples that appeared to be tap water dominated, and six samples from systems that included recirculation, both averages and standard deviations of TSS, nitrate and cBOD5 were markedly lowered. The highest total phosphorus value of 98 mg/L was not associated with high concentrations of any of the other analytes, and continued to skew the average results. Other nutrient concentrations and total alkalinity did not change much, and the interquartiles and medians remained roughly the same. Based on a median test, there were not significant differences between the influent measurements for residential PBTS, ATUs and commercial PBTS for cBOD5, TSS, TKN, TN, TP, and total alkalinity.

Looking at the six influent samples from systems with recirculation in isolation (Table 4c), their median values are generally similar to the influent concentrations overall. Even the values for TKN and total nitrogen, which appear to be somewhat lower, and cBOD5 and TSS, which appear to be somewhat higher, were not significantly different as determined by the median test.

Table 4. Summary statistics of composite influent samples: a) all influent samples; b) influent samples without high solids concentrations (>1000 mg/L), tap water, and recirculation; c) influent samples with recirculation

a) all influent samples

		CBOD5*	TSS	AMMONIA-N	NITRATE-N	NITRITE-N	TKN	TN	TP	TOTAL ALK.
N	Valid	49	50	50	50	50	50	50	49	39
Mean		146.4898	250.2400	53.54460	.51800	.20340	82.66660	83.00000	16.66449	375.538
Std. Deviation		150.09804	610.57202	40.617567	1.293862	.264183	60.487644	60.093293	19.883239	245.6132
Minimum		60.00	14.00	.200	.047	.025	.830	1.800	.960	59.0
Maximum		780.00	3700.00	220.000	7.000	.980	290.000	290.000	98.000	1400.0
Percentiles	5	60.0000	20.4000	.55550	.04700	.02500	1.57500	7.46200	1.64000	77.000
	25	60.0000	40.0000	31.72250	.04925	.03900	46.51500	46.51500	7.55000	270.000
	50	99.0000	64.0000	49.00000	.19000	.09400	73.44500	73.44500	10.00000	300.000
	75	175.0000	135.0000	63.25000	.47000	.20000	94.25000	94.25000	14.50000	460.000
	95	630.0000	1745.0000	138.00000	3.58850	.94000	233.50000	233.50000	68.00000	1000.000

*one cBOD5 result below a reporting limit of 300 mg/L was excluded from analysis.

b) influent samples without high solids concentrations (>1000 mg/L) tap water, and recirculation

		CBOD5*	TSS	AMMONIA-N	NITRATE-N	NITRITE-N	TKN	TN	TP	TOTAL ALK.
N	Valid	38	39	39	39	39	39	39	38	28
Mean		122.2895	117.4872	55.68385	.25272	.16421	80.80538	80.89410	15.96395	389.286
Std. Deviation		85.96728	156.94650	40.212588	.328943	.235855	54.873544	54.796139	19.669758	246.8913
Minimum		60.00	24.00	.200	.047	.025	1.800	1.800	2.300	120.0
Maximum		520.00	710.00	220.000	1.460	.980	290.000	290.000	98.000	1400.0
Percentiles	5	60.0000	24.0000	7.30000	.04700	.02500	13.00000	14.00000	3.06000	142.500
	25	60.0000	40.0000	34.00000	.04700	.03900	49.20000	49.20000	7.57500	270.000
	50	98.5000	64.0000	50.00000	.09400	.09400	76.00000	76.00000	10.00000	310.000
	75	152.5000	110.0000	69.00000	.25000	.13000	94.00000	94.00000	14.25000	460.000
	95	254.0000	640.0000	120.00000	1.20000	.94000	220.00000	220.00000	77.10000	1116.500

c) influent samples with recirculation

		CBOD5	TSS	AMMONIA-N	NITRATE-N	NITRITE-N	TKN	TN	TP	TOTAL ALK.
N	Valid	6	6	6	6	6	6	6	6	6
Mean		132.6667	116.6667	40.08500	.20067	.21833	62.77667	62.86000	9.83167	291.667
Std. Deviation		51.70171	65.79564	15.220097	.157311	.209473	18.8329	18.959121	2.082791	42.1505
Minimum		60.00	24.00	23.000	.050	.026	40.160	40.160	6.200	240.0
Maximum		180.00	190.00	58.000	.470	.500	86.420	86.920	12.000	360.0
Percentiles	5	60.0000	24.0000	23.00000	.05000	.02600	40.16000	40.16000	6.20000	240.000
	25	81.0000	48.0000	24.50000	.08000	.07400	41.07500	41.07500	8.15000	262.500
	50	144.0000	130.0000	38.75500	.17200	.11200	66.29000	66.29000	10.49500	280.000
	75	180.0000	175.0000	57.25000	.30500	.47750	78.69500	78.82000	11.25000	330.000
	95	180.0000	190.0000	58.00000	.47000	.50000	86.42000	86.92000	12.00000	360.000

3.3.2 Intermediate Composite Samples

The grouping of intermediate samples encompasses samples from a variety of locations before the final treatment step. These samples were taken as far upstream in the treatment process train as the samplers were able to access. This included aeration chambers, clarifiers, or relatively stagnant compartments preceding but in connection with the aeration chamber. One way to assess the importance of sampling influent from a pretreatment tank rather than the upper end of a treatment system is to compare influent results to intermediate samples. Generally, the influent concentrations should be higher than intermediate concentrations. Table 5a summarizes the overall intermediate concentrations. Of the 51 samples, 7 had high solids concentrations (>1000 mg/L) associated with them. While these samples may accurately reflect the solids concentration, for example if the sample was obtained from an aeration chamber, they appear not well comparable to other samples. Table 5b shows the effect of removing these samples from the statistics. cBOD5, TSS, TKN, TN and TP show a marked reduction in means and standard deviations, but a lesser reduction in the median. In both tables, the summary statistics indicate that these samples show the influence of aerobic treatment. Over 75% of all samples or about 90% of the samples without high solids had cBOD5 results at or below the laboratory reporting limit of 60 mg/L. More than 80% of samples show nitrate-N in excess of 3 mg/L and only two had below detectable levels of this analyte. The presence of nitrate as an indicator of aeration points most clearly to the effect of aeration in this sample group. But TKN is still a prominent constituent of total nitrogen, exceeding 10 mg/L in somewhat over half of the samples.

One particular distinction in the data is that a few samples were taken from after the aerobic treatment at the beginning of the phosphorus reduction media tank. These sample locations stemmed from the inaccessibility of the compartments containing the aerobic treatment unit to the samplers at two systems. The differences between samples further up the treatment train, such as in aerobic treatment units (Table 5c), and the samples from the two systems (Table 5d) where the upper end of the P-media was sampled was only significant for TP using the median test. This is counterintuitive, given that the purpose of the samples was to sample the partially treated effluent prior to total phosphorus reduction. A possible reason for the reduction of total phosphorus measured could be that the sample consisted of ponded effluent that was in contact with the phosphorus adsorption media.

Table 5. Statistics of intermediate composite samples, i.e. samples that were taken at the beginning of the treatment train: a) all samples; b) excluding samples with TSS >1000 mg/L; c) samples taken in aerobic treatment unit tanks; d) sample taken at the beginning of a phosphorus reduction filter tank

a) all samples

		CBOD5	TSS	AMMONIA-N	NITRATE-N	NITRITE-N	TKN	TN	TP	TOTAL ALK.
N	Valid	49	49	50	51	51	50	50	50	32
Mean		91.4490	777.8571	10.81980	19.39557	1.66749	64.98920	85.70400	20.49322	128.531
Std. Deviation		140.47243	2287.92957	25.790763	19.884928	4.636731	125.171022	123.528269	38.209321	211.4002
Minimum		2.00	1.20	.039	.094	.025	.070	3.280	.035	5.0
Maximum		940.00	14000.00	150.000	103.200	27.000	763.450	763.450	240.000	990.0
Percentiles	5	2.0000	2.0000	.04615	1.57800	.02500	.46000	10.08500	.08330	5.000
	25	60.0000	9.8000	.40500	4.70000	.13000	3.98500	23.83000	5.40000	14.000
	50	60.0000	46.0000	1.95000	15.32000	.33000	18.54000	42.01500	8.50000	57.500
	75	60.0000	370.0000	6.45000	29.00000	1.31000	85.44000	106.46000	23.00000	155.000
	95	335.0000	5800.0000	72.25000	65.32200	11.30000	298.83900	306.63650	88.75000	827.500

b) excluding samples with TSS >1000 mg/L

		CBOD5	TSS	AMMONIA-N	NITRATE-N	NITRITE-N	TKN	TN	TP	TOTAL ALK.
N	Valid	42	42	43	44	44	43	43	43	26
Mean		54.5476	128.9286	8.08088	21.02305	1.78618	33.15651	55.80000	10.45723	70.308
Std. Deviation		17.74920	207.28909	17.027974	20.545683	4.974905	44.784861	52.581712	10.154816	80.7449
Minimum		2.00	1.20	.039	.094	.025	.070	3.280	.035	5.0
Maximum		72.00	870.00	75.000	103.200	27.000	190.000	223.180	43.000	330.0
Percentiles	5	2.0000	2.0000	.05520	2.20250	.02500	.39000	7.04000	.08120	5.000
	25	60.0000	7.4500	.41000	6.77000	.12250	2.80000	23.00000	5.00000	10.500
	50	60.0000	30.5000	1.90000	16.50000	.26500	11.74000	39.00000	7.70000	43.000
	75	60.0000	157.5000	3.90000	29.19500	1.21000	46.29000	62.00000	14.00000	94.500
	95	68.2500	652.5000	65.40000	74.99250	16.37500	128.00000	199.44200	37.20000	298.500

c) samples taken in aerobic treatment unit tanks

		CBOD5	TSS	AMMONIA-N	NITRATE-N	NITRITE-N	TKN	TN	TP	TOTAL ALK.
N	Valid	40	40	41	42	42	41	41	41	30
Mean		102.0750	947.9700	12.89637	19.45652	1.30769	68.02659	88.73659	24.64512	132.133
Std. Deviation		153.35285	2506.16595	28.106202	21.312062	3.171708	134.313092	133.244583	41.098396	217.3971
Minimum		2.00	2.00	.039	.094	.025	.070	3.280	.290	5.0
Maximum		940.00	14000.00	150.000	103.200	20.000	763.450	763.450	240.000	990.0
Percentiles	5	8.7000	2.1000	.05880	.91200	.02500	.74100	6.27000	2.12000	5.000
	25	60.0000	24.0000	.53000	4.34000	.13000	4.56500	23.66000	6.55000	18.000
	50	60.0000	93.0000	2.30000	14.17000	.33000	19.67000	41.03000	11.73000	57.500
	75	63.0000	602.5000	9.40000	29.44500	1.36750	78.40000	92.91500	26.61500	160.000
	95	384.5000	6520.0000	74.50000	77.75550	5.14450	368.32800	370.34300	122.50000	852.500

d) sample taken at the beginning of a phosphorus reduction filter tank

		CBOD5	TSS	AMMONIA-N	NITRATE-N	NITRITE-N	TKN	TN	TP	TOTAL ALK.
N	Valid	9	9	9	9	9	9	9	9	2
Mean		44.2222	21.8000	1.35989	19.11111	3.34656	51.15222	71.88889	1.57900	74.500
Std. Deviation		25.98931	27.07231	1.247920	11.975333	8.886115	74.178640	66.560958	2.450320	92.6310
Minimum		2.00	1.20	.039	2.300	.025	.350	14.000	.035	9.0
Maximum		64.00	76.00	3.900	40.000	27.000	190.000	200.000	6.400	140.0
Percentiles	5	2.0000	1.2000	.03900	2.30000	.02500	.35000	14.00000	.03500	9.000
	25	16.0000	4.5000	.26500	7.85000	.03200	.61000	20.50000	.08300	9.000
	50	60.0000	7.0000	1.10000	22.00000	.20000	4.00000	43.00000	.17000	74.500
	75	60.0000	42.5000	2.05000	26.50000	1.17500	125.00000	132.50000	3.55000	140.000
	95	64.0000	76.0000	3.90000	40.00000	27.00000	190.00000	200.00000	6.40000	140.000

3.3.3 Effluent Composite Samples

Effluent concentrations are present from two sources: grab samples and composite samples. Time composite samples are more comparable to the influent and intermediate composite samples obtained, and so these are discussed here first and Table 6 shows their summary statistics. Grab samples will be discussed in the following section.

Among the effluent composite samples there were no samples with TSS-concentrations >1000 mg/L. While cBOD5, nitrite, TN, TP, and alkalinity have comparatively narrow distributions (75th percentile is not more than five times the 25-percentile), TSS and the other nitrogen species vary much more. 75% of cBOD5 results and about 60% of TSS-concentrations meet a concentration limit of 10 mg/L.

One key distinction in the group of effluent samples is whether or not there was a design phosphorus reduction step present before the location of the effluent sample. This, rather than the design classification, is used here as an initial distinction. Table 6b summarizes the results of composite samples following a phosphorus reduction step, and Table 6c shows the effluent composite results following only the aerobic treatment step. The median test function of Statistical Package for the Social Sciences (SPSS) served to assess the significance of differences between the two sets of effluent results (Table 7). For cBOD5 and TSS, the additional treatment step resulted in significantly lower concentrations. Because the populations of manufacturers of aerobic treatment systems differ between the two groups, it is not conclusive but likely that the additional residence time and treatment provided by the phosphorus reduction step is at least partly a reason for the better effluent results.

For ammonia, nitrate, TKN and TN, no significant differences between the two groups of effluent samples could be detected. Nitrite-N is somewhat lower (P=0.07) following a phosphorus reduction step. Overall, total nitrogen in the effluent varies widely but is typically between 20 and 40 mg/L (interquartile 15-43 mg/L), which is considerably lower than the influent concentrations (interquartile 47-94 mg/L)and intermediate sample results (interquartile 24-106 mg/L). While the lowering of concentrations shows that the treatment is effective, an effluent concentration standard of 10 mg/L that applies to systems with phosphorus reduction is only met slightly more than 10% of the time by those samples. Additional analysis is needed to assess reasons for this deviation.

Total phosphorus showed a significant effect of a phosphorus reduction treatment step. Because the differences in aerobic treatment units are not expected to influent P-treatment, this difference can likely be attributed to the P-treatment. Still, the effluent concentration standard of 1 mg/L is met by less than 10% of samples. Additional analysis is needed to assess reasons for this deviation.

Total alkalinity does show no significant differences as measured by the median test, even though there appears to be a tendency toward a slight increase with the phosphorus reduction step.

Table 6. Statistics of effluent composite sample concentrations: a) all samples; b) effluent samples following phosphorus reduction treatment step; c) effluent samples not following phosphorus reduction treatment step

a) all samples

		CBOD5	TSS	AMMONIA-N	NITRATE-N	NITRITE-N	TKN	TN	TP	TOTAL ALK.
N	Valid	111	111	110	111	111	110	110	109	76
Mean		8.1612	32.2955	10.73959	14.94288	.85684	20.94282	36.51609	6.42327	125.000
Std. Deviation		11.89332	75.37617	17.030477	17.654600	2.207711	30.023846	34.432948	5.010278	105.2158
Minimum		2.00	1.00	.039	.047	.025	.070	3.790	.036	5.0
Maximum		95.10	510.00	70.960	116.720	19.000	185.380	185.660	34.000	540.0
Percentiles	5	2.0000	1.0000	.03900	.05000	.02500	.37750	6.48250	.38500	5.000
	25	2.0000	2.4000	.36500	2.10000	.12000	2.44750	15.49500	3.45000	49.000
	50	3.1000	9.0000	2.65000	11.00000	.34000	9.71000	23.51500	5.70000	100.000
	75	9.2000	23.0000	11.00000	20.00000	.58000	26.20250	42.75250	7.75000	185.250
	95	30.8000	168.0000	59.00000	41.74200	3.27600	86.28700	117.12450	16.00000	331.500

b) effluent samples following phosphorus reduction treatment step

		CBOD5	TSS	AMMONIA-N	NITRATE-N	NITRITE-N	TKN	TN	TP	TOTAL ALK.
N	Valid	82	82	82	82	82	82	82	81	58
Mean		7.5182	30.3902	11.55263	15.11946	.74417	21.46012	36.95878	5.90136	133.586
Std. Deviation		9.06605	83.43561	16.762218	19.088660	2.266753	30.504994	36.846665	4.539155	100.1320
Minimum		2.00	1.00	.039	.047	.025	.070	3.790	.080	5.0
Maximum		34.00	510.00	64.000	116.720	19.000	185.380	185.660	27.000	540.0
Percentiles	5	2.0000	1.0000	.03900	.05000	.02500	.33200	6.31500	.55100	9.750
	25	2.0000	2.0000	.23750	1.70000	.09300	2.06750	15.49500	3.15000	66.500
	50	2.5500	7.0000	3.00000	11.00000	.21500	10.09000	22.25500	5.20000	115.000
	75	9.1250	16.2500	15.50000	20.00000	.55500	29.77750	40.90750	7.60500	190.000
	95	30.0000	178.0000	57.35000	44.09450	2.35800	83.05000	134.13000	15.60000	330.500

c) effluent samples not following phosphorus reduction treatment step

		CBOD5	TSS	AMMONIA-N	NITRATE-N	NITRITE-N	TKN	TN	TP	TOTAL ALK.
N	Valid	29	29	28	29	29	28	28	28	18
Mean		9.9793	37.6828	8.35854	14.44359	1.17541	19.42786	35.21964	7.93307	97.333
Std. Deviation		17.70007	46.27225	17.890998	13.039805	2.035076	29.056063	26.665620	6.015130	118.9953
Minimum		2.00	1.00	.039	.050	.025	.350	10.000	.036	5.0
Maximum		95.10	180.00	70.960	42.000	9.590	120.000	130.000	34.000	415.0
Percentiles	5	2.0000	1.5000	.07095	.07200	.02550	.45350	10.90000	.09630	5.000
	25	2.7500	7.4000	.41250	3.25000	.19000	3.67000	16.00000	5.40000	13.750
	50	4.7000	18.0000	1.85000	9.39000	.47000	8.61500	26.34000	7.10000	45.000
	75	10.5000	46.5000	7.00000	23.66500	.87500	17.57000	43.68750	9.19250	155.000
	95	65.0500	170.0000	67.82800	40.17000	7.54000	105.53700	111.03700	25.90000	415.000

Table 7. Median test results for differences between effluent composite samples taken after phosphorus reduction and effluent samples not taken after phosphorus reduction treatment steps.

Test Statistics[a]

		CBOD5	TSS	AMMONIA-N	NITRATE-N	NITRITE-N	TKN	TN	TP	TOTAL ALK.
N		111	111	110	111	111	110	110	109	76
Median		3.1000	9.0000	2.65000	11.00000	.34000	9.71000	23.51500	5.70000	100.000
Chi-Square		5.920	8.875	.767	.002	4.004	.192	1.725	6.133	3.171
Df		1	1	1	1	1	1	1	1	1
Asymp. Sig.		.015	.003	.381	.963	.045	.662	.189	.013	.075
Yates' Continuity Correction	Chi-Square	4.915	7.634	.431	.029	3.186	.048	1.198	5.094	2.280
	df	1	1	1	1	1	1	1	1	1
	Asymp. Sig.	.027	.006	.511	.865	.074	.827	.274	.024	.131

a. Grouping Variable: P_reduction_sampled

3.3.4 Effluent Grab Samples

This section discusses effluent grab sample results. As was the case for composite samples, the samples are distinguished by whether or not a phosphorus reduction step was present upstream of the sampling location. Table 8 summarizes the results. A median test shows significant differences between systems with and without phosphorus reduction step not only for total phosphorus but also for cBOD5, TSS, ammonia, nitrite, total nitrogen, and total alkalinity. .

The number of analytes for which significant differences occur is much larger for grab samples than composite samples, for which only cBOD5, TSS, and total phosphorus were significantly different. One reason for this could be that the higher number of samples allows detection of smaller differences as significant. Another reason could be that grab and composite samples are different. A median test for samples after a phosphorus reduction step showed that only cBOD5 was different between grab and composite samples, with the composite samples tending higher. The same test for effluent samples without a phosphorus reduction step showed no significant differences between grab and composite samples. This indicates that grab and composite samples were overall not different from each other as measured by the median test. The detection of significant differences for more analytes in grab effluent sample concentrations is then likely due to the larger sample size of grab samples. But, the assumption of the statistical test that samples are independent of each other is not strictly met because grab samples were taken in short intervals over the course of a single day and grab samples vary much less over the course of a day than between sampling events. For these reasons the finding of additional significant effects of the phosphorus reduction treatment step appears to be an artifact.

A comparison of these results of the grab sampling with the distribution of grab sample results from a broader survey in the Florida Keys is of interest: The median concentration results for about 900 samples in that study were 5 mg/L, 32 mg/L, 26 mg/L, and 7.8 mg/L respectively, for cBOD5, TSS, TN, and TP. Most of those samples were from aerobic treatment units without phosphorus reduction step, and may therefore be comparable to the results in Table 8c. The medians reported there are 4.2 mg/L, 20 mg/L, 27 mg/L, and 7.1 mg/L, respectively. This suggests that the typical effluent for ATUs has remained very similar, which is supported by the observations that median concentrations from intermediate composite results (Table 5a) are similar in magnitude to the treatment unit samples reported by Roeder and Brookman (2006). In contrast to these areas of agreements, this study found far fewer very high concentration results, so that the relative standard deviations and the 95-percentiles of this study are generally lower than the 90-percentile reported by Roeder and Brookman (2006). The lack of influent concentration measurements in the previous study makes it difficult to assess what combination of reduced water use, differences in employed technology, and differences in operation and maintenance in the two sample populations combined to yield these results.

Table 8. Statistics of effluent grab sample concentrations: a) all samples; b) effluent samples following phosphorus reduction treatment step; c) effluent samples not following phosphorus reduction treatment step

a) all samples

		CBOD5	TSS	AMMONIA-N	NITRATE-N	NITRITE-N	TKN	TN	TP	TOTAL ALK.
N	Valid	445	448	449	449	449	449	449	445	308
Mean		9.1968	25.9670	11.38101	14.83197	.70231	20.79302	36.09156	6.23426	125.484
Std. Deviation		17.08720	67.56809	17.523687	17.340984	1.486672	30.971103	34.401153	4.306848	108.1260
Minimum		2.00	1.00	.010	.047	.025	.038	2.700	.035	5.0
Maximum		170.00	910.00	90.000	121.030	11.550	198.920	199.050	30.000	590.0
Percentiles	5	2.0000	1.0000	.03900	.05000	.02500	.21500	6.50000	.25900	9.000
	25	2.0000	2.0000	.32500	2.44000	.12000	1.97500	15.00000	3.40000	52.500
	50	2.1000	6.3000	3.46000	11.30000	.24000	8.92000	24.00000	6.00000	98.500
	75	9.0000	22.0000	12.00000	21.00000	.58500	25.38000	44.08000	8.36000	180.000
	95	31.0000	110.0000	55.00000	42.93500	2.95000	78.18500	110.84500	13.00000	325.500

b) effluent samples following phosphorus reduction treatment step

		CBOD5	TSS	AMMONIA-N	NITRATE-N	NITRITE-N	TKN	TN	TP	TOTAL ALK.
N	Valid	328	331	332	332	332	332	332	328	236
Mean		7.3490	13.9807	12.36192	14.74019	.52129	21.21756	36.21759	5.65994	135.542
Std. Deviation		9.38602	28.73034	17.293897	18.587893	1.084422	31.877712	36.992441	4.050515	105.2342
Minimum		2.00	1.00	.010	.047	.025	.038	2.700	.080	5.0
Maximum		60.00	300.00	69.000	121.030	9.540	198.920	199.050	30.000	590.0
Percentiles	5	2.0000	1.0000	.03900	.04700	.02500	.07000	5.64300	.31150	11.700
	25	2.0000	2.0000	.21500	1.40000	.09000	1.54000	13.63750	2.70000	66.250
	50	2.0000	4.6000	4.00000	11.41000	.20000	9.05500	23.00000	4.90000	110.000
	75	8.3750	13.0000	17.50000	20.00000	.51000	26.99500	43.96000	7.80000	190.000
	95	28.5500	50.8000	52.05000	43.41900	1.60000	75.14200	122.56100	12.00000	321.500

c) effluent samples not following phosphorus reduction treatment step

		CBOD5	TSS	AMMONIA-N	NITRATE-N	NITRITE-N	TKN	TN	TP	TOTAL ALK.
N	Valid	117	117	117	117	117	117	117	117	72
Mean		14.3768	59.8769	8.59757	15.09241	1.21597	19.58832	35.73393	7.84432	92.514
Std. Deviation		28.85286	116.93906	17.944036	13.242922	2.195551	28.335685	25.798742	4.604402	111.6220
Minimum		2.00	1.00	.039	.050	.025	.074	5.800	.035	5.0
Maximum		170.00	910.00	90.000	44.000	11.550	143.260	143.260	27.000	406.0
Percentiles	5	2.0000	1.0000	.06060	.09400	.02600	.80300	7.33000	.03500	5.000
	25	2.0000	6.0000	.60500	3.51500	.18000	3.25000	18.53500	5.40000	11.000
	50	4.2000	20.0000	1.90000	11.23000	.47000	7.69000	27.00000	7.10000	32.000
	75	9.4000	50.0000	7.05000	24.89500	1.20000	17.63000	45.00000	9.60000	140.000
	95	99.5700	269.0000	69.37900	39.22900	5.28700	90.38200	90.38200	16.20000	397.000

Table 9. Median test results of differences between effluent grab samples with and without phosphorus reduction step.

		CBOD5	TSS	AMMONIA-N	NITRATE-N	NITRITE-N	TKN	TN	TP	TOTAL ALK.
N		445	448	449	449	449	449	449	445	308
Median		2.1000	6.3000	3.46000	11.30000	.24000	8.92000	24.00000	6.00000	98.500
Chi-Square		22.235	37.585	4.725	.087	15.678	.525	5.750	16.101	16.314
Df		1	1	1	1	1	1	1	1	1
Asymp. Sig.		.000	.000	.030	.768	.000	.469	.016	.000	.000
Yates' Continuity Correction	Chi-Square	21.231	36.278	4.269	.035	14.838	.381	5.246	15.249	15.244
	df	1	1	1	1	1	1	1	1	1
	Asymp. Sig.	.000	.000	.039	.852	.000	.537	.022	.000	.000

3.3.5 Bacteriological Samples

Late in Phase 2 and early in Phase 3, samplers obtained some effluent samples that they delivered to a local laboratory for bacteriological analysis. The small number of samples, together with the occurrences of some "too numerous to count" results and varying reporting limits, limit the precision of the results. Table 10 provides the summary of numerical values of effluent samples. Five of the twenty fecal coliform samples exceeded both the 200 cfu/100 mL annual average standard and the 400 cfu/100 mL grab sample standard for secondary treatment standards. Two of these high samples stemmed from systems discharging to drainfields, for which disinfection requirements do not apply. One of these systems also did not include a phosphorus reduction treatment step. Two of the 13 enterococci samples resulted in concentrations of 80 cfu/100 mL or larger.

Table 10. Bacteriological sample results

		Fecal_coliform(cfu/100mL)	Enterococcus(cfu/100mL)
N	Valid	20	13
Mean		326.45	104.62
Std. Deviation		636.769	329.821
Minimum		2	2
Maximum		2250	1200
Percentiles	5	2.00	2.00
	25	2.00	2.00
	50	20.00	4.00
	75	394.00	20.00
	95	2221.00	1200.00

3.4 Water Use

During most sampling events, samplers obtained an event 24-hour water use measurement based on water meter recordings. For residences overall, this resulted in 73 daily water use measurements with a mean of 190 gpd, standard deviation of 170 gpd, a median of 150 gpd, and a interquartile range from 70 to 235 gpd. As mentioned before, for the very first sampling event, samplers added water to the treatment system to trigger a dosing event. After eliminating this data point, mean, standard deviation and median remained approximately the same, and the interquartile range changed from 65 to 230 gpd. Figure 2 shows the distribution of (daily) event water uses. The distribution appears bimodal: one mode (0-67 gpd) is located at very low water uses, which may represent that no users were present on that day. The second mode (133-200 gpd) includes the median and mean water use and in this way represents a "typical water use". A determination of the Spearman correlation between water use and influent concentration (29 data pairs) did not detect any significant correlation.

The individual measurements of water use were averaged by system or house. This resulted in a mean water use of the 32 houses of 190 gpd with a standard deviation of 120 gpd, a median of 170 gpd, and an interquartile range from 110 to 240 gpd. The upward shift of the lower quartile and the reduction in standard deviations suggests that some houses that had no water use on one sampling event day, had high to very high water use on another sampling event day.

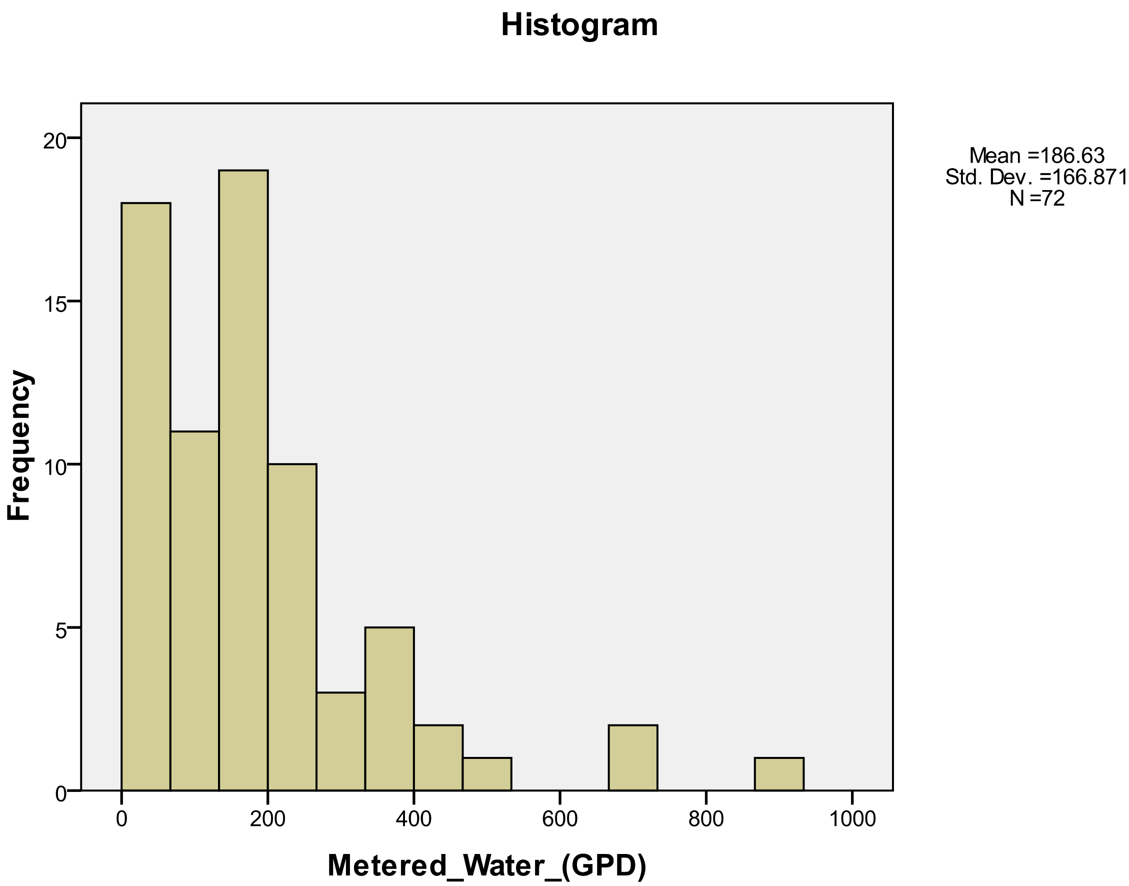


Figure 2. Histogram for residential event water use (except first sampling event)

3.5 Variations Between Grab Samples During a Composite Sampling Period

3.5.1 Variability Between Pairs of Grab Samples

One way to assess how representative one grab sample is for a sampling period is to compare it to other grab samples taken during the same sample sampling period. For the sampling periods of this study, this resulted in nearly 700 pairs. For the purposes of this analysis, a difference of zero was assigned to two samples that were below the laboratory detection limit (qualified as “U”), even though the reported detection limit may have varied. Table 11 summarizes the relative standard deviations observed. For cBOD5 and nitrite a substantial fraction of sample pairs did not show a difference, as many samples had concentrations below the detection limit. TSS showed the highest variability with an average RSTD of 35%. The various nitrogen species varied on average more than total nitrogen. TP and total alkalinity tended to vary the least.

Table 11. Relative standard deviations for pairs of grab samples taken during the same event.

relative standard deviation	cBOD5	TSS	Ammonia -N	TKN	Nitrate-N	Nitrite-N	TN	TP	Total Alkalinity
number of pairs	688	692	694	694	694	694	694	688	476
fraction with rstdev=0	0.47	0.18	0.19	0.10	0.23	0.49	0.14	0.17	0.30
5-percentile	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25-percentile	0.000	0.070	0.018	0.036	0.002	0.000	0.013	0.013	0.000
50-percentile	0.034	0.286	0.085	0.109	0.034	0.015	0.046	0.045	0.030
75-percentile	0.227	0.535	0.303	0.262	0.118	0.241	0.103	0.123	0.073
95-percentile	0.794	0.979	0.936	0.850	0.718	1.020	0.383	0.330	0.356
Average	0.166	0.351	0.230	0.206	0.131	0.199	0.100	0.098	0.070
Stdev	0.261	0.322	0.320	0.267	0.267	0.324	0.176	0.167	0.122

3.5.2 Influence of Time Lag

Several grab samples collected over time allowed an assessment of how quickly concentrations change over the course of a day. This analysis compared the time differences between the times when two grab samples were taken to the relative standard deviations of their concentration results.

Table 12 summarizes the relative differences between a sample and subsequent samples. Initial inspection suggested that the differences between the first grab sample and all subsequent samples might be different from the relationships between all subsequent samples. An explanation for such behavior could be, for example, that the first sample is more influenced by the deployment of the sampling apparatus. Therefore, Table 12 distinguishes three groupings: all data, comparisons to the first grab sample of all other grab samples, and comparisons between grab samples other than the first. For cBOD5 and TSS there is a distinct difference between the two latter sub-groupings, that is highly significant as measured by a two-tailed t-test with unequal variances; for total alkalinity the difference is less significant with a significance level of 0.057. For TSS, the first grab sample appears to show noticeably higher concentrations (relative differences median 15%, average 24%) than subsequent samples. For subsequent samples there is still some average decrease in concentrations but to a lesser extent (average 7%, median 0%). For cBOD5, the average relative difference between the first and subsequent samples is about 10%, but the median is 0 %, and for subsequent sample there appears to be no strong downward pattern. For all other analytes, there did not appear to be a significant difference between the differences to the first sample and differences between all subsequent samples.

Table 13 shows the median of the resulting relative standard deviations grouped by time difference between sampling events. Results are based on at least 30 samples in each group. In contrast to the plausible expectation that later samples should generally be more different from an initial sample compared to earlier samples, there is no consistent pattern showing such behavior. Given the anomaly of the first grab sample results for TSS and cBOD5 discussed before, the same sub-grouping was used in this analysis. TSS, which in all groupings showed the highest variability, showed a median relative standard deviation between 30 and 40% compared to the first grab sample, but only 20-30% for differences between subsequent grab samples. For nitrate and cBOD5 the typical variability is diminished to about half, from levels less than 10% to levels below 5%. Total alkalinity, ammonia, nitrate-, and nitrite nitrogen do appear to have a tendency towards increased variability with time in both sub-groupings, but the overall effect is small, with increases in relative nitrate and total alkalinity standard deviations of less than 5% in all cases, and increases of ammonia and nitrite relative standard deviations of 11% or less.

Table 12. Median relative difference between two grab samples, the first grab sample and subsequent grab samples, and relative differences between grab samples other than the first grab sample.

Relative differences		cBOD5	TSS	Ammonia-N	TKN	Nitrate-N	Nitrite-N	TN	TP	Total Alk.
overall	Median	0.000	-0.064	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Average	-0.044	-0.153	-0.022	0.009	-0.006	0.041	0.010	-0.009	-0.021
first sample	Median	0.000	-0.154	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Average	-0.099	-0.240	-0.028	-0.005	-0.003	0.040	0.011	-0.017	-0.039
all other samples	Median	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Average	0.009	-0.070	-0.016	0.023	-0.010	0.042	0.009	-0.002	-0.004
Significance level of two-tailed t-test w/ unequal variance between first and all other samples		0.001	0.001	0.786	0.437	0.832	0.961	0.927	0.473	0.057

Table 13. Median relative standard deviation between different grab samples.

	Time Difference (d)		Parameter								
	between	and	cBOD5	TSS	TKN	Ammonia -N	Nitrate-N	Nitrite -N	TN	TP	Total Alk.
first grab sample	0.04	0.10	0.06	0.30	0.10	0.08	0.04	0.02	0.03	0.03	0.02
	0.10	0.21	0.05	0.40	0.12	0.08	0.03	0.06	0.05	0.05	0.05
	0.22	0.39	0.07	0.37	0.11	0.07	0.04	0.05	0.06	0.09	0.04
	0.71	1.17	0.06	0.34	0.15	0.15	0.06	0.13	0.05	0.05	0.05
all other grab samples	0.04	0.10	0.03	0.22	0.09	0.06	0.02	0.00	0.04	0.04	0.02
	0.10	0.21	0.03	0.30	0.12	0.09	0.02	0.00	0.05	0.03	0.02
	0.22	0.39	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d
	0.71	1.17	0.00	0.22	0.12	0.11	0.04	0.06	0.03	0.05	0.03

3.6 Variability of Grab Samples During Diurnal Sampling

Relative standard deviations for the grab samples for each sampling period were determined. Table 14 summarizes the distribution of grab sample relative standard deviations. As could be expected, there is considerable variability in this measure between no changes at all during the course of a day, and relative standard deviations that exceed 100%. Generally, total alkalinity, TN, and TP show the lowest variability, with 95% of sampling events resulting in a relative standard deviation of 40% or less. The individual nitrogen species have usually higher variability than the total nitrogen measurements. Nitrate, cBOD5, TKN, ammonia and nitrite show increasing variability. The highest variability by far is shown by TSS, for which only 25% or sampling events show a relative standard deviation of 40% or less.

A Pearson correlation of the ranks of relative standard deviations indicated very limited associations. The highest correlation was 0.56 between nitrate and nitrite nitrogen variability, and 0.53 between TSS and total alkalinity variability. The next highest correlations were between TKN and total nitrogen (0.4), nitrate and total nitrogen (0.39), total nitrogen and total phosphorus (0.38), and ammonia and TKN (0.37). The correlation of variability between nitrogen species is plausible. More interesting is the result that some association exists between analytes that are not as obviously related, such as TSS and total alkalinity, and TN and TP.

Linear correlations between the mean concentration during a day and the relative standard deviations resulted in correlation coefficients of less than 0.1 for all analytes except for TSS, for which the correlation coefficient was only 0.17. This indicates that the normalization of standard deviations to relative standard deviations was successful in removing the influence of the absolute magnitude of concentrations from the variability assessment.

This and the previous section developed two measures of the variability of grab samples: the distribution of relative standard deviations between any two individual grab samples taken during an event (previous section), and the relative standard deviations of all grab samples taken during an event. A comparison between the two indicates that the relative standard deviations of all grab samples taken during a sampling event tend to be larger, in particular for nitrite, TSS, and cBOD5. The exception is nitrate. While no further analysis of this was attempted, one possible reason for this could be that the analysis of this section utilized the numerical value for any sample, while the analysis for inter-grab sample variability assigned a difference of zero to two grab samples that were both below the detection limit, even though the detection limit may have been different due to different dilutions.

Table 14. Distribution of relative standard deviations for grab samples collected over a day

	CBOD5	TSS	AMMONIA-N	NITRATE-N	NITRITE-N	TKN	TN	TP	TOTAL ALK.
number of events	110	111	111	111	111	111	111	110	76
fraction with rstdev=0	0.35	0.07	0.11	0.12	0.39	0.04	0.05	0.05	0.17
5-percentile	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00
25-percentile	0.00	0.24	0.04	0.02	0.00	0.08	0.03	0.03	0.02
50-percentile	0.13	0.40	0.14	0.06	0.14	0.15	0.06	0.08	0.05
75-percentile	0.36	0.66	0.42	0.19	0.44	0.36	0.13	0.14	0.10
95-percentile	0.95	1.03	0.95	0.71	1.22	0.68	0.40	0.36	0.38
Average	0.24	0.47	0.28	0.18	0.29	0.25	0.12	0.13	0.09
Stdev	0.31	0.32	0.35	0.30	0.40	0.24	0.15	0.19	0.12

3.7 Differences Between Grab and Composite Samples

Table 15 shows the relative differences between the average of grab samples and the time composite samples taken during the same sampling event. Negative numbers indicate that the composite sample had higher concentrations than the average of the grab samples. The median and average of the relative differences are very close to zero, indicating that there is no systematic bias between the two measures of daily effluent concentrations.

The standard deviation of the relative differences provides a measure of how frequently the differences are large. The most varying analyte is TSS, while total alkalinity, TP, TN and nitrate are the least variable. This order of variability is the same as the one for average relative standard deviations of grab samples over the course of a day (see Table 14).

A different approach to comparing grab samples and composite samples consists in performing a median test between all composite effluent samples and all individual grab samples. Table 16 shows the results of this test. This analysis indicates that cBOD5 (p=0.012) and to a lesser extent (p=0.065), TSS, are somewhat but significantly higher in composite samples than in grab samples. It may require further analysis to discern what causes this result to be different from the results shown in Table 15.

Table 15. Distribution of relative differences between average of grab samples and time-composite samples during the same sampling event, generally a 24-hour period.

	CBOD5	TSS	AMMONIA-N	NITRATE-N	NITRITE-N	TKN	TN	TP	TOTAL ALK.
Number of events	110	111	110	111	111	110	110	109	76
5-percentile	-0.76	-1.54	-0.89	-0.37	-0.72	-1.05	-0.36	-0.45	-0.37
25-percentile	-0.23	-0.47	-0.10	-0.06	0.00	-0.17	-0.06	-0.06	-0.08
50-percentile	0.00	0.00	0.01	0.00	0.00	0.02	0.01	0.01	-0.01
75-percentile	0.10	0.47	0.22	0.07	0.14	0.19	0.10	0.09	0.05
95-percentile	0.80	1.27	1.09	0.42	1.11	0.62	0.34	0.21	0.31
Average	-0.01	-0.01	0.07	0.01	0.05	-0.05	0.02	-0.02	-0.01
Stdev	0.51	0.78	0.55	0.33	0.57	0.53	0.28	0.26	0.22

Table 16. Median test results between all effluent composite and effluent grab samples.

Test Statistics[a]

		CBOD5	TSS	AMMONIA-N	NITRATE-N	NITRITE-N	TKN	TN	TP	TOTAL ALK.
N		556	559	559	560	560	559	559	554	384
Median		2.400	6.800	3.000	11.11500	.24500	8.980	24.00	5.880	99.500
Chi-Square		6.812	3.802	.621	.101	.551	.199	.004	.560	.066
Df		1	1	1	1	1	1	1	1	1
Asymp. Sig.		.009	.051	.431	.750	.458	.655	.947	.454	.798
Yates' Continuity Correction	Chi-Square	6.269	3.400	.465	.045	.405	.116	.002	.411	.016
	df	1	1	1	1	1	1	1	1	1
	Asymp. Sig.	.012	.065	.495	.832	.525	.734	.968	.521	.898

a. Grouping Variable: sample_type

3.8 Observations Relating to High Variability

Notes taken by the samplers on the sampling events suggest a few possible sources for variability between grab samples and differences between grab and time-composite samples.

In the very first sampling event, substantial amounts of water were added to the influent, in order to trigger a dosing event, which in turn would refill the sampling port. This resulted in a total water use for the day of 630 gallons. The series of grab samples from this event show a pronounced step increase in concentrations from the first grab sample to subsequent grab samples for all parameters. Relative to other sampling events, this event had among the highest relative standard deviations for TN, nitrite, and nitrate (top ten), and fairly high for TKN and cBOD5 (top twenty). The differences between the average of grab samples and the time-composite samples were among the ten largest positive for cBOD5, nitrite, TKN, and TN; and negative for nitrate.

For the 53rd and 54th events, notes indicated that the sampler requested the owner to use additional water because not enough was left in the sampling port to sample, resulting in a total water use of 150 and 50 gallons. In both cases, the total suspended solids show a marked elevation during the grab samples preceding the request, and a drop in the samples after the request. The other parameters do not change clearly. The relative standard deviations for event 53 were not particularly high for any parameter, while cBOD5 for the event 54 showed the 5th highest relative standard deviation. In contrast, the relative differences between grab samples and composite samples were among the ten highest positive for cBOD5, TSS, TN, and TP in the first case and the ten highest for cBOD5 and TSS in the second case.

For the 76th event, a sampling note indicated that after the first grab sample, water was added for about 15 minutes to the building sewer cleanout, which increased the total usage to 150 gallons on that day. The influence on effluent concentration is less clear, as suspended solids in the next grab sample increased and then decreased markedly over the next two samples. For this day the TP concentrations show the fifth highest relative standard deviation and cBOD5 concentrations the 17th highest. Among the relative differences between grab and time-composite samples, only ammonia showed a relatively high negative difference.

Event 106 included addition of 15 minutes of water after the first grab sample, after having advised the owner to use some water before the sampling event. This resulted in a water use of 340 gallons. While some decrease in the concentrations of several parameters in subsequent grab samples during the same afternoon appears to be present, the composite sample results are consistent with the initial grab samples. Ammonia and total nitrogen relative standard deviations were in the top 20 of sampling events.

A note for event 59 indicated that the owner returned home overnight after being absent while the grab samples were taken. Even though the return occurred after the grab samples were taken, the grab samples show comparatively high relative standard deviations for nitrate and nitrite (in top 10) and TSS (in top 20). The composite effluent sample shows a marked change from the grab effluent samples for all parameters, with ammonia and nitrate showing among the largest negative relative differences, and TKN and TN the highest positive differences. This occurred, even though the water use for the day was only 30 gallons.

A sampling note for event 60 indicated that it rained after the last grab sample was taken, and that surface runoff flowed into to the effluent sampling port. Given that the disturbance occurred after the grab samples were taken, it is not surprising that the relative standard deviations were not very high compared to other events. A comparison of grab and composite effluent samples shows that the composite samples contained about twice as high suspended solids, and about a third lower TKN, nitrate, nitrite, TN, and TP concentrations than the fairly steady grab samples. In terms of relative differences between grab sample average and composite sample for this event, nitrate, TN, TP and total alkalinity are among the ten highest events, but TSS was not.

Overall, these anecdotes suggested that water use patterns over the course of the day can influence grab samples, which in turn can influence the variability of the grab samples obtained and the differences between composite and grab sample averages. Perhaps because timing of water use and grab samples was variable in this study, there was no general pattern in these differences discernable.

3.9 Differences Between Repeat Sampling Events

3.9.1 Effluent Samples

Over the course of the study, systems were sampled repeatedly, with one exception of a single sample event system. For some systems that were included in all phases of the study, up to 7 sampling events occurred, for systems that were only included in the last phase, only two sampling events occurred. These sampling events provide an opportunity to assess the variability between samples at the same system on different days. The intervals between two sampling events at the same site ranged from the next day to 799 days, with 90% between 49 and 730 days.

The results for relative differences for all possible combinations of sampling event results are shown in Table 17. Both TSS and ammonia appear to show a bias that later sampling events are higher in concentration than earlier events, while total alkalinity shows an element of the reverse. Given the large standard deviations, these biases are not significant when assuming a normal distribution.

Tables 18 and 19 illustrate the distribution of relative standard deviations between samples of the same system based on averages of grab samples (Table 18) and composite samples (Table 19). To exclude the effect of some systems having been sampled more frequently than others, Table 20 summarizes average relative standard deviations and their variability after first averaging the observations for each system and then averaging across the 38 systems with more than one sampling event. In all cases, TN and TP show the lowest variability, while nitrite and ammonia show the highest variability.

Table 17. Summary of relative differences between event samples at the same system.

Parameter	CBOD5	TSS	AMMONIA-N	NITRATE-N	NITRITE-N	TKN	TN	TP	TOTAL ALK.
Average of relative differences between composite	0.08	0.33	0.38	-0.09	-0.01	-0.03	0.00	-0.09	-0.18
stdev comp	0.84	1.02	1.18	0.87	1.29	1.11	0.65	0.62	0.74
Average of relative differences between average of event grab samples	0.05	0.23	0.35	-0.12	0.01	-0.02	0.08	-0.08	-0.17
stdev grab	0.90	0.92	1.15	0.91	1.23	1.13	0.68	0.63	0.75

Table 18. Distribution of relative standard deviations between event averages of multiple grab samples taken from the same system

Parameter	CBOD5	TSS	AMMONIA-N	NITRATE-N	NITRITE-N	TKN	TN	TP	TOTAL ALK.
Number	132	138	138	138	138	138	138	136	47
5-percentile	0.00	0.02	0.03	0.03	0.05	0.07	0.01	0.02	0.04
25-percentile	0.02	0.22	0.28	0.11	0.37	0.23	0.10	0.10	0.17
50-percentile	0.36	0.44	0.73	0.40	0.79	0.58	0.31	0.21	0.33
75-percentile	0.80	0.89	1.12	0.80	1.14	1.07	0.58	0.46	0.56
95-percentile	1.21	1.24	1.37	1.30	1.31	1.33	1.03	0.93	1.10
Average	0.46	0.54	0.72	0.49	0.76	0.66	0.37	0.32	0.42
Stdev	0.44	0.40	0.45	0.42	0.41	0.44	0.31	0.31	0.34

Table 19. Distribution of relative standard deviations between composite effluent samples taken from the same system.

Parameter	CBOD5	TSS	AMMONIA -N	NITRATE -N	NITRITE-N	TKN	TN	TP	TOTAL ALK.
Number	138	138	133	138	138	133	133	131	47
5-percentile	0.00	0.00	0.04	0.03	0.07	0.06	0.02	0.01	0.03
25-percentile	0.14	0.35	0.32	0.13	0.55	0.22	0.11	0.11	0.17
50-percentile	0.39	0.62	0.86	0.32	0.85	0.62	0.27	0.23	0.30
75-percentile	0.80	0.97	1.14	0.71	1.18	1.03	0.50	0.46	0.50
95-percentile	1.08	1.28	1.38	1.30	1.34	1.33	0.99	0.97	1.05
Average	0.47	0.64	0.75	0.46	0.81	0.65	0.35	0.32	0.41
Stdev	0.36	0.39	0.45	0.41	0.41	0.44	0.30	0.31	0.35

Table 20. Average relative standard deviations based on averaging relative standard deviations for each system (n=38).

Parameter	CBOD5	TSS	AMMONIA -N	NITRATE -N	NITRITE -N	TKN	TN	TP	TOTAL ALK.
Average grab system averages	0.45	0.54	0.60	0.57	0.77	0.54	0.34	0.31	0.43
Stdev	0.38	0.34	0.41	0.41	0.33	0.38	0.28	0.28	0.36
Average comp sample systems	0.38	0.61	0.63	0.58	0.80	0.55	0.35	0.31	0.43
Stdev	0.33	0.35	0.39	0.41	0.37	0.39	0.29	0.25	0.37

The Pearson correlation coefficient between length of time between sampling events and relative standard deviations was less than 0.2 for all analytes. This indicates that there is no common pattern of samples becoming more different as more time elapses between sampling events. For grab samples, the following pairs showed Pearson correlation coefficients between 0.5 and 0.7: TKN and TN, TKN and cBOD5, total alkalinity and cBOD5, and ammonia and total alkalinity. These pairs appear to indicate a common pattern of completeness of biochemical stabilization and nitrification. Composite effluent samples have similar correlations, except lower for ammonia and total alkalinity, and cBOD5 and total alkalinity, and higher between total alkalinity and TKN.

One-way ANOVAs allowed an assessment of the importance of differences between systems relative to the variability of grab samples or composite samples. Differences between systems were significant ($P<0.05$) relative to variability between events (composite samples) and variability between grab samples (grab samples), with the exception of nitrite for composite samples, while nitrate showed the largest F-value of all composite sample parameters. For grab samples, TN and TP were the largest F-values. This indicates that there are differences in the consistency of treatment between systems.

3.9.2 Influent Samples

Table 21 shows the distribution of the resulting relative differences between influent samples from the same system. While the averages suggest some bias, the highest for total phosphorus, ammonia and nitrate, compared to the standard deviation, they are not significantly different from zero (based on a normal distribution). A negative bias would indicate that influent concentrations decrease over time for the same system, for example due to changing patterns of household behavior.

A Pearson correlation between the relative standard deviations of influent samples and the time difference between influent samples showed no correlation coefficient larger than 0.3. Pearson correlations between the relative differences of analytes showed many correlation coefficients larger than 0.5, indicating that for influents, changes occur for several analytes together. The highest correlations were between TKN and TN (0.98) and ammonia and total alkalinity (0.82). TKN and ammonia, TN and ammonia, TKN and total alkalinity, and TN and total alkalinity all showed correlation coefficients between 0.7 and 0.8. With correlation coefficients between 0.5 and 0.7, total phosphorus and total alkalinity, total phosphorus and TKN, total phosphorus and TN, cBOD5 and TSS, TN and cBOD5, TKN and cBOD5, TN and cBOD5, and TN and TSS show much stronger correlations than they did for effluent samples.

Table 22 shows the distribution of relative standard deviations between influent samples from the same system. This table is comparable to Table 11 for effluent samples. Table 23 averages the relative standard deviations over the number of systems that were repeatedly sampled. The two tables show similar results, but nitrate appears more variable between systems and total phosphorus less variable between systems. Ammonia and total alkalinity show somewhat lower variability between systems Average relative standard deviations are generally of similar magnitude for influent and effluent samples. An analyte that appears to be more variable in influent samples is nitrate, which in influents is generally a small fraction of the total nitrogen, while ammonia is less variable.

A one-way ANOVA allowed an assessment of the importance of differences between systems relative to the variability of composite samples. Differences between systems were not significant relative to variability between events (composite samples) for cBOD5, TSS, and nitrate, and significant ($p<.05$) for total phosphorus, total alkalinity, ammonia, nitrite, TKN and total nitrogen. This indicates that the influent variability is large enough for each system that differences between systems are not identifiable for cBOD5 and TSS, but that differences by system are identifiable for TN and TP.

Table 21. Distribution of relative differences between influent composite samples taken from the same system.

Parameter	CBOD5	TSS	AMMONIA-N	NITRATE-N	NITRITE-N	TKN	TN	TP	TOTAL ALK.
Number	44	48	48	48	48	48	48	46	21
5-percentile	-1.19	-1.44	-1.36	-1.62	-1.79	-1.05	-0.85	-1.40	-0.45
25-percentile	-0.53	-0.78	-0.16	-0.15	-0.71	-0.53	-0.53	-0.77	-0.19
50-percentile	-0.03	-0.19	0.09	0.00	0.25	-0.10	-0.11	-0.33	-0.04
75-percentile	0.33	0.50	0.62	0.94	0.50	0.47	0.47	0.19	0.12
95-percentile	1.12	1.96	1.33	1.64	1.69	1.35	1.31	1.44	0.50
Average	-0.10	-0.05	0.18	0.12	0.08	0.02	0.05	-0.23	-0.07
Stdev	0.73	1.00	0.83	1.07	1.07	0.83	0.76	0.88	0.38

Table 22. Distribution of relative standard deviations between influent composite samples taken from the same system.

Parameter	CBOD5	TSS	AMMONIA-N	NITRATE-N	NITRITE-N	TKN	TN	TP	TOTAL ALK.
Number	44	48	48	48	48	48	48	46	21
5-percentile	0.01	0.10	0.00	0.00	0.01	0.01	0.01	0.06	0.03
25-percentile	0.12	0.25	0.10	0.00	0.24	0.09	0.09	0.19	0.05
50-percentile	0.29	0.48	0.26	0.65	0.42	0.38	0.38	0.40	0.14
75-percentile	0.73	0.86	0.74	0.96	1.10	0.65	0.58	0.83	0.27
95-percentile	0.95	1.39	1.17	1.24	1.27	1.27	1.00	1.16	0.40
Average	0.40	0.57	0.43	0.56	0.60	0.43	0.40	0.51	0.19
Stdev	0.32	0.40	0.41	0.50	0.45	0.39	0.35	0.38	0.20

Table 23. Average relative standard deviations based on averaging relative standard deviations for each system (n=18).

Parameter	CBOD5	TSS	AMMONIA-N	NITRATE-N	NITRITE-N	TKN	TN	TP	TOTAL ALK.
Average	0.36	0.57	0.46	0.74	0.68	0.42	0.36	0.38	0.22
Stdev	0.32	0.33	0.44	0.40	0.42	0.44	0.35	0.31	0.22

3.10 Summary of Variability of Samples

The preceding sections described the variability observed between samples that could be thought of a representing the same observation points. Repeated analyses of the same sample, multiple grab samples during the same sampling events, and multiple sampling events at the same systems provide measures of variability at different time scales. Within the event time-scale, there was some indication that the variability of total alkalinity, ammonia, nitrate-, and nitrite nitrogen increased with longer time intervals between samples, but the effect was small. There was no such effect identified for the between event variability, because the variability was too high.

Figure 3 summarizes the variability as average relative standard deviation and its standard deviation, and as 75th percentile of relative standard deviations. Figure 3 a and 3 b show this for grab sample variability, including the variability of replicate samples as a baseline variability. Figure 3 c and 3 d compare influent and effluent time composite samples. In most cases, the between-event variability is at least twice as large as the within-event variability. The only exception to this is TSS, which has the highest replicate and within-event variability of all analytes and for which the within-event variability is only about a third lower than the between-event variability.

Time composite effluent samples result in very similar variability characteristics as the grab samples. Influent and effluent time composite samples vary similarly with the possible exception that influent TP is more variable than effluent TP and influent total alkalinity is less variable than effluent total alkalinity.

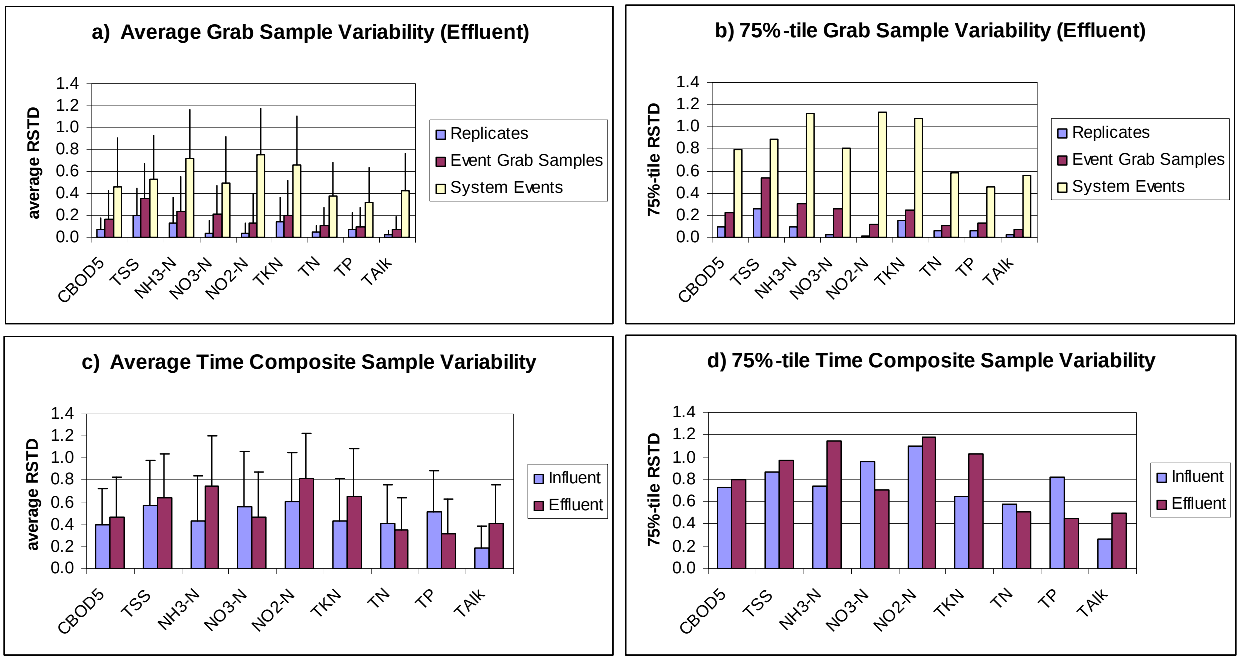


Figure 3. Comparisons of variability between samples. a) average relative standard deviations (+ one standard deviation) of replicates, grab samples during an event, and events for a system; b) 75%-tile of the relative standard deviations of replicates, grab samples during and event, and events for a system; c) average relative standard deviations (+one standard deviation) for influent and effluent time composite samples between events for a system; d) 75%-tile for influent and effluent relative standard deviations between events for a system

3.11 Differences between Days, Months and Seasons

3.11.1 Differences Between Days

Each sampling event spanned parts of two days, usually from the morning of one day to the morning of the next day. Sampling equipment was usually deployed on Monday, Tuesday, or Wednesday and composite samples taken on the following day, to allow for shipments to the laboratory to arrive by Friday. Only in three cases did sampling start on a Sunday.

Differences in results between days could result from patterns in user behavior over the course of a week. Only the individual home residential treatment systems were included in the analysis. To assess this effect, a median test for differences between water use measurements and composite sample concentration results by day was performed. In this assessment of composite samples, "Monday" represents the results from an event that began on a Sunday and ended on a Monday, while for grab samples, the day is the day when the sample was collected.

For effluent composite samples, water use is the only measurement that varies significantly between days. In follows a pattern of decreasing use from Monday through Thursday. Even after excluding the three Monday measurements, which all exceeded the median, the differences were still significant. For influent composite samples the differences between any concentration results, including water use, were not significant even at the 30%-level. The conflicting results on differences in patterns of water use indicates that for the smaller (n=30) number of measurements from systems that did allow for influent sampling, water use was fairly even, while the larger (n=73) number of measurements from all systems included enough differences in water use to become significant. This indicates that generalizations of user behavior need to proceed with caution.

Interestingly, for effluent grab sample concentrations, there appeared to be significant differences for TSS and ammonia-nitrogen ($P<0.05$), and to a lesser extent for total nitrogen ($P=0.088$). Using a different test (Kruskal-Wallis), the differences for total nitrogen were not significant. The TSS-concentrations followed a decreasing pattern from Sunday through Thursday. This could be, in part, related to the finding that the first grab samples tended to have higher TSS concentrations than later ones. On Sundays and Mondays, the proportion of first samples was much higher than Thursdays when sampling wrapped up.

This study showed a consistent lack of significant concentration differences by day in either influent or effluent composite samples, and only limited differences between effluent grab samples. This contrasts with results from a wider survey of systems with individual grab samples a few years earlier in the same area (Roeder and Brookman, 2006). Their analysis found generally higher concentrations on Wednesdays than on other days. Overall, this suggests that differences by day are not consistent.

3.11.2 Differences Between Months

As a first step towards assessing seasonal differences, data were analyzed for significant differences by the month of sample taken. Only the individual home residential treatment systems were included in the analysis. Effluent composite samples showed significant ($P<0.05$) differences for TKN and total nitrogen in the median test, but only significant differences for TKN in the Kruskal-Wallis test. The validity of this finding appeared impacted by the highest and lowest months being represented by very few samples (highest month n=1; two lowest months, n=2,3). No significant differences were found in event water use measurements between months. This indicates that the overall system population was not impacted by seasonal use patterns. This may be related to the initial system selection, which looked for homesteaded residences. Roeder and Brookman (2006) discuss similarly a lack of consistent differences between sample months for grab samples taken in February through November.

3.11.3 Differences Between Seasons

The initial experimental plan envisioned to classify samples according to visitor season, from the beginning of sampling through May as the peak season, and subsequent samples through December as off-season. The extension of sampling over several years and the finding of no significant differences in water use by month in the previous section suggest a modification of this approach. Instead of usage pattern, season is conceptualized as climatic season. The soil survey of the Keys area contains climatic data that closely align with, but are slightly different from the initial divisions (Hurt et al., 1995). For the purposes of analysis, the warm, wet season includes those months with average daily temperatures in exceeding 80^{o}F and monthly precipitation exceeding 3.2 in. These are the months from May through October. The cold, dry season includes the other months with average daily temperatures below 78^{o}F and monthly precipitation below 2.7 in. About two thirds of sampling events occurred during the cold, dry season.

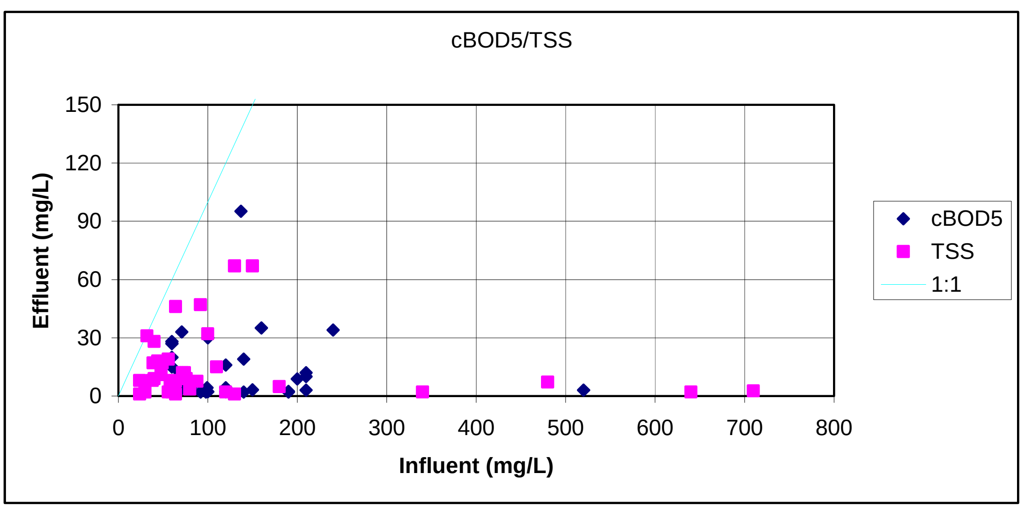
Assessments of differences by season for individual home system composite effluent and influent samples showed no significant differences for concentrations and water use. This indicates that for the individual home treatment systems considered the steady use and possibly the confinement to a treatment system are more important than seasonal differences temperature and precipitation. This finding may be specific to the Florida Keys, where the average daily temperature for January, the month with the lowest average daily temperature, is 69.3^{o}F.

4 INFLUENCES ON EFFLUENT CONCENTRATION

4.1 Influent Strength

The first level of analysis consists of a comparison of influent and effluent concentrations, in this case composite samples on the same sampling event. Figure 4 shows the results for up to 38 samples for laboratory analyses (excluding high solids, tap water, and recirculation samples). For comparison purposes, a 1:1 line, representing no treatment is also included. A result above the line indicates higher concentrations leaving the treatment system than entering it. One cause for such behavior is variability of the influent, combined with ineffective treatment, as in a situation where the influent concentration is lower for the sampling event period but the effluent concentration reflects prior, higher concentrations for a time influenced by the hydraulic residence time in the treatment system. Few sampling events yielded results that were above this line, and in agreement with the scenario outlined, they occur at relatively low influent concentrations. The most occurrences were for TP. Relative to TN, it appears unlikely that the influent variability is larger, so this is more likely a reflection of treatment effectiveness.

The overall results shows no correlations between influent and effluent concentrations (maximum $R^2=0.14$ between influent TN and effluent NO3-N). For cBOD5 and TSS, Figure 4 a illustrates that most effluent samples contain less than 10 mg/L of either. While TN effluent concentrations overall did not correlate with influent concentrations, there appears to be one group of results that remains close to the 1:1 line, indicating little treatment effectiveness, and another group with effluent concentrations remaining below 40 mg/L regardless of influent concentrations. Only about a quarter of influent samples contain less than 50 mg/L TN. TP shows most points just below the 1:1 line, with a few points indicating higher treatment effectiveness, mainly at high influent concentrations. Total alkalinity shows a pattern somewhat similar to TN, with a group of results close to the 1:1 line, indicating little removal, and a group that has seen higher alkalinity reductions. This corresponding pattern is consistent with the concept that nitrification, one of the treatment steps in nitrogen reduction, reduces alkalinity.



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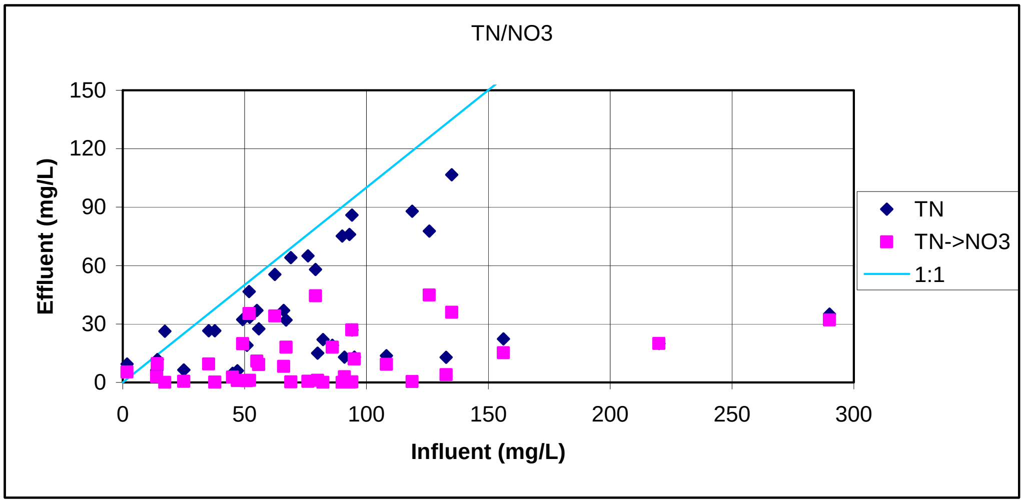

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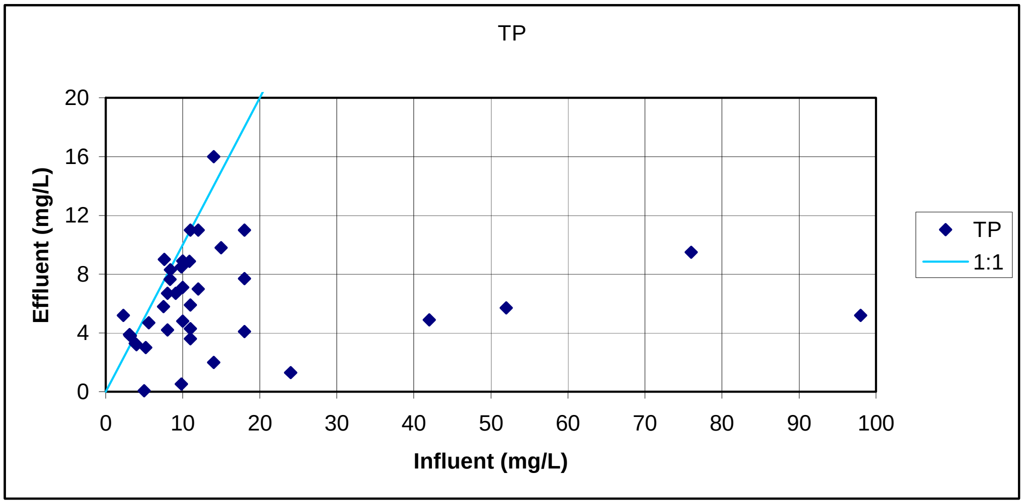

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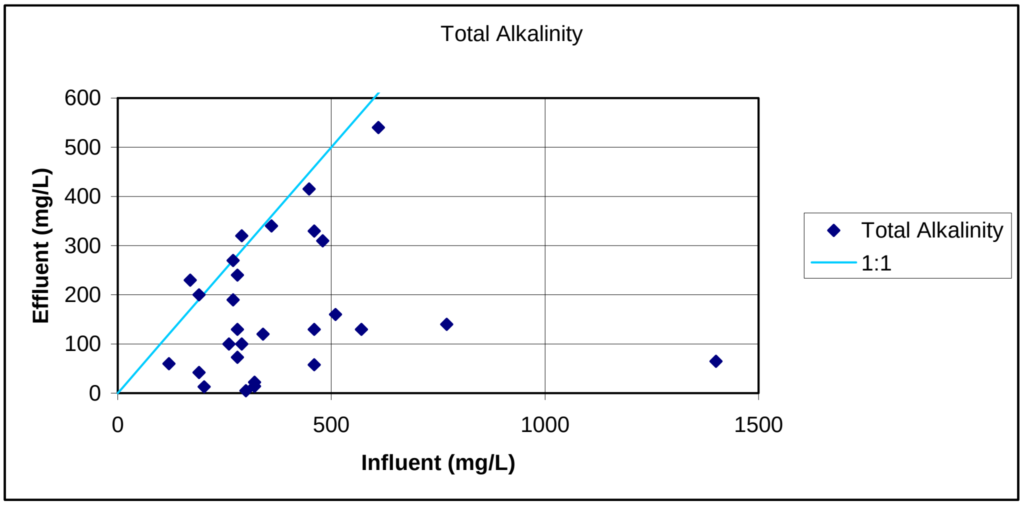


d)

Figure 4. Influent and effluent concentrations for composite samples, where both were sampled during the same sampling event. Influent excludes samples with high solids, tap water and recirculation systems. a) cBOD5 and TSS; b) TN; c) TP; d) total alkalinity.

Based on a median test, the influent did not differ significantly among the permitting categories (residential PBTS, ATU, commercial PBTS) for cBOD5, TSS, TKN, TN, TP and total alkalinity. On the other hand, effluent concentrations differed significantly between the different groups (<0.05) for cBOD5, TSS, ammonia-N, and total phosphorus. TKN had a lower level of significance (0.062). A comparison between just single family residences PBTS and ATU had similar results. One difference between many of the PBTSs and the ATUs is the presence of a phosphorus reduction treatment step, which was previously shown to have a significant effect on many of the same analytes.

4.2 Phosphorus Reduction Treatment Approaches

Six phosphorus treatment approaches were included as part of this study. The classification was based on field observations and permit review. The treatment approaches were: AOS, a type of light expanded clay aggregate (LECA) material; brickchips either unsaturated or undetermined; LECA filtralite either saturated or unknown; and mid-floc, a chemical additive. Of these, LECA and brick chips had been tested in unsaturated conditions in a treatment feasibility demonstration study in the Florida Keys (Ayres Associates 1998, 2000). This study included the side-by-side comparison of a variety of treatment technologies on Big Pine Key. The results were available when the treatment system standards were set and have informed subsequent designs. Since then, engineers have specified LECA-filtralite also in saturated conditions in part based on information by the manufacturer; and occasionally, engineers have specified mid-floc, likely based on experiences with larger wastewater treatment plants. A median test indicated significant differences in effluent quality for most of the analytes.

Table 24 shows the statistics of total phosphorus concentrations after each of these treatment steps. These statistics indicate that the mid-floc and AOS treatments result in the highest median TP-concentrations, while the Leca filtralite treatment systems provide the lowest concentrations. The mid-floc treatment relies on the addition of chemicals to a treatment tank. The apparent lack of effectiveness could be due to either lack of maintenance, as in keeping chemicals supplied and the dosing mechanism operating, or a lack of technological treatment effectiveness. All the other treatment approaches are designed to rely on absorption, and the design usually contain a note that there is a limited lifetime for the absorption capacity. The lack of treatment effectiveness for at least two of the treatment approaches sampled, AOS and unsaturated brick chip, indicates that the performed monitoring and maintenance is not sufficient to determine that replacement was needed or that design or installation shortcomings had occurred.

	AOS	mid-floc	brick chip unsaturated	brick chip unknown	LECA saturated	LECA unknown
Mean	6.79	10.39	5.64	6.83	3.99	1.48
Std. Deviation	4.47	6.36	4.63	2.13	2.65	1.03
Median	8.90	8.75	4.60	6.15	3.95	1.20
N	9	8	36	12	10	6

Table 24. Statistics of total phosphorus concentration after different phosphorus reduction treatment steps.

4.3 Nitrogen Reduction: Nitrification

A pairwise comparison of influent and effluent composite samples was used to assess limitations on treatment effectiveness for nitrogen. The details are contained in Roeder and Brookman (2010). The general results of that effort were the following:

The most nitrified samples (TKN/TN <0.2) show the lowest total nitrogen concentrations along with consistently very low levels of cBOD5. This is consistent with the result of an influent-effluent comparison that TN-reduction between influent and effluent was very strongly correlated with the TKN-reduction, or nitrification. For these highly nitrified samples with low cBOD5 concentrations, a carbon limitation for further denitrification appears likely.

The least nitrified (TKN/TN >0.9) effluent samples also tended to have a substantial amount of cBOD5 left. Both lack of nitrification and remaining cBOD5 are consistent with a lack of aeration or aerobic activity. There are no data available at this point to assess if this lack stems from toxicity, technological limitations, or operational upsets, including shutting off the system. Intermediately nitrified effluents also showed some, albeit lower, levels of cBOD5. Some of these effluent samples contained very low alkalinity, which could suggest an alkalinity limitation to further nitrification.

Nitrogen reduction effectiveness was estimated for the three groups of nitrification completeness based on influent/effluent composite sample pairs in each group and found noticeable differences between the groups: for highly nitrified effluent samples (14 effluent samples), the median removal was 75%; for intermediately nitrified effluent samples (34 samples) the median removal was 44%; for the 15 least nitrified effluent samples, the median removal was 28%. This indicates that there are differences in well as compared to poorly operating treatment systems. The analyses so far have not concluded what causes the differences in operational quality have. Anecdotes exist that homeowners occasionally switch off the aeration of the treatment system, or an electrical malfunctions stops aeration until the malfunction is remedied, but the extent of this problem was not quantified in this study. It appears likely that operation and maintenance play a role in ensuring proper and optimal functioning of a treatment system.

5 SCREENING TESTS

The study included several screening tests to assess whether the results agreed with the results of laboratory analytical methods. This agreement could be useful in two ways: a quantitative agreement to allow prediction of laboratory results from field screening tests, or the determination that a sample exceeds a given concentration value.

5.1 Visual Classification

The visual classification consisted of three values: clear, grey, and black. Grey included a combination of “slight”, “intermediate”, and “grey”observations,. The samplers deemed none of the samples assessed “black”. A median test between “grey” and “clear” samples indicated significant differences for TSS, TKN, and ammonia. Complicating the diagnostic value is the overlap between concentrations in samples that appeared clear (n=96) and grey (n=19), respectively. Further analysis indicated that the visual analysis can serve as a good indicator if a sample exceeds 10 mg/L TSS. Grey samples had high odds of exceeding 10 mg/L TSS (18:1), while clear samples had comparatively low odds (28:68). The resulting odds ratio of 44 was the highest found for the three analytes for which visual classification appeared to be significant.

5.2 Olfactory Classification

The olfactory classification consisted of the categories “no odor”, “earthy”, “musty”, and “septic” or “pungent”. The classification relied on the understanding by the sampler of these terms. The samplers classified most (n=96) of the assessed samples as containing no odor, only three as smelling earthy, eleven as smelling musty, and nine as smelling septic. A median test indicated significant differences between these classes in regards to the visual classification, TSS, ammonia, and TKN. As in the case of visual classifications, the overlap of concentrations for each olfactory class complicates the use of smell as indicator of exceeding certain concentrations. For example, all samples classified as musty or septic contained at least 3 mg/L TSS and TKN, but about two thirds of the non-odorous samples contained also at least 3 mg/L, allowing little distinction. Overall, the presence of smell appeared to be an indicator for TSS, ammonia or TKN exceeding 10 mg/L with odd ratios between 17 and 19.

5.3 Hach Test Kits

The study utilized a Hach DR/890 to analyze samples for nitrate, ammonia, and reactive-phosphorus. The sample volume analyzed by the Hach kit stemmed from the same intermediate sampling container that the laboratory samples were taken from. Based on this origin, variability similar to the replicate variability is expected. An additional way to assess the ease and reliability of using the screening test consisted in keeping separate the data from Phase 1 and 2 and from Phase 3, which coincided with differences in the staff performing the measurements. For the first two phases, half a dozen staff had worked on this project, while in the third phase, only a couple of people performed the sampling. This splitting provides a repetition of the experiment and allows an assessment of the importance of the analyst. Figure 5 compares the laboratory results to the results of the Hach analyses. In each of the three analytes, there are noticeable differences between the phases.

For ammonia (Figure 5 a), the slope of the correlation is slightly less than one for both phase categories, indicating a slight underestimate when using the Hach-kit. While the slope is very similar, the correlation coefficient was higher for Phase 1 and 2 than in Phase 3 (0.9 vs. 0.7). This appears to be due largely to a few outliers during Phase 3. For nitrate, the data shown in Figure 5 b were truncated at a laboratory concentration of 25 mg/L. This removed the influence of exceeding the upper end of the undiluted measurement range with the screening test, which was 33 mg/L, and resulted in a flattening of the Hach data points. The slope of the correlation between laboratory and screening methods was close to one in both data sets, indicating a good correspondence. The correlation coefficients were higher than for ammonia, and again higher for the first two phases than the third phase (0.97vs 0.68).
For phosphorus, the correlation coefficients were the lowest of this set (0.56 and 0.46, respectively). One possible reason for higher variability is that in contrast to the other two measurements, the screening test does not measure the same chemical species as the laboratory test (reactive vs. total phosphorus) but only a subset. But there are also indications, that the procedure of the screening test gave rise to misunderstandings: During Phase 1 and 2, several screening measurements cluster along a 3:1 line; such points are likely the result of analysts forgetting to convert from phosphate (PO4) to phosphorus (PO4-P) by multiplying with 0.326. The upper limit of the measurement range is less than two mg/L phosphorus. This necessitated sample dilutions, usually at a ratio of 1:10 to obtain a result in the measurement range, and this dilution step could lower measurement precision and introduce recording errors.

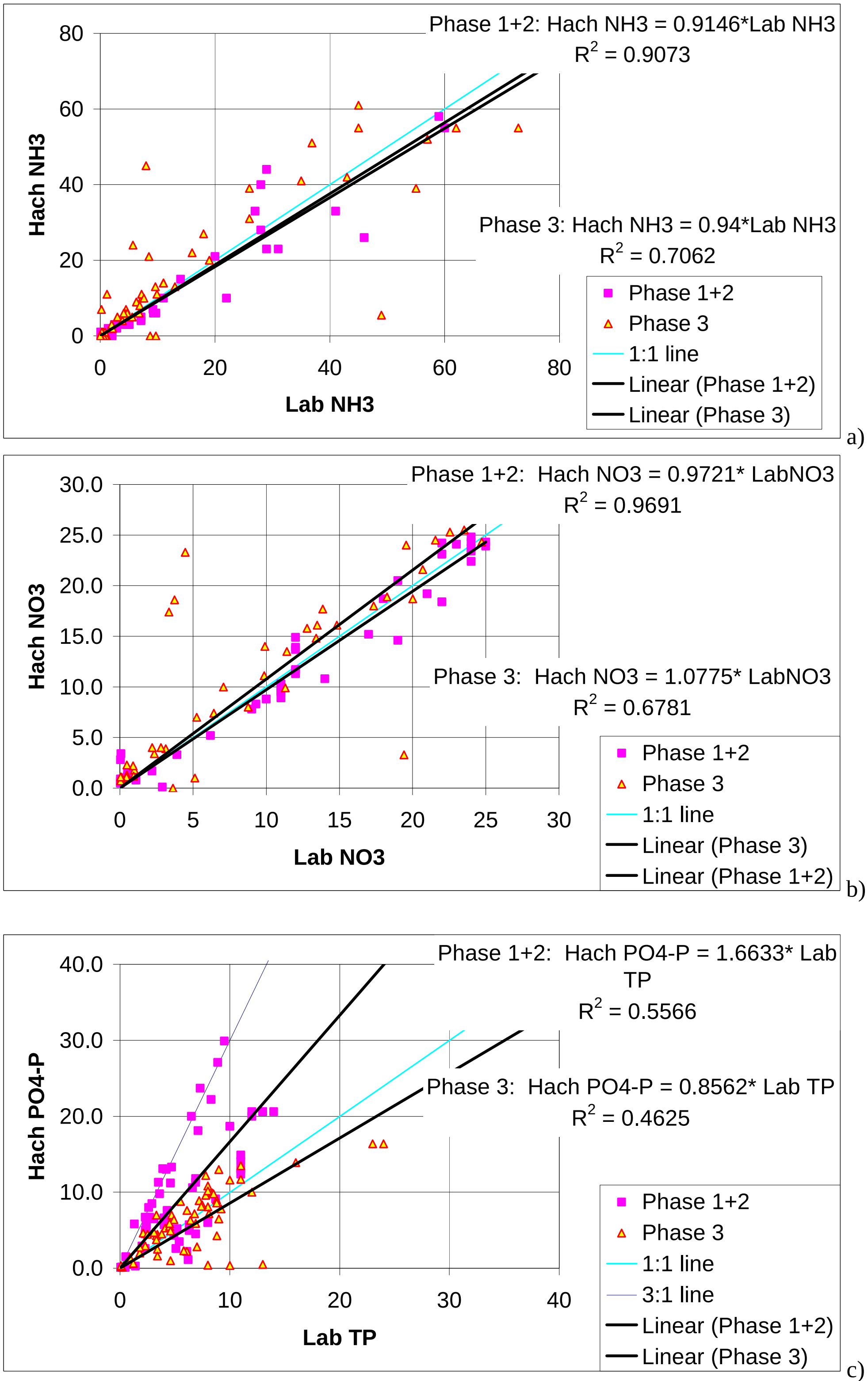


Figure 5. Comparison of laboratory analysis results and results of analysis by samplers using Hach DR/890 test kits. a) NH3-N; b) NO3-N; c) reactive-P vs. total P

5.4 Taylor Kit

A Taylor swimming pool kit provided an alternative means of assessing pH, total alkalinity and free chlorine. For 37 samples, results from both the laboratory and a Taylor titration of alkalinity were available. Figure 6 illustrates the relationship between laboratory and Taylor measurements of total alkalinity. Except for two visible outliers during Phase 1 and 2, the correlations are high in all phases (0.74 and 0.92) and indicate a one-to-one correspondence between the two measurements. One of the outliers was associated with the highest measured total alkalinity sample in the group (540 mg/L), and exceeded 1000 mg/L during Taylor titration. Only one of the three lowest Taylor alkalinity results was associated with below detectable levels of alkalinity in the laboratory analysis. The reasons for the other deviations remain speculative, one possibility, at least for two low Taylor measurements of less than ten, is that the recorder of the measurement omitted the conversion calculation from drops to mg/L, which usually would result in a multiple of ten. Overall, total alkalinity appears a measurement that has potential for reliable determination in the field.

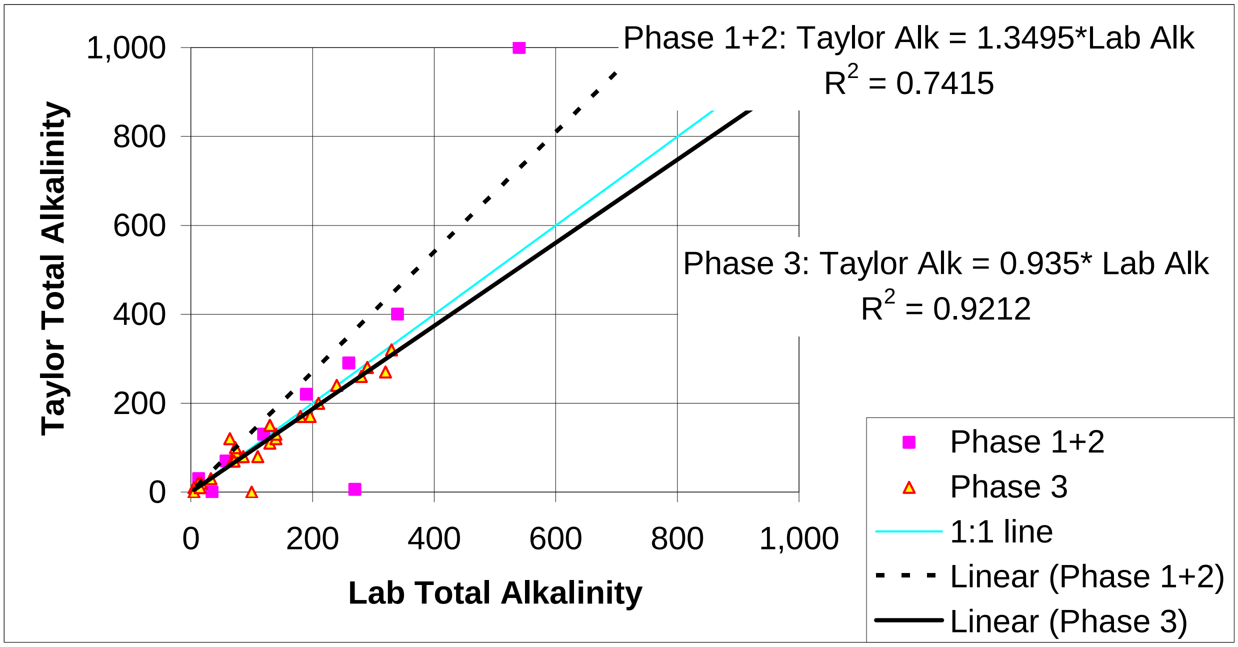


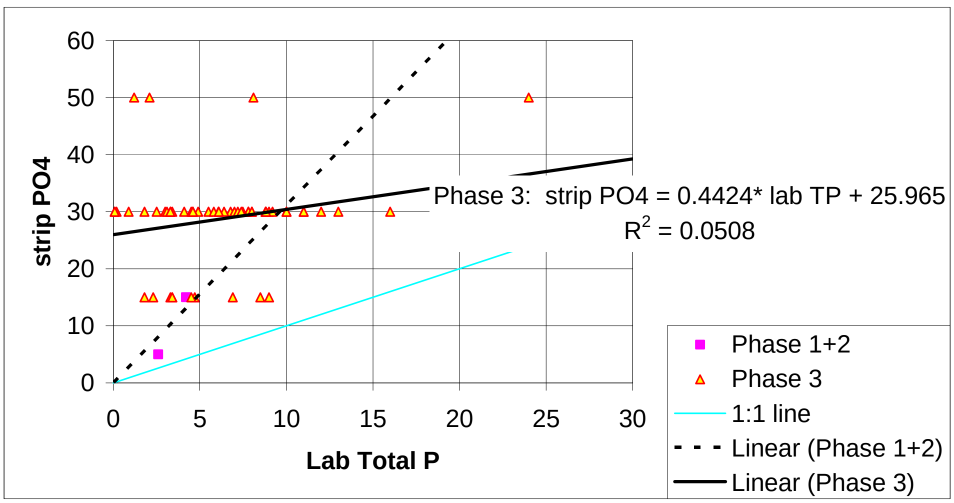
Figure 6. Illustration of the relationship between total alkalinity measurements in the laboratory and measurements using a Taylor kit.

Of the 27 chlorine measurements during Phase 3, fourteen, or about half showed no or less than 0.5 mg/L free chlorine, which is below the standard of 64E-6 for free chlorine prior to an injection well. No laboratory measurement of chlorine occurred, so an assessment of the accuracy is not feasible. The chlorine measurements did not coincide with bacteriological samples, so no assessment of the effectiveness of chlorination is feasible.

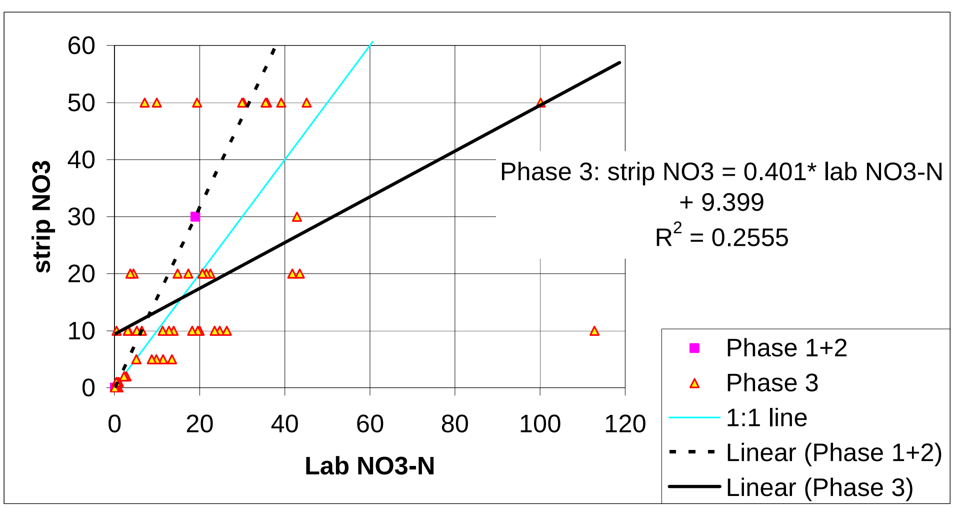
Although four of these measurements occurred apparently before the point of chlorination, these results indicate that the supply of a steady sufficient chlorine level is frequently not achieved. No data are available to assess how much of this problem is lack of maintenance, e.g. in the form of supplying chlorination tablets, and how much is due to design issues, e.g. the chlorinators, frequently based on erosion of a stack of tablets, not being suitable to provide the chlorine.

5.5 Test Strip Measurements

For up to 58 samples, test strips results are available for reactive phosphorus, nitrate, nitrite, alkalinity and chlorine. Of these, only alkalinity showed any promise as a somewhat quantitative measure of measurements obtained by other methods. Too few data were collected during Phase 1 and 2 to perform a meaningful correlation assessment. For reactive phosphorus, the results from Phase 3 show no meaningful correlation (0.05) with laboratory concentrations. For nitrate, the results are similar, for Phase 3, a very low correlation (0.25) was present. For nitrite, there was no correlation. For total alkalinity, a correlation can be seen, but appears to be leveling off, resulting overall only in a correlation coefficient of 0.5. The correlation coefficient increases to 0.68 if the y-intercept is allowed to vary. For chlorine, the few samples for which both measurements by test strip and by Taylor kit had been obtained showed no apparent correlation between the two.



a)



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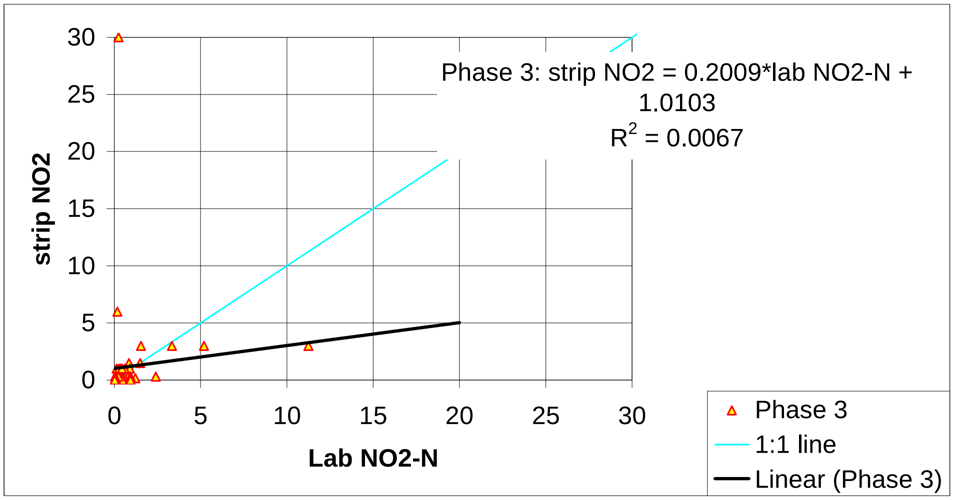

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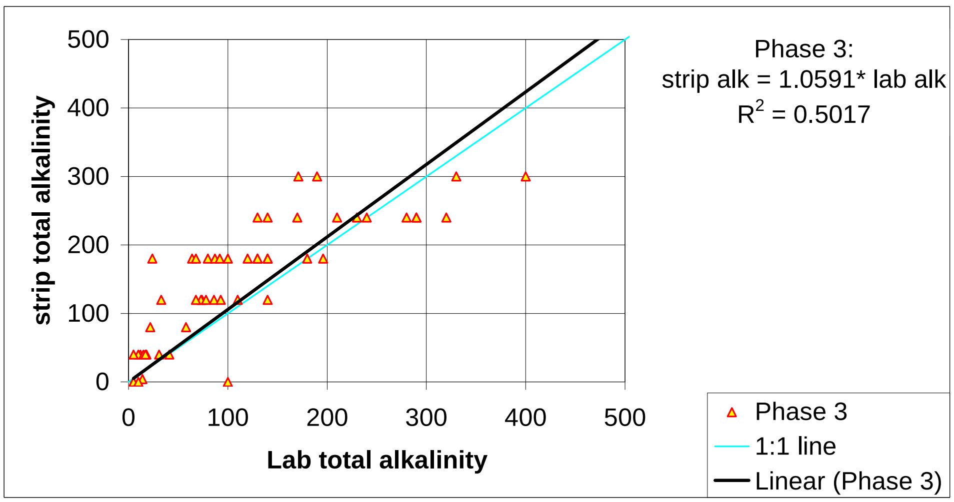

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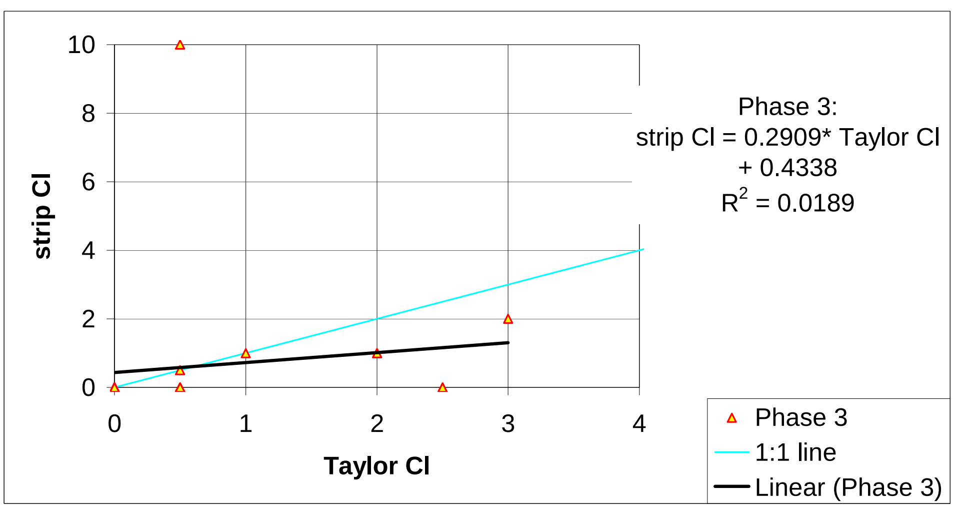

e)

Figure 7. Relationships between other measures of concentrations and results of test strip measurements: a) ortho-phosphorus vs. lab TP b) nitrate vs lab nitrate-N c) nitrite vs lab nitrite d) alkalinity vs. lab total alkalinity e) chlorine vs Taylor chlorine

6 CONCLUSIONS AND RECOMMENDATIONS

This study reports on samples from aerated onsite sewage treatment systems in Florida Keys. Over the course of the study between February 2007 and June 2009 we obtained grab and composite samples from 40 treatment systems in Monroe County at different frequencies. Experiences and conclusions can be categorized into two groups: (1) Validation of a sampling protocol and (2) Preliminary assessments on the treatment effectiveness of treatment systems based on the sampling protocol.

6.1 Validation of a Sampling Protocol

Occasional spurious high concentrations were reported, in many cases for one analyte but not for others in the same sample. While this may influence means, median concentration results are less impacted by this and appear generally reliable. Rapid review of sample results on the background of typical results and communication with the laboratory appear to be a way to resolve some of these. The conditions for such interaction were much improved for Task 4.

Relative to target concentrations, results from analysis of blanks indicated that the approach to sampling using peristaltic pumps was successful. For the sampling project of Task 4 of this grant agreement, flushing volumes were increased in an attempt to further reduce TKN and TN in equipment blanks, which had been detected most frequently.

TSS appeared to be the most variable parameter in replicate samples from an intermediate container with a median relative standard deviation of 12%, but for cBOD5, TN, and TP this measure was 3% and less. Concerns about samples obtained from intermediate containers are thus less warranted for nutrient analyses than for TSS analyses.

Detailed characterization of the treatment systems and sampling locations are very important. Particularly in treatment systems with multiple treatment steps, “influent” and “effluent” need further qualification, and may be ambiguous to a sampler encountering the treatment system or to a data analyst. In the present study this required some reclassification during data analysis from “influent” to “intermediate”. For Task 4, data fields for sample location description were more extensive, and a screen for the validity of “influent” samples was developed.

Effluent concentrations varied widely overall, but less so than in a previous survey of ATUs in the Keys. The operational and maintenance conditions of a treatment system need to be better characterized if one wants to distinguish between technical limitations of treatment and shortcomings due to operator error or lack of maintenance. The assessment protocol for Task 4 included a more detailed assessment, including characterization if the power was on, observation of problems and the dissolved oxygen concentration as a measure of aeration.

Assessments of variability between grab samples showed that TSS had the highest variability, while TP and total alkalinity had the least, followed by TN. The first grab sample of a sampling event tended to be about 20% higher in TSS and 10% in cBOD5 than subsequent grab samples. This difference did not exist for nutrient species. Given that the emphasis of the project is on nutrient treatment effectiveness, grab sampling appeared appropriate for Task 4.

There was no overall bias found between the effluent composite and average of grab samples during the same event, even though for any event there could be differences. These differences were the least for total alkalinity, TP, TN, and nitrate, with more than 50% of events showing a relative difference of less that 10%.

The between event variability as expressed by relative standard deviations, is at least twice as large as the within event variability for all parameters, except for TSS.

Analysis for differences by weekday showed no consistent results. Flow measurements for a subset of systems, but not for all measurements, appeared to decrease from Monday through Thursday. Grab, but not composite, effluent sample results for TSS and cBOD5 indicated a decrease from Sunday through Thursday, but this is at least partly due to differences in the occurrence of first grab samples on each day. Differences in concentrations between the wet/hot and dry/cold seasons were not significant.
Some screening tests held some promise, and should be further investigated.

Visual/olfactory assessments appeared to be able to discriminate a threshold-value of TSS (visual) and possibly TSS, ammonia, and TKN (olfactory). During Task 4, the assessment protocol was refined to use more standardized terminology.

The Hach DR/890 colorimeter showed good agreement with laboratory nitrate and ammonia measurements and less so for ortho-phosphorus compared to total phosphorus. In all cases there was an indication of between study-phase variability. To address these issues the recording forms for Task 4 were revised to better capture dilution and conversion factors.

Taylor kits provided good agreement with laboratory measurements for total alkalinity. Task 4 relied largely on Taylor kits for this measurement, with some additional laboratory measurements for confirmation. Chlorine measurements by Taylor kit could not be independently assessed. They were utilized occasionally during the implementation of Task 4 to assess the effectiveness of chlorination devices.

6.2 Preliminary Assessment of Treatment Systems

Maintenance and operation of treatment systems appear to be important variables that were not systematically characterized in this study. Both the sampling results of processes that require replenishment of materials and anecdotes by the samplers indicated that this is an important, but not quantified, element of performance variability.

Typical influent concentrations of cBOD5 and TSS were consistent with domestic sewage, and total phosphorus slightly elevated. TN concentrations were about twice as high as concentrations during a study that established the feasibility of current treatment standards and as the septic tank effluent concentrations provided in Florida performance-based treatment system regulations as point of comparison. Overall, 50% of influent composite samples showed a TN concentration between 47 and 94 mg/L, compared to 15 and 43 mg/L for the effluent.

While overall, increased TN influent concentrations may be related to the use of water-saving devices, within the study there was no correlation between influent concentrations and the event water use measurements. Average water use for the individual homes treatment systems during sampling events was 190 gpd, both as average of individual measurements and as average of the site averages.

Intermediate composite samples indicated some influence of aerobic treatment systems but incomplete nitrification.

Overall, the addition of a phosphorus reduction treatment step, usually a media filter, improved treatment for TSS, cBOD5, nitrite-nitrogen, and total phosphorus. Systems without that treatment step had median concentration results similar to an earlier survey of ATUs in the Keys.
Among the phosphorus treatment approaches sampled there were significant differences in effluent concentrations. While overall, total phosphorus was significantly reduced, the Keys treatment standard was not met in most cases, even for the better performing approaches.

Within the treatment systems sampled, nitrification appeared to be a limiting step to nitrogen reduction. The sampling events with the most nitrified effluent achieved typically about a 75% reduction compared to their influents, while the events with the least nitrified effluent only achieved a typical TN-reduction of about 28% and did not eliminate cBOD5. Events with intermediate nitrification showed intermediate TN-reduction and some indications of occasional alkalinity limitation.

25% of the obtained fecal coliform samples exceeded the secondary grab sample standard of 400 cfu/100 mL. Nearly half of the obtained chlorine measurements did not meet the system-required chlorine residual. Such observations confirm that aerobic treatment alone is not sufficient to meet secondary fecal coliform standards. The chlorine measurements also point to the need for monitoring the effectiveness of chlorination units.

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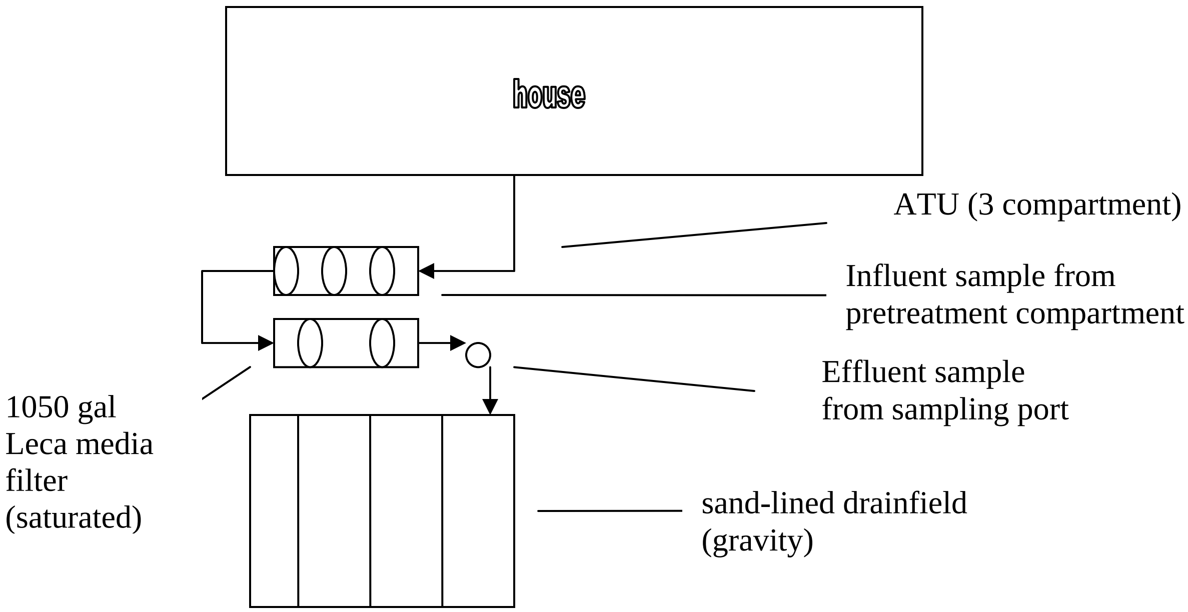
APPENDIX A: SCHEMATICS OF SAMPLED SYSTEMS

Note: These are not-to-scale flow schematics of treatment systems, based on observations by the samplers and reviews of permit records.

001: RP-001



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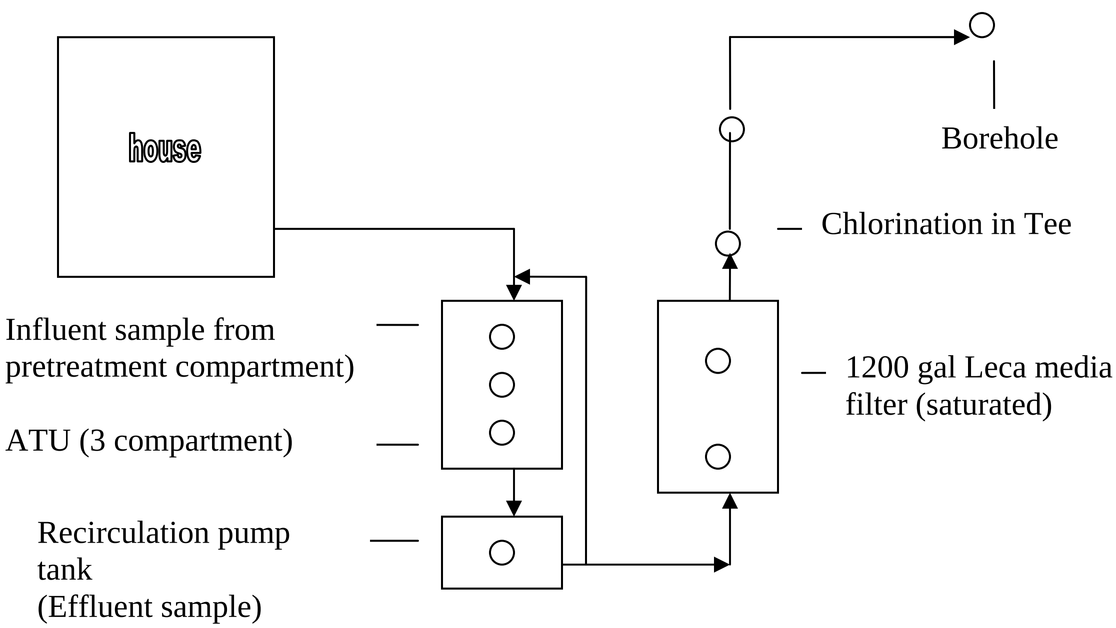

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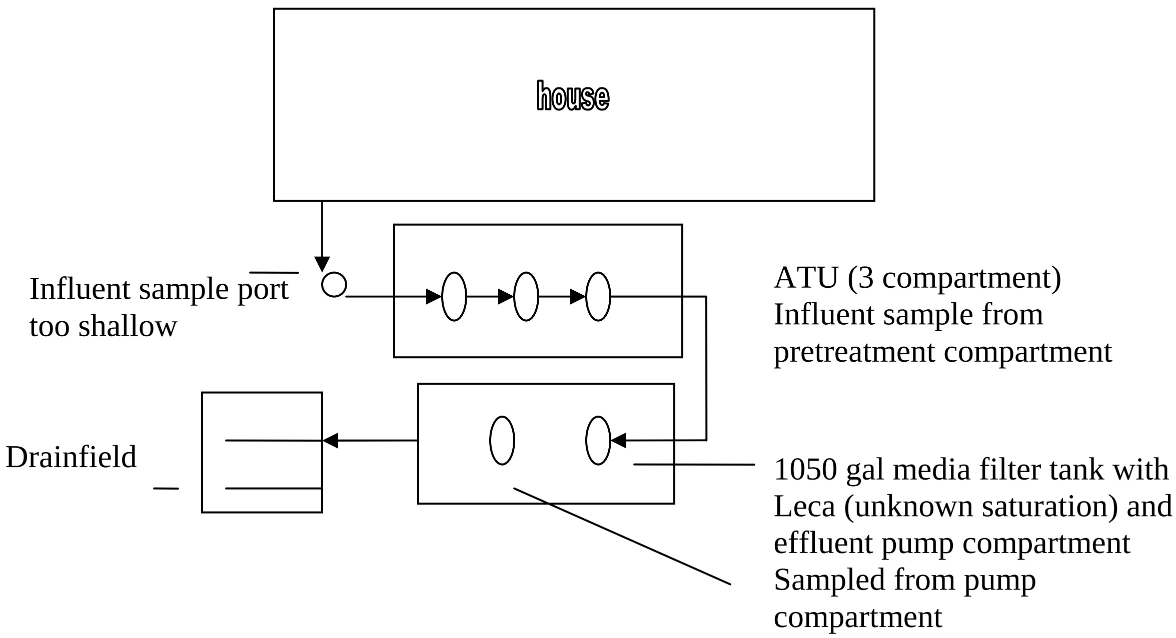

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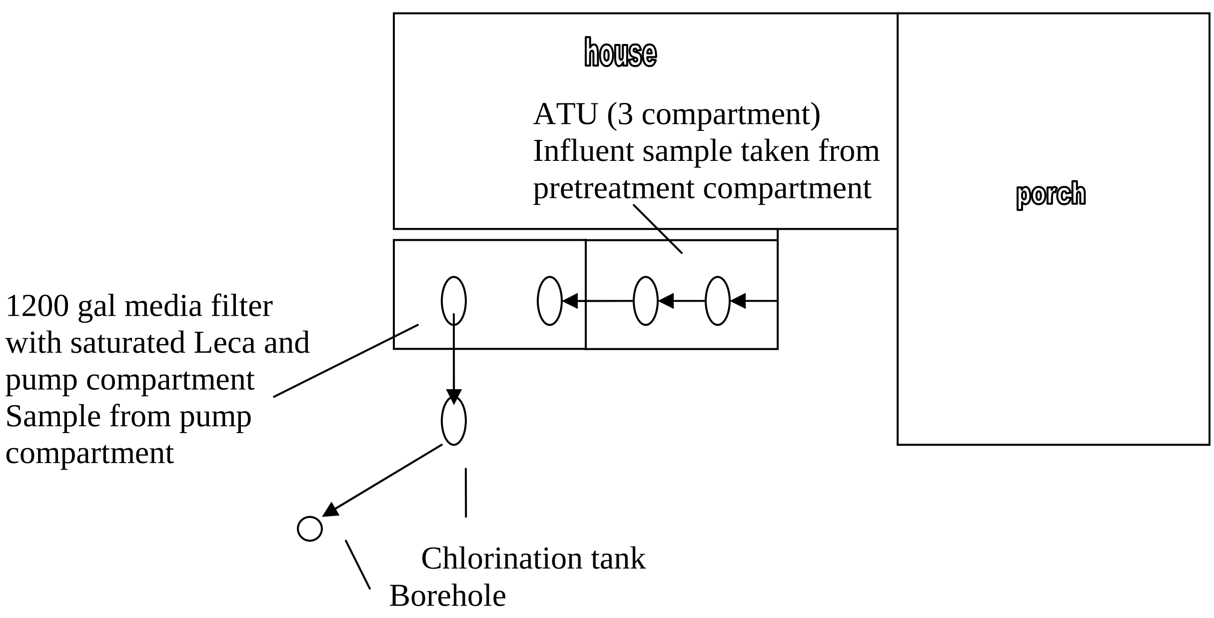

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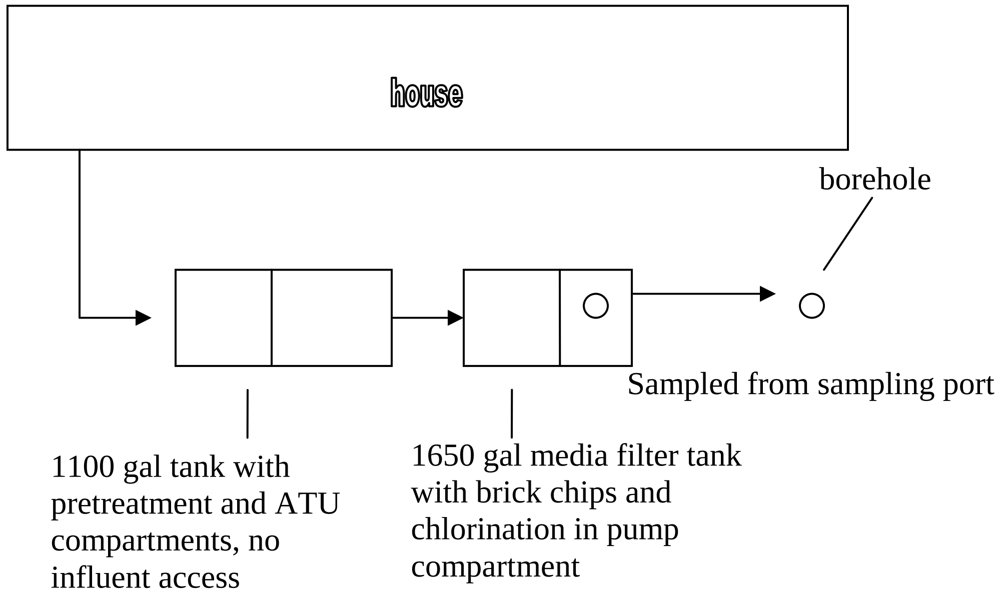

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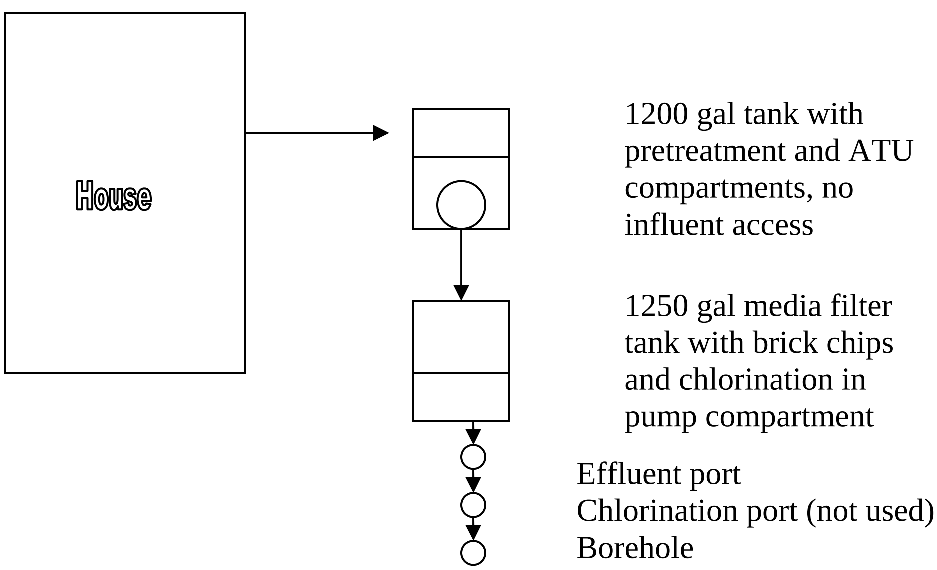

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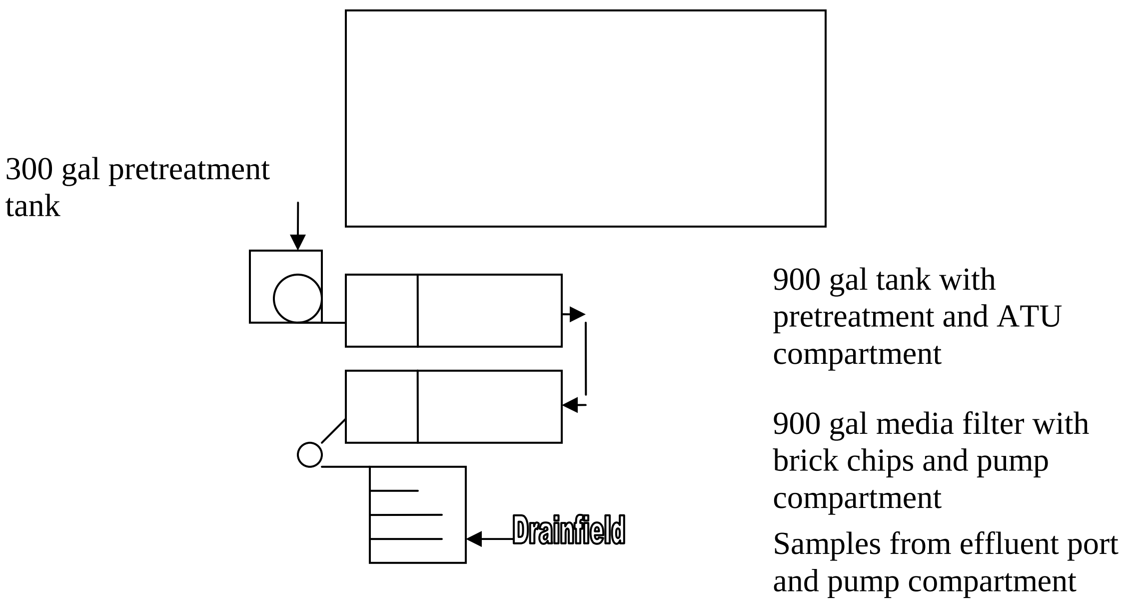

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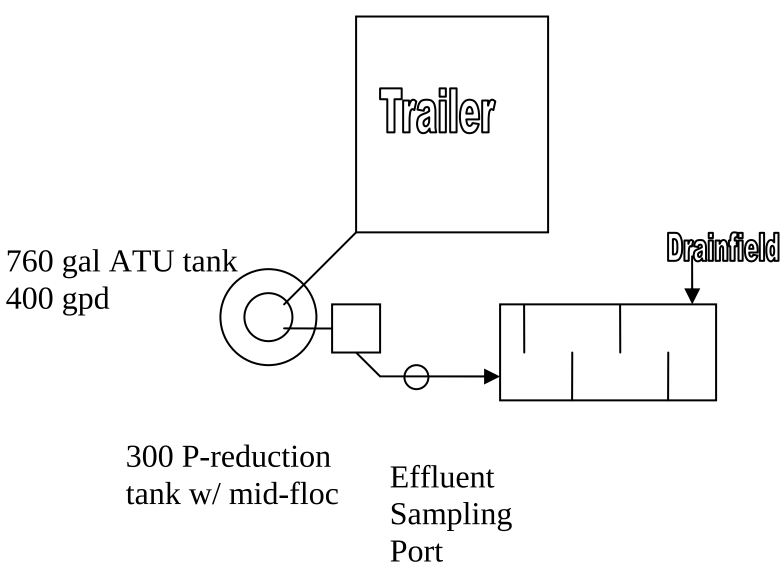

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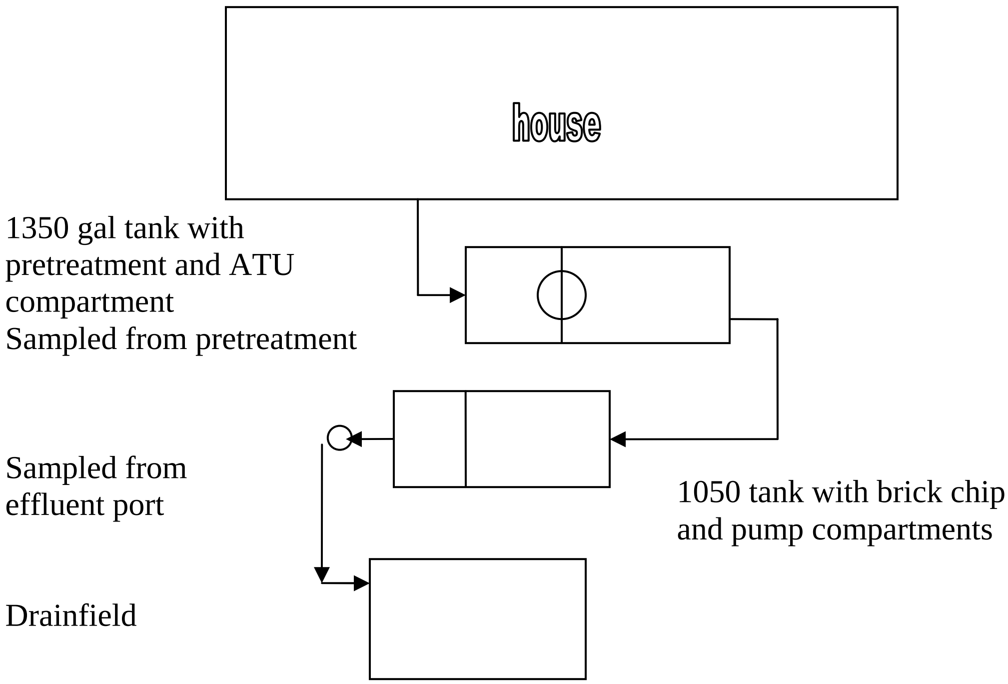

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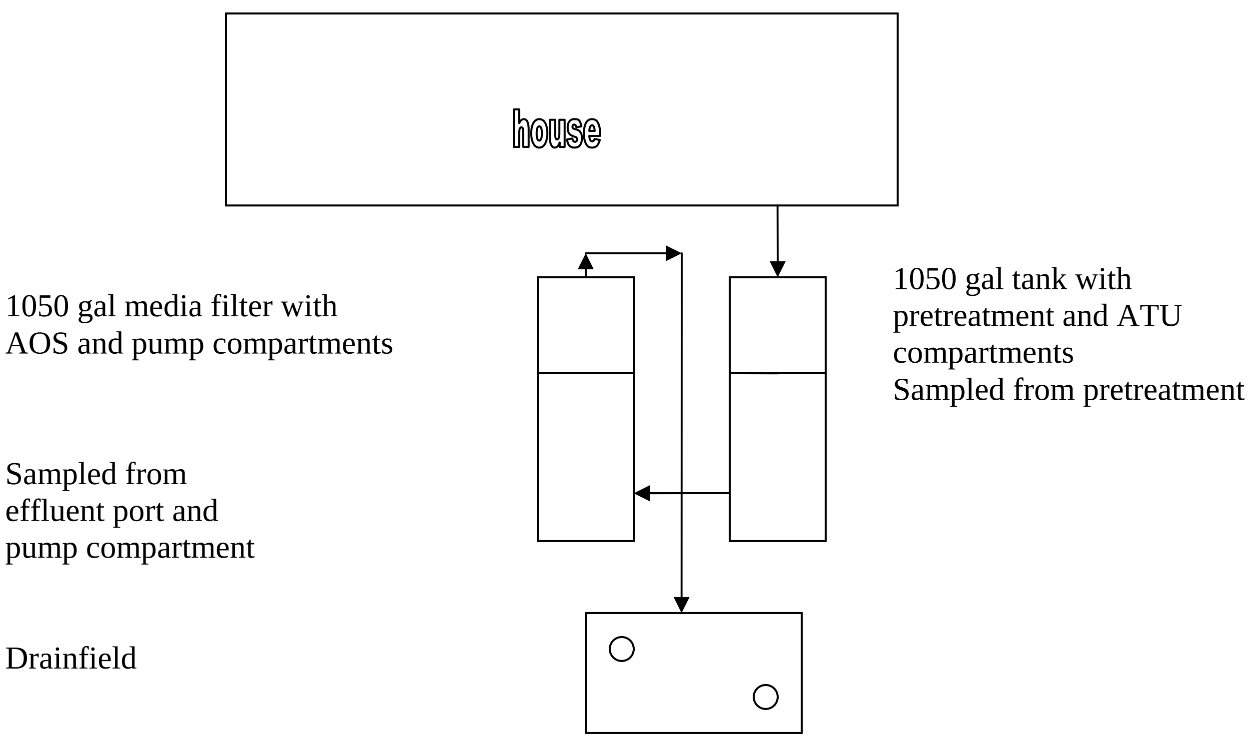

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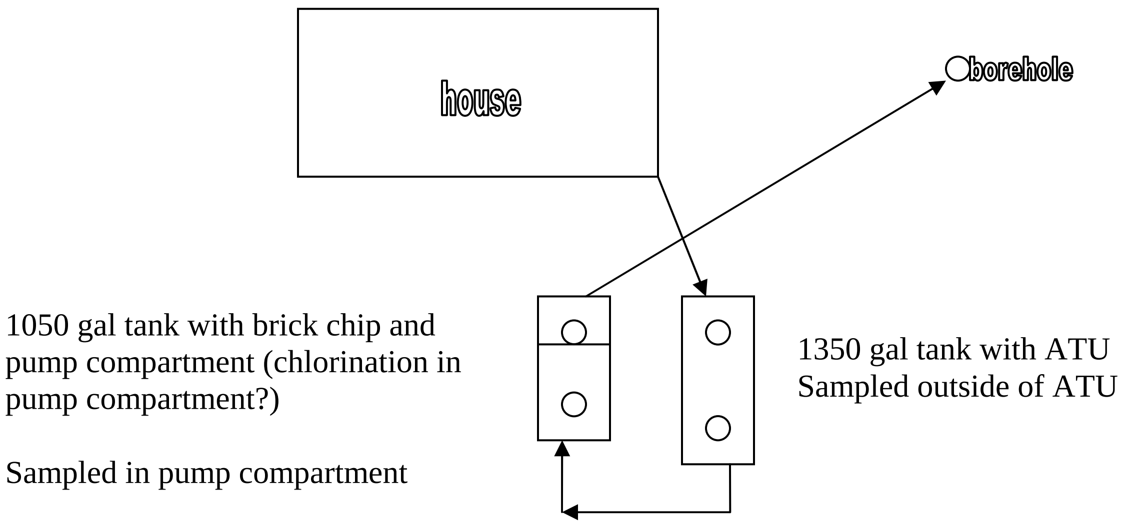

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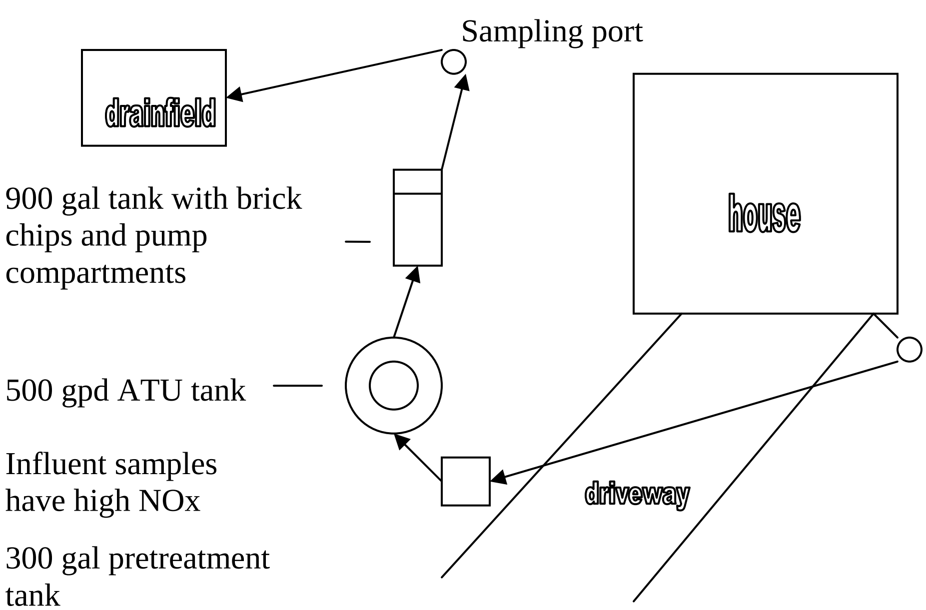

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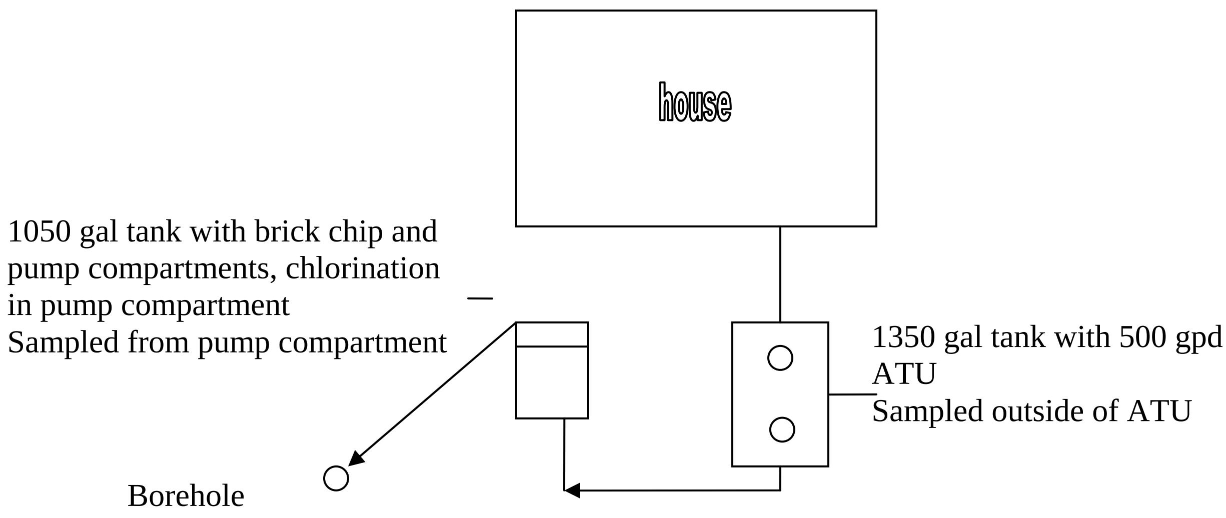

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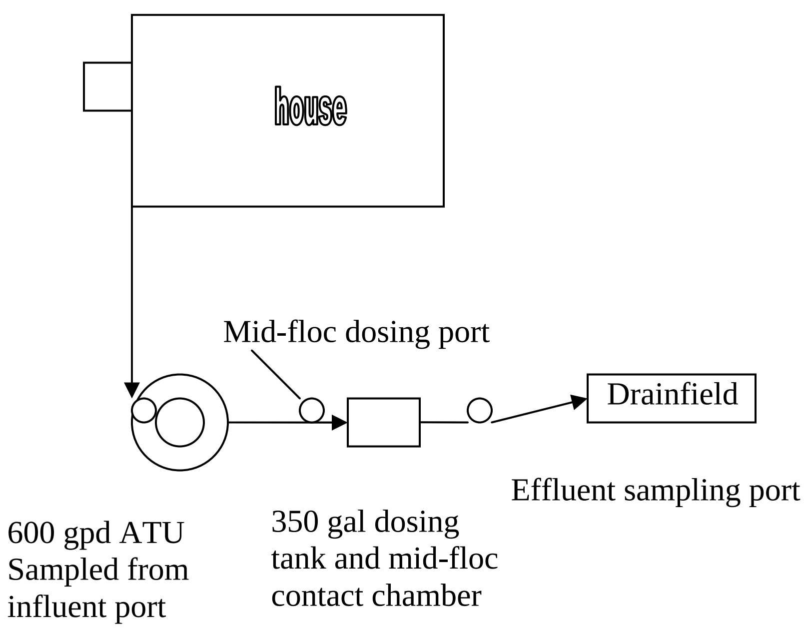

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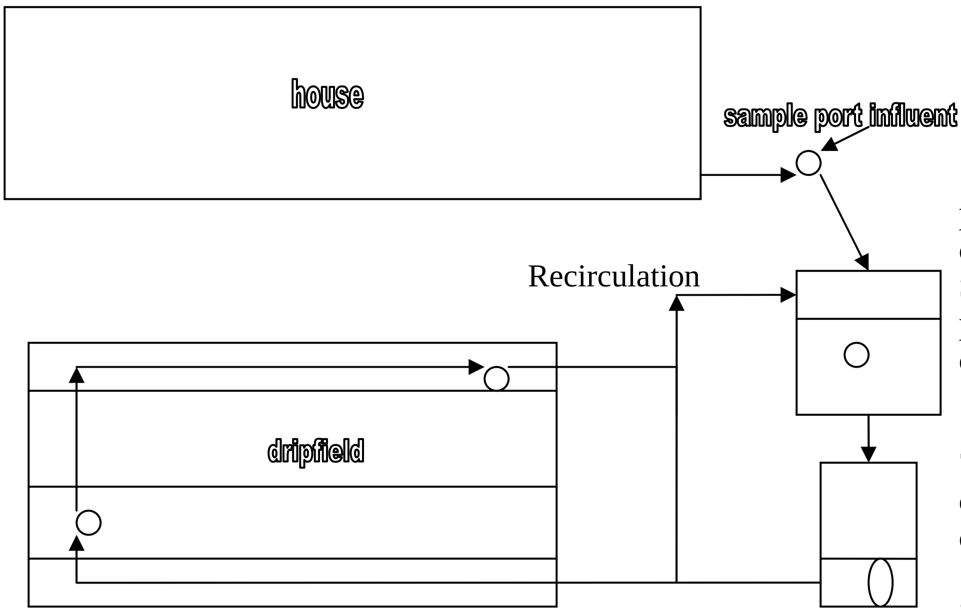
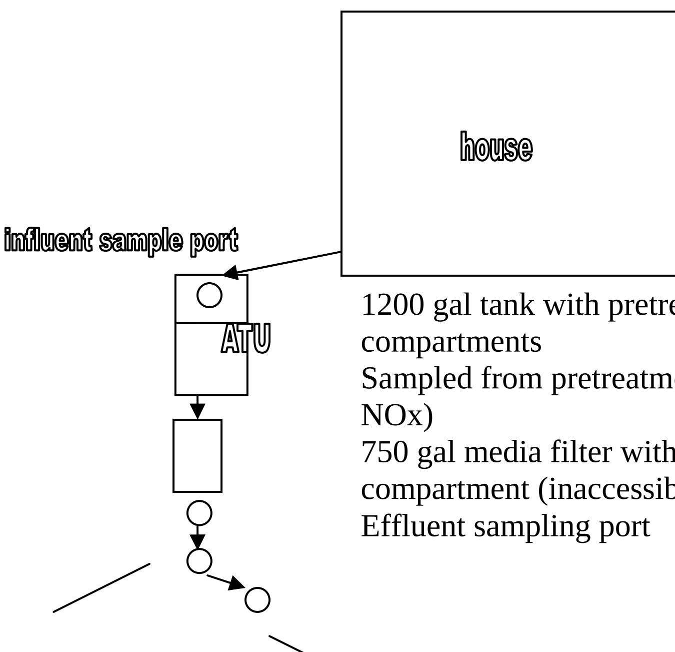


1200 gal tank with pretreatment and ATU compartments
Sampled from pretreatment compartment

750 gal tank with brick chip and pump compartments

Sampled from pump compartment

016_RP-016

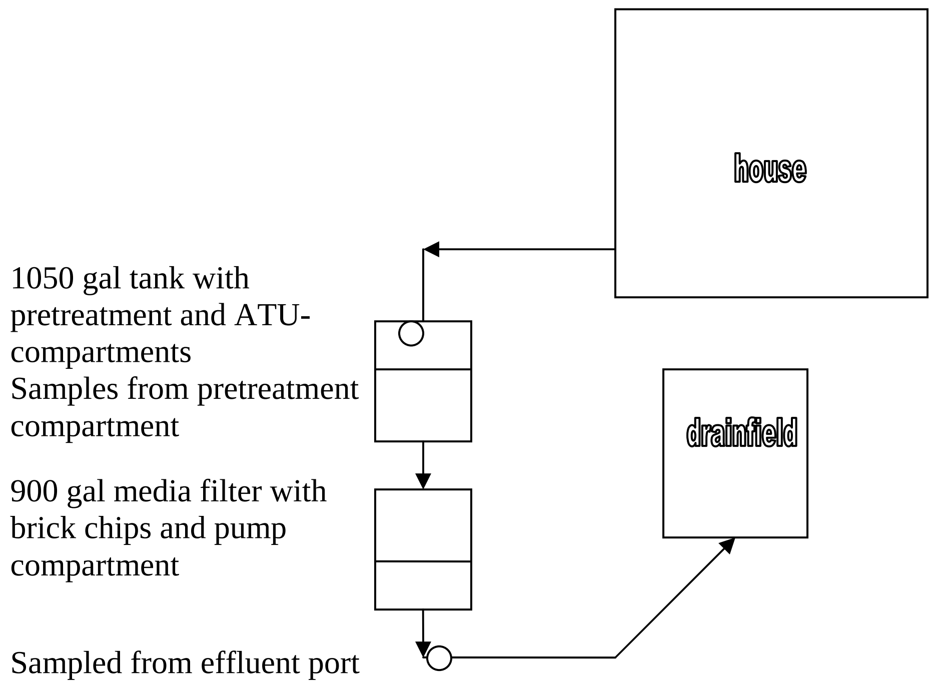


1200 gal tank with pretreatment and ATU compartments
Sampled from pretreatment (one sample has high NOx)
750 gal media filter with brick chip and pump compartment (inaccessible)
Effluent sampling port

Chlorination moved from pump compartment to port

Borehole

017_RP-017



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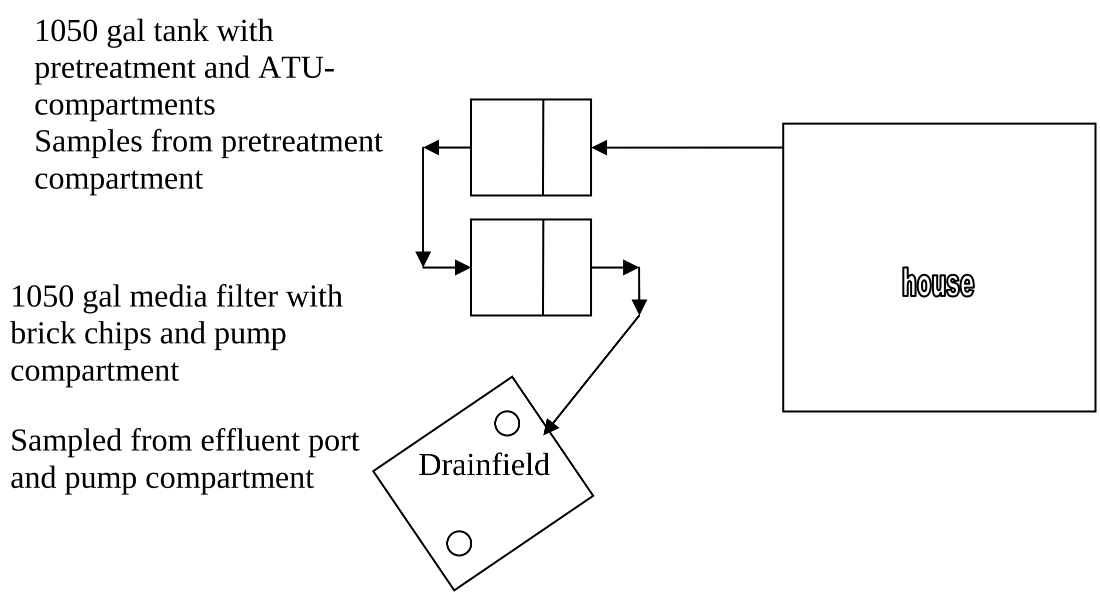

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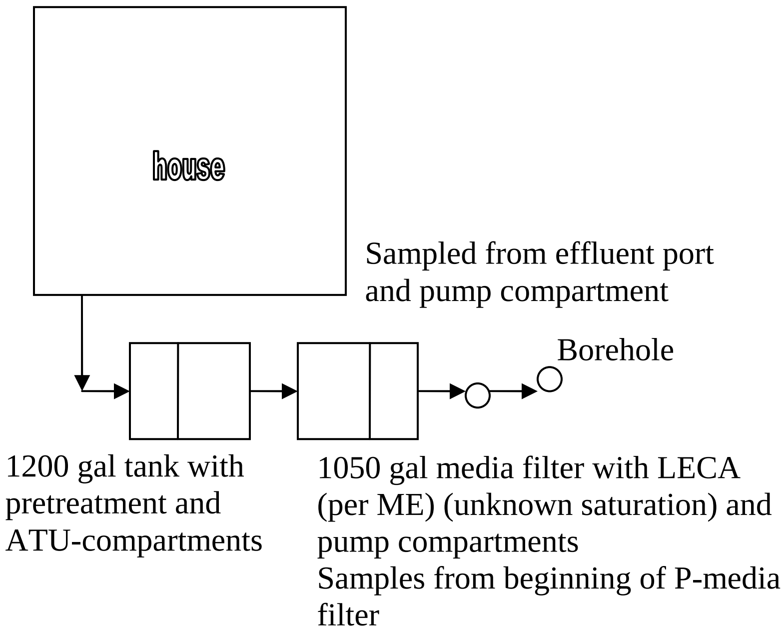

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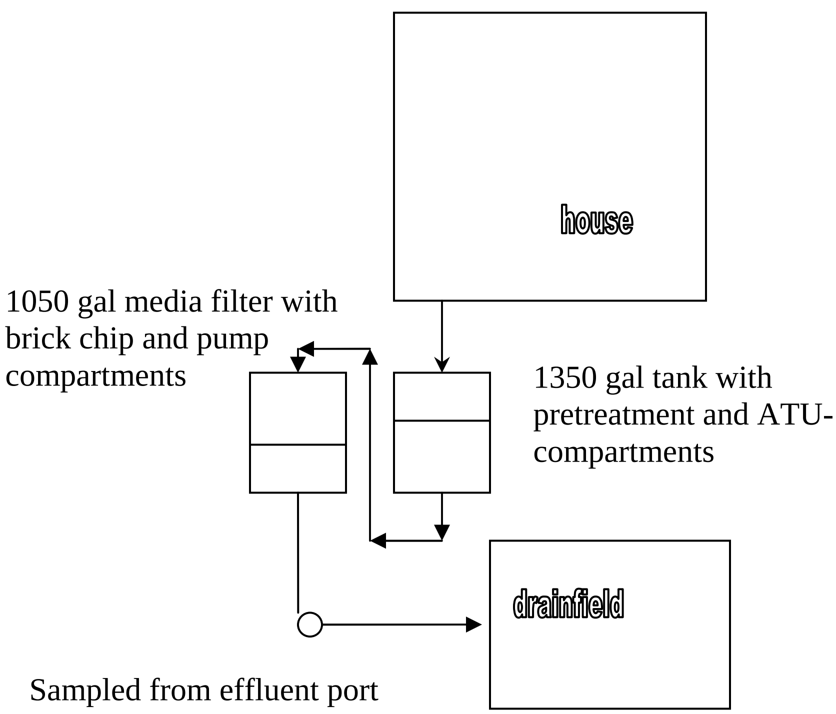

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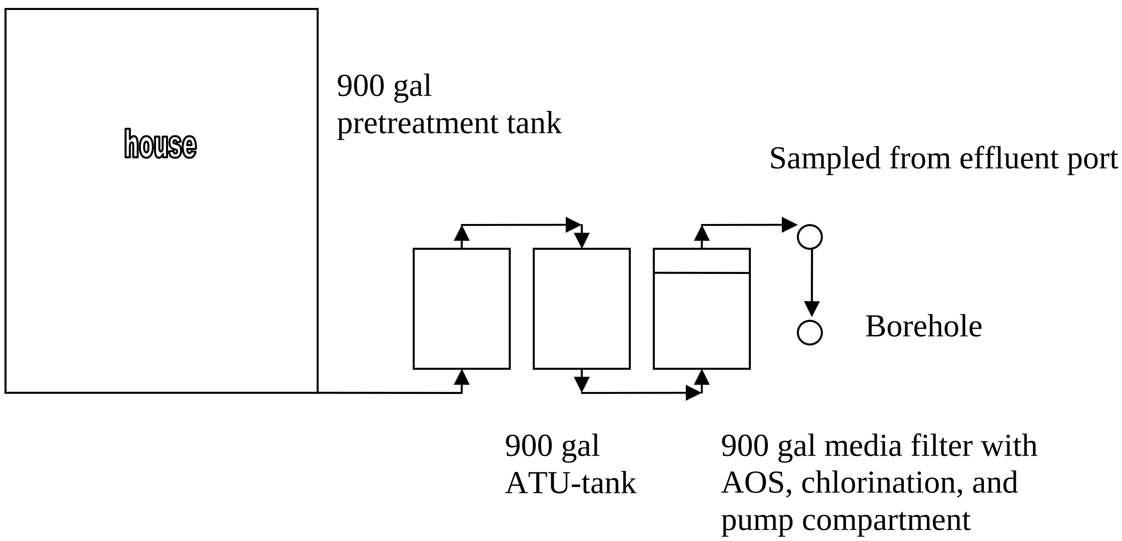

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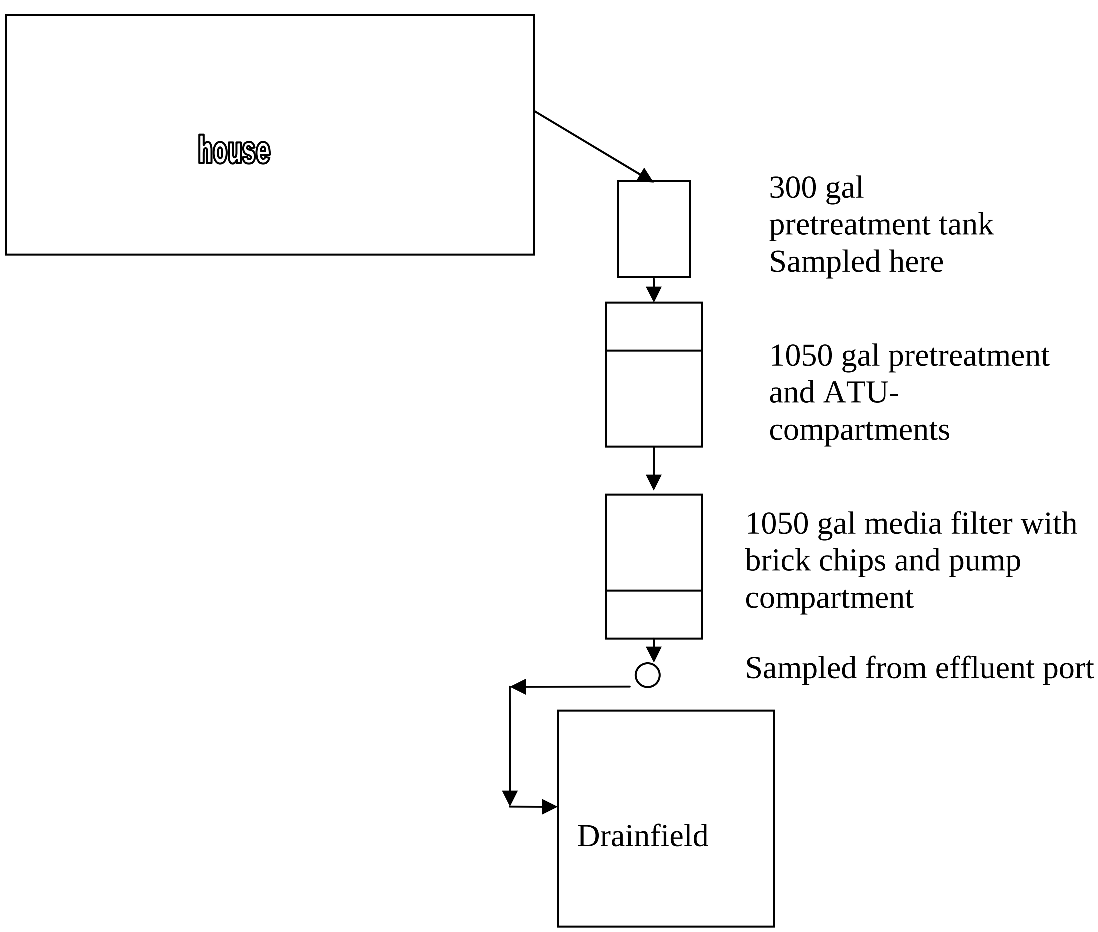

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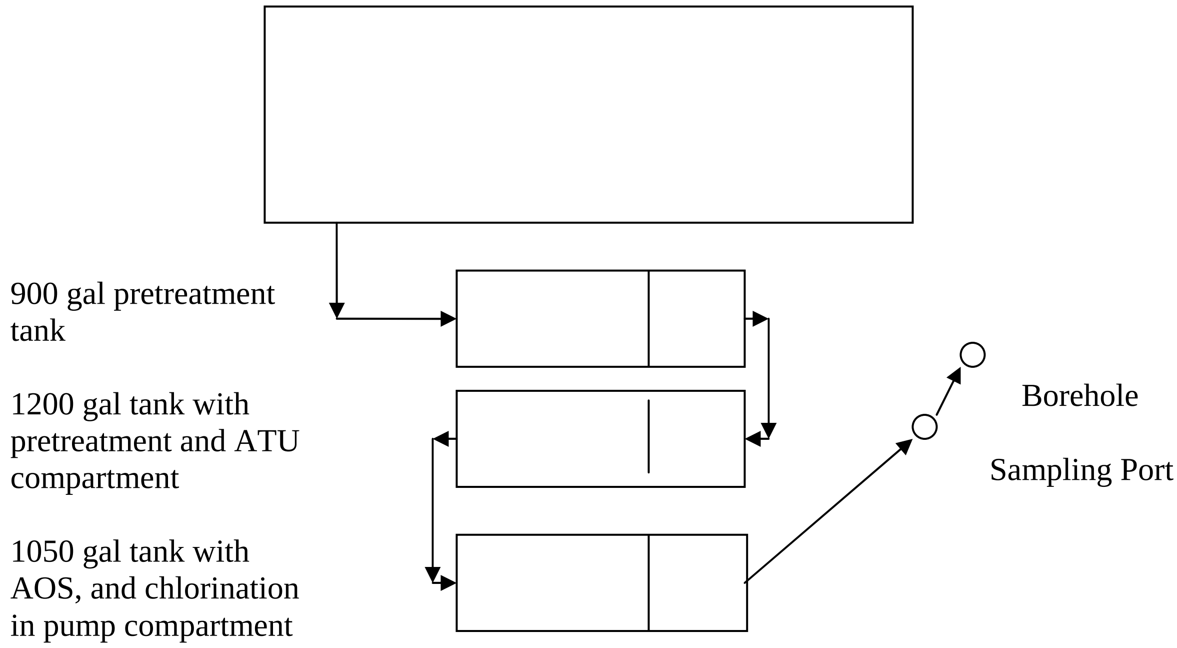

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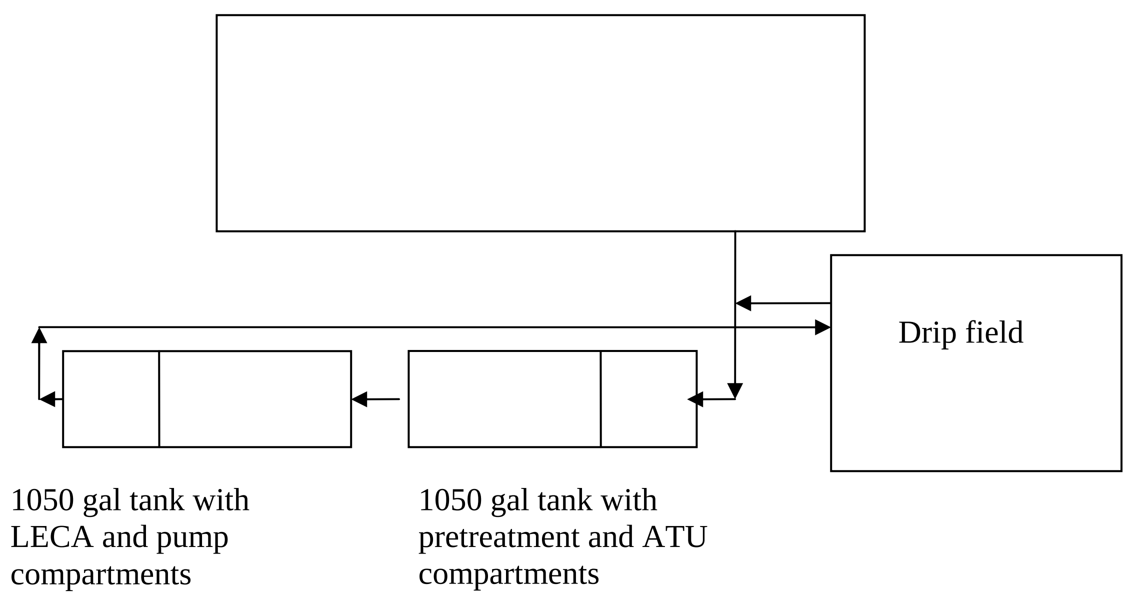

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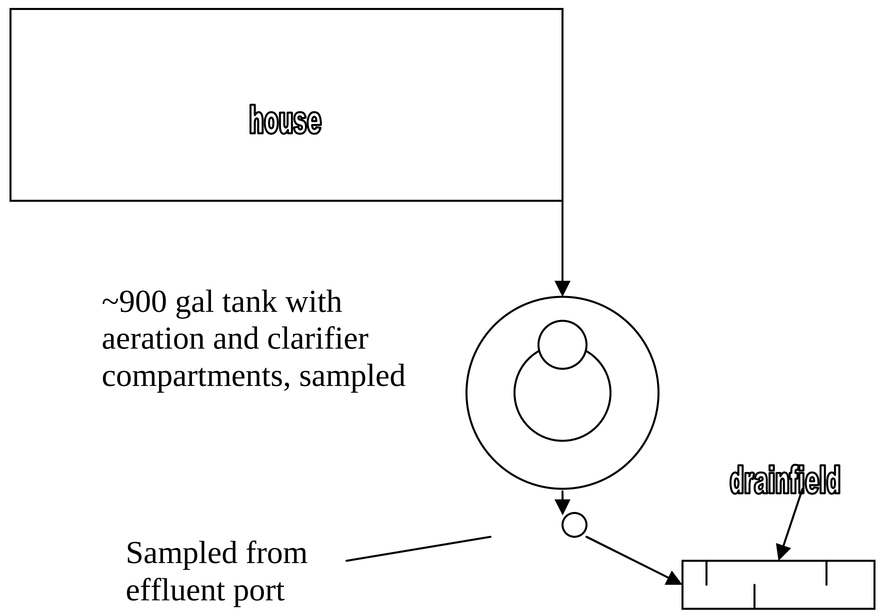

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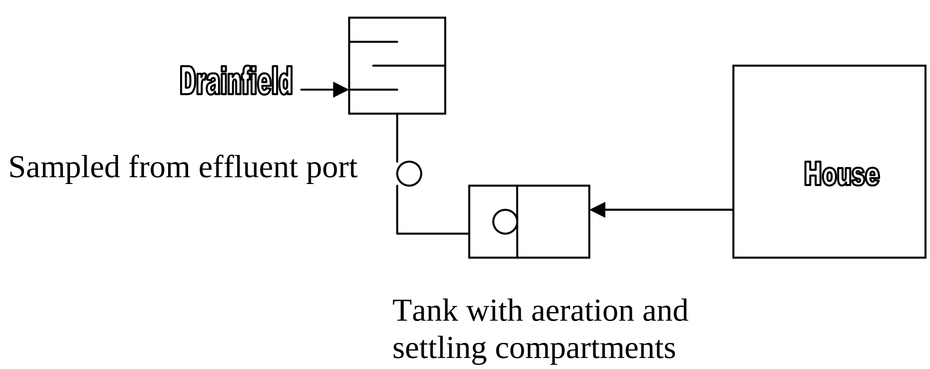

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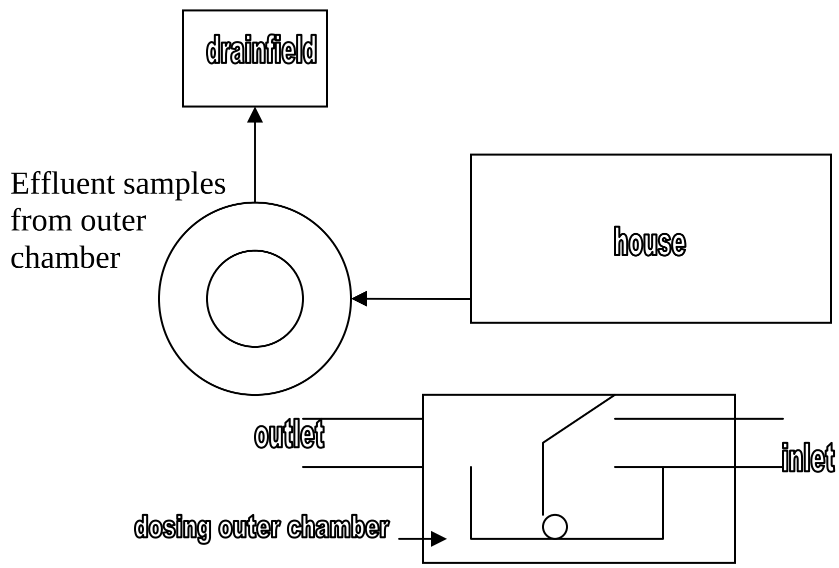

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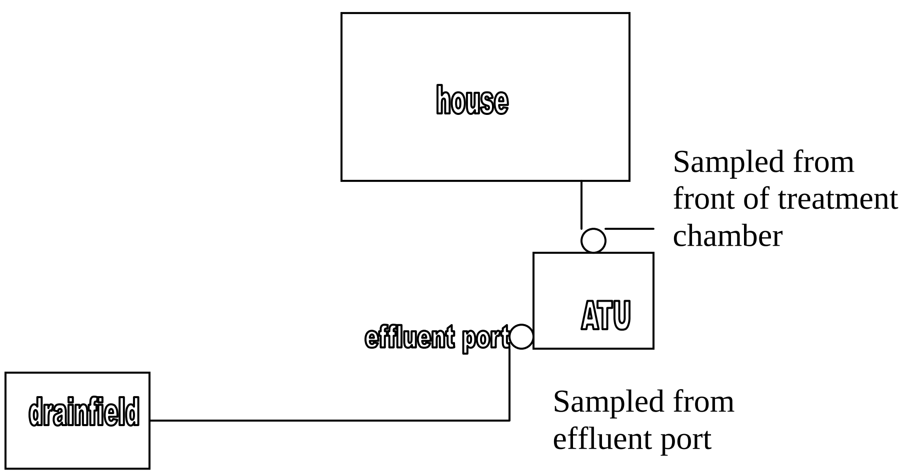

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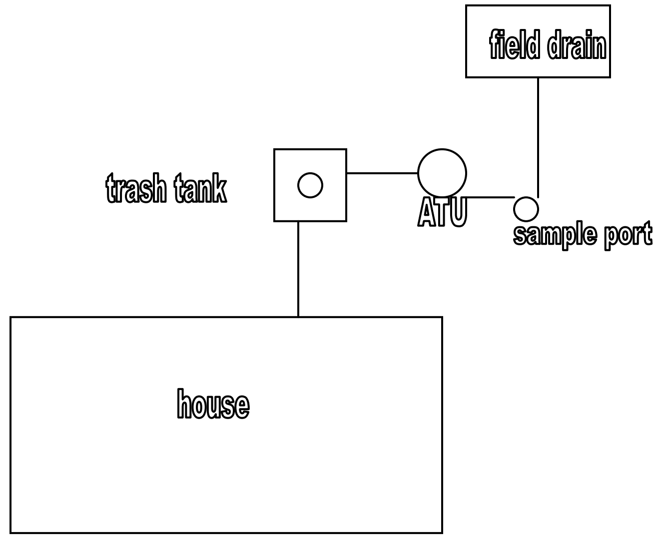

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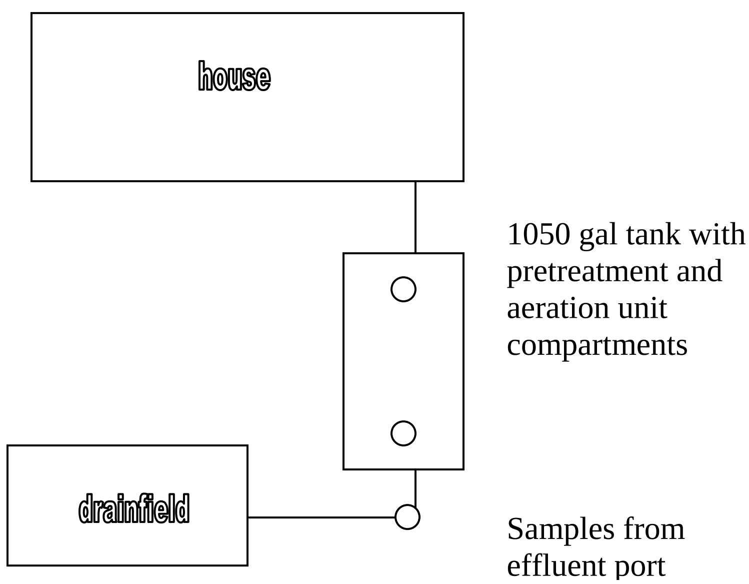

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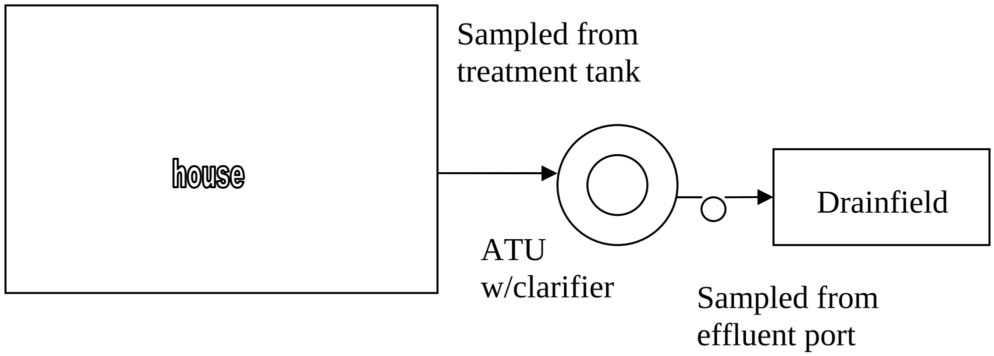

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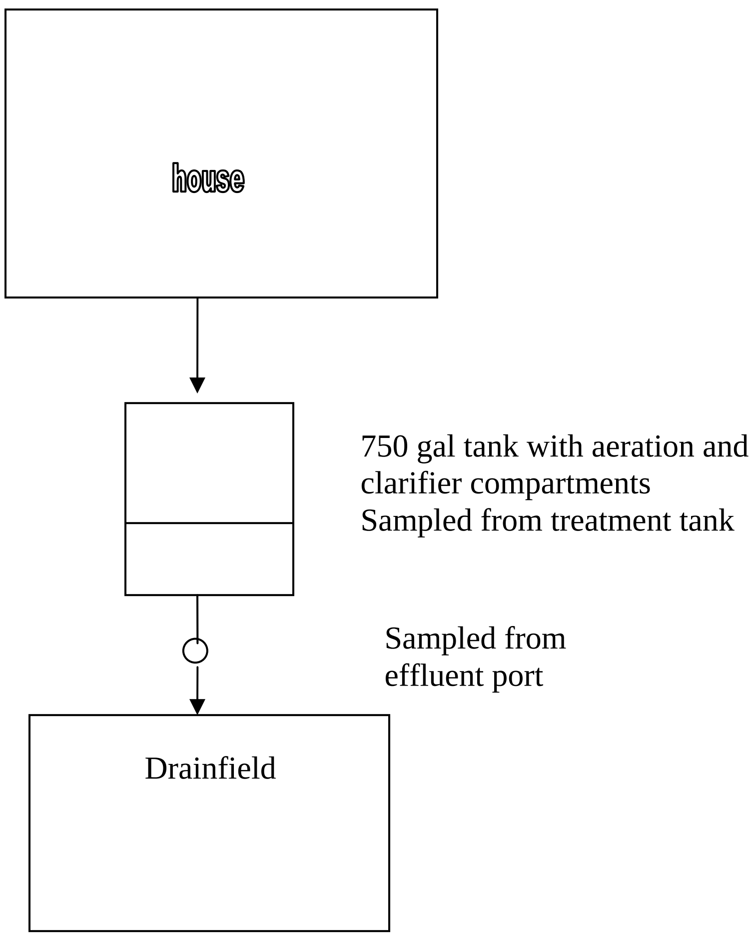

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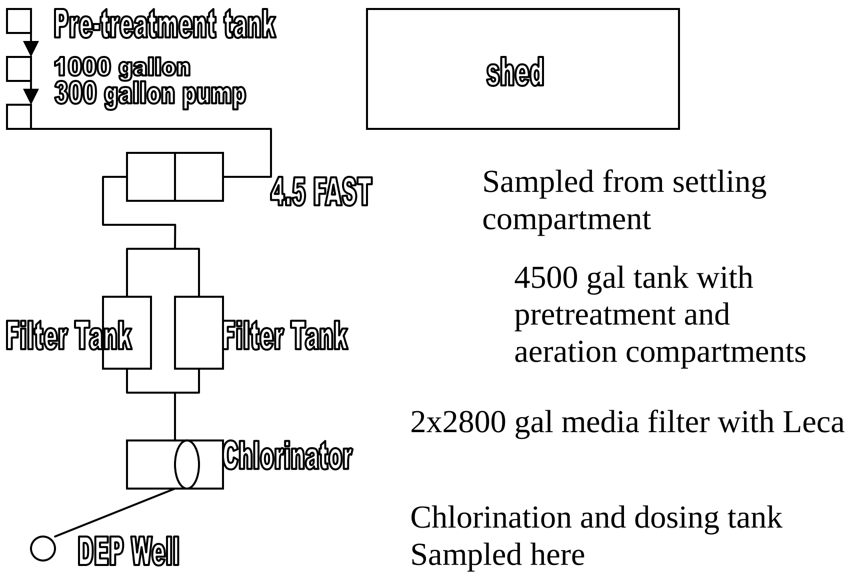

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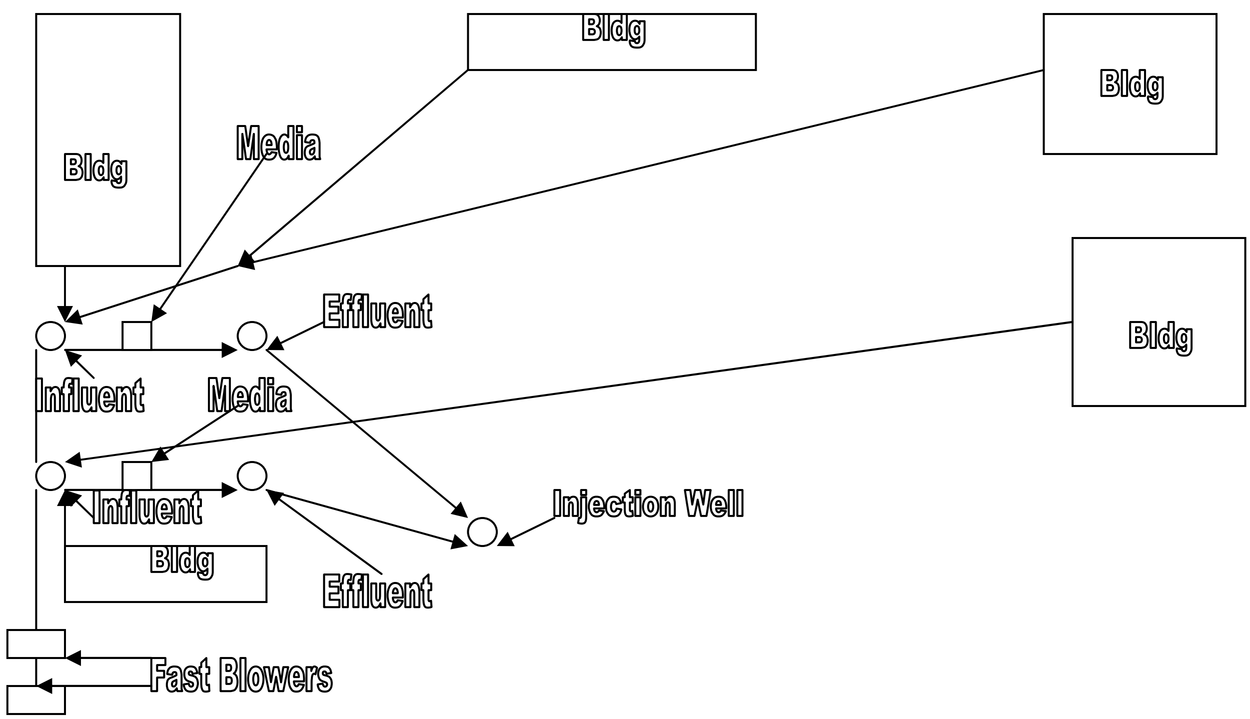

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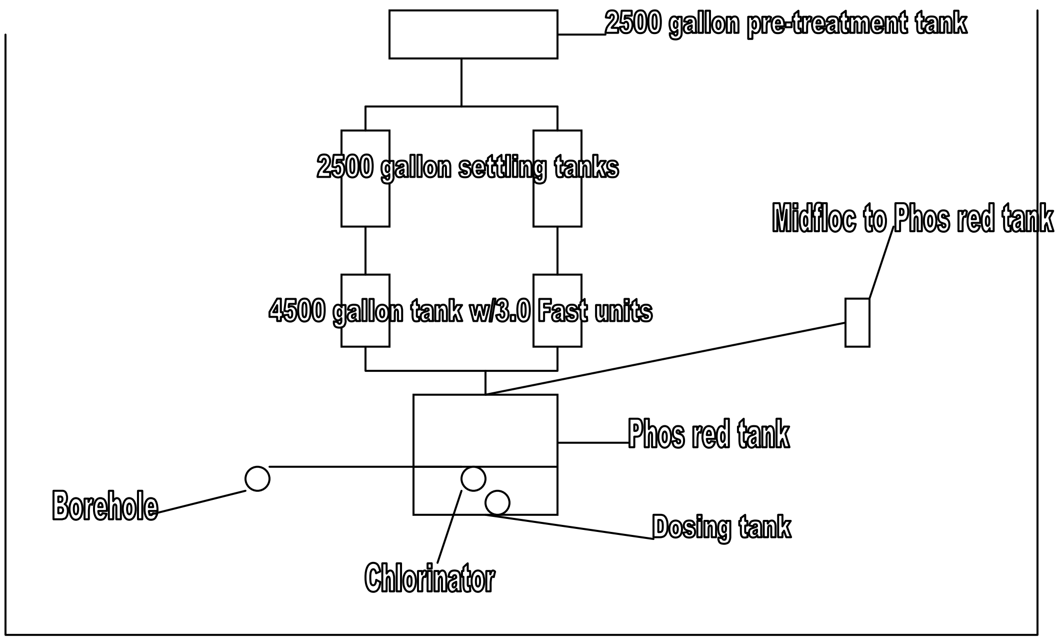

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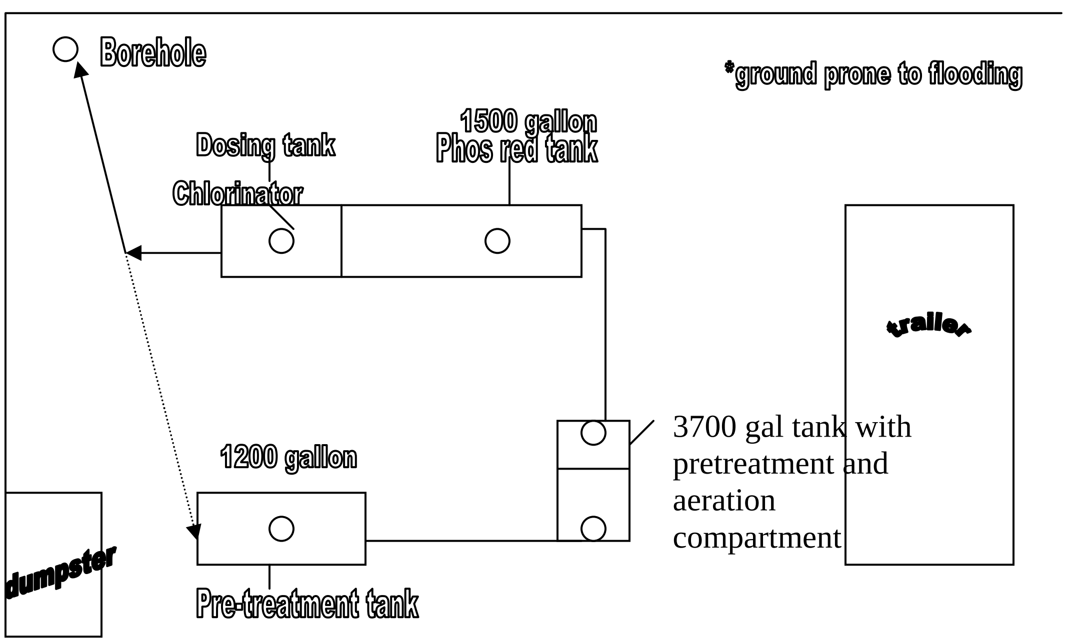

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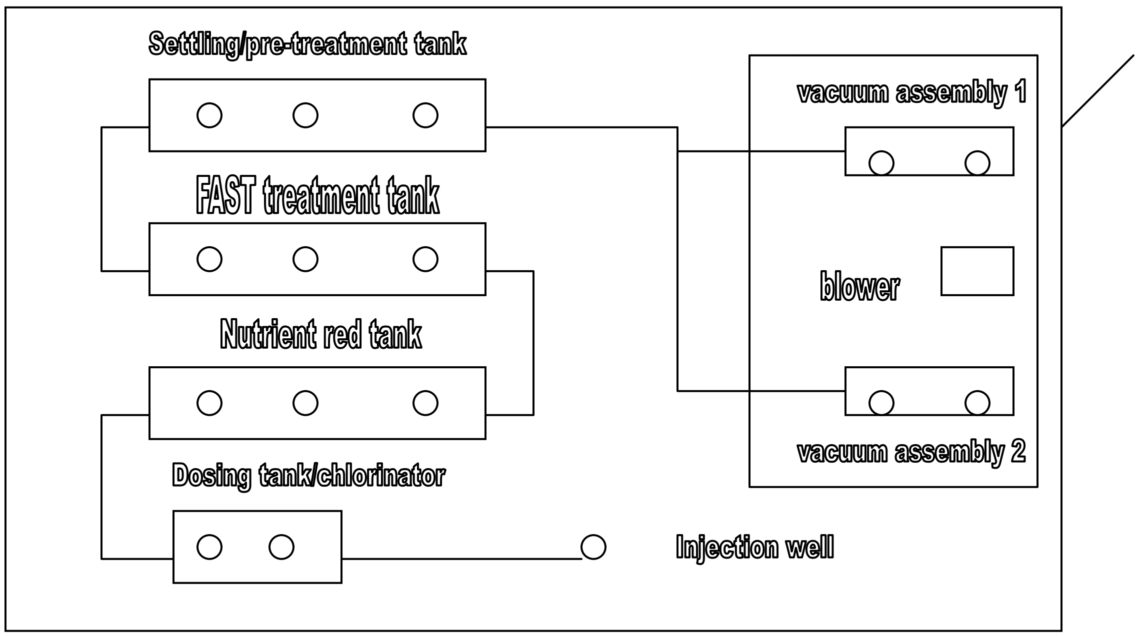

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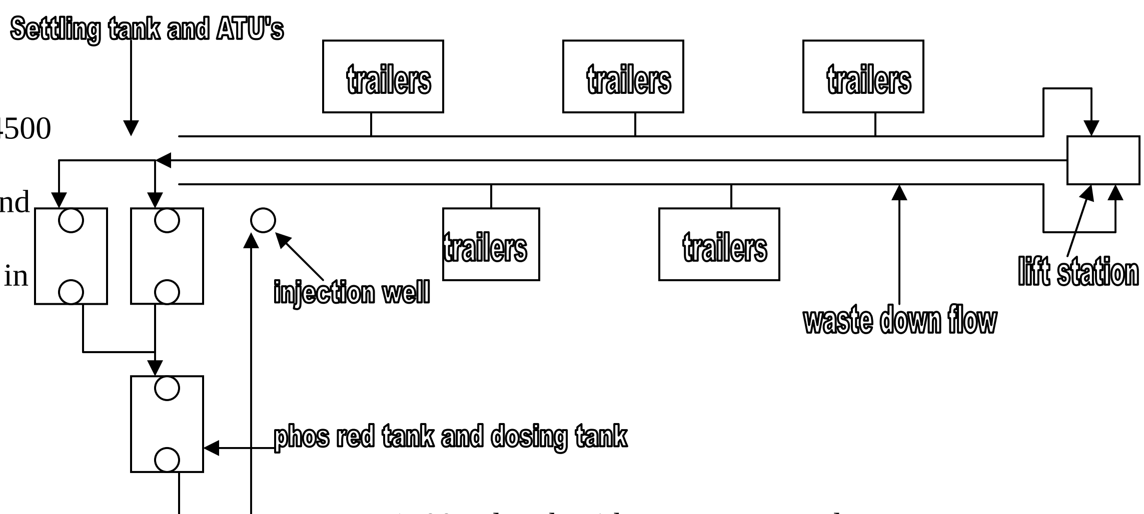
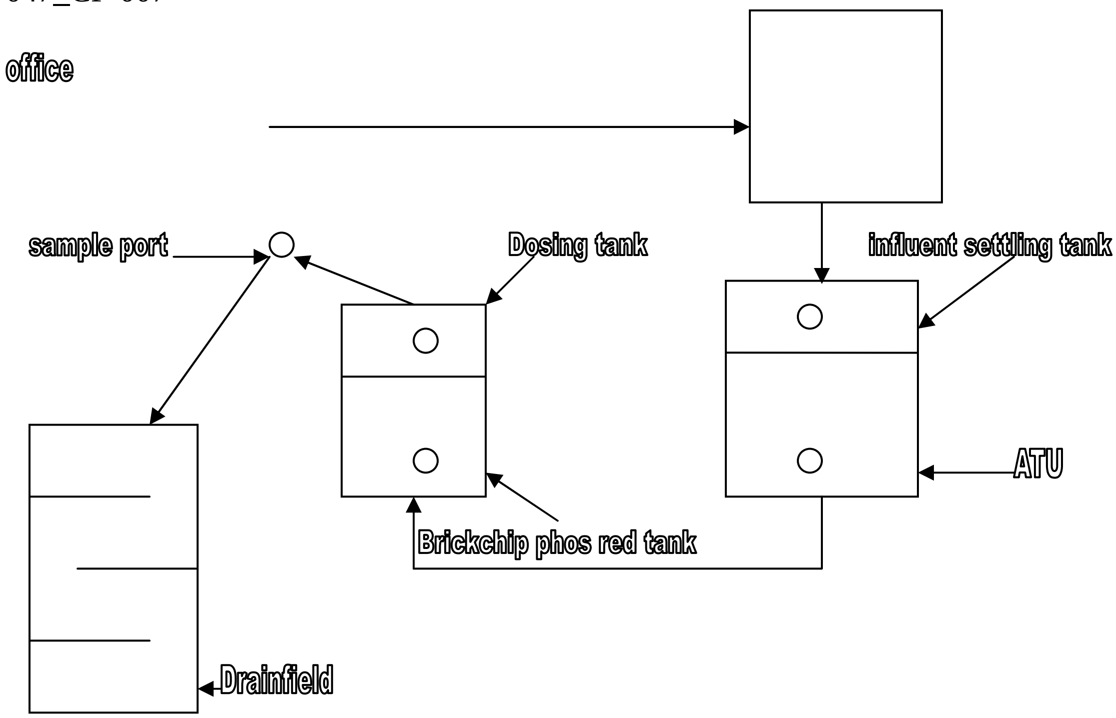


4400 gal and 4500 gal tanks with pretreatment and aeration compartments in parallel
Sampled from pretreatment

1500 gal tank with P-treatment and chlorination/pump compartments
Sampled from pump compartment

047_CP-007



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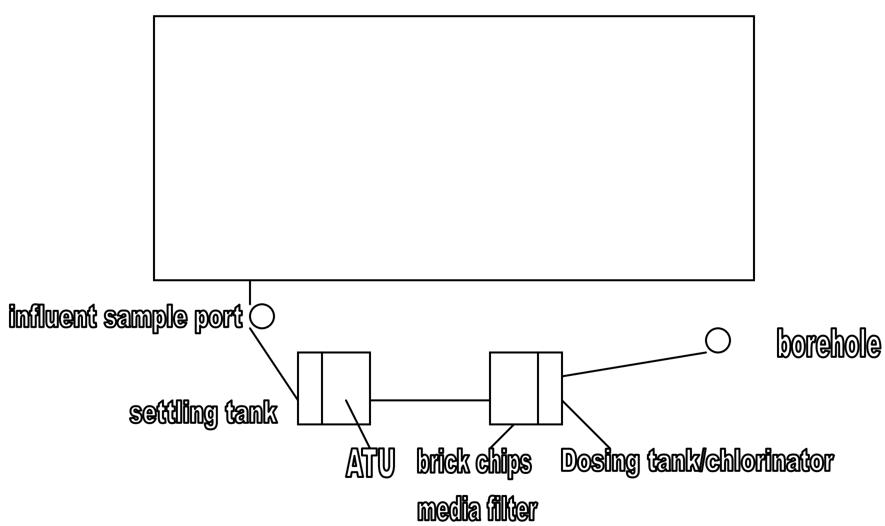

APPENDIX B: ELECTRONIC TASK 1 DATABASE