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EVALUATION OF MICROSEPTEC ENVIROSERVER RESIDENTIAL WASTEWATER TREATMENT SYSTEM

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1. Introduction

An innovative residential wastewater treatment plant process has been developed and tested by MicroSepTec Inc. of Laguna Hills, California, for on-site treatment of residential wastewater. In February of 1999 MicroSepTec authorized the Department of Chemical and Environmental Engineering at the University of California, Riverside (UCR) to conduct a full-scale treatment study to evaluate the capabilities of the Enviroserver, a proprietary residential wastewater treatment process manufactured and sold by MicroSepTec. Studies were conducted at the UCR campus where an Enviroserver 600 gpd treatment unit, complete with sampling and monitoring equipment, was connected to a University owned single-family residence occupied by a family of four.

Objectives

The primary objectives of the study were to assess effluent quality that can be achieved using the Enviroserver treatment system connected to a single household and to develop data that would provide additional insight regarding the mechanisms for enhanced nutrient removal and treatment efficiency under varying loading conditions. Specific objectives were:

1. Quantification of average 24-hour influent and effluent concentrations and flow rates.
2. Quantification of temporal influent and effluent concentrations and flow rates at hourly time intervals for four 24-hour periods during weekdays.
3. Evaluation of long-term performance of Enviroserver treatment system operated in automatic mode.
4. Evaluation of stress loading.

Optimization of the treatment process for effluent quality in general or enhanced nutrient removal and sludge management in particular were not part of this study.

Scope of Work

The evaluation was conducted in three main parts: 1) initial acclimation period, 2) long-term removal efficiency, and 3) stress loading study. Unaltered, raw wastewater from a single-household residence located on the UCR campus was used as influent to an Enviroserver 600 residential wastewater treatment unit provided by MicroSepTec.

Performance and effluent quality were measured in terms of total dissolved solids (TDS), total suspended solids (TSS), total organic carbon (TOC), carbonaceous biological oxygen demand ($CBOD_5$), total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), total phosphorus (TOT-P), reactive phosphorus (PO_4-P), total coliform (COL-T), fecal coliform (COL-F), free chlorine (CHL-F), and total chlorine (CHL-T).

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2. Background

Wastewater management systems in metropolitan areas are most likely to be conventional activated sludge plants where wastewater is collected from individual households through an extensive wastewater collection network. Economies of scale make the use of centrally located treatment plants justifiable for large communities but exceedingly expensive for smaller communities and for sparsely populated areas. Special problems faced by small communities and isolated households in rural areas include limited finances, high per capita costs for a centrally located treatment facility, and limited operation and maintenance capability. Restrictive discharge requirements may also impose treatment requirements that must be met considering the potential assimilation capacity of leach fields and receiving water bodies, the potential for on-site or off-site reuse, and final disposal.

Traditional On-site Systems

The septic tank is the most widely on-site wastewater treatment alternative in the United States. Today, approximately 25% of the new homes being constructed in the United States use septic tanks for treatment prior to disposal of residential wastewater. Septic tanks are buried watertight receptacles designed and constructed to receive residential wastewater with the primary purpose of solids separation and to discharge the clarified liquid for further treatment via natural treatment mechanisms in the leach field. Residential wastewater enters the septic tank where incoming solids and partially decomposed sludge settle to the bottom of the tank to form a sludge layer; oils, greases, and other lightweight materials rise to the top to form a scum layer. In most instances, septic tank effluent is discharged to a soil absorption field for additional biological treatment utilizing the assimilative capacity of naturally occurring microorganisms. Typically, a soil absorption system consists of a series of narrow, deep trenches filled with gravel. Perforated pipe is used to distribute the septic tank effluent throughout the trenches which then infiltrates into the soil mantle. In areas where conditions are not suitable for wastewater infiltration due to either soil characteristics or shallow groundwater tables, septic tank effluent can in some cases be discharged to engineered mounds that serve as biological filters or to constructed wetlands for treatment. Alternatively, a high efficiency on-site residential treatment unit can be employed to positively control treated effluent water quality.

High Efficiency On-site Systems

In areas with shallow ground water tables, adjacent to sensitive receiving water bodies, or areas where discharge of treated wastewater effluent from a typical septic tank is either limited or prohibited, high efficiency treatment units are required that can produce an effluent to near-potable or potable water standards. In areas subject to periodic drought there is also a need for a reliable source of water. The benefits with high efficiency treatment also include a reduced demand for potable water by substitution, which would lessen overall water consumption. High efficiency treatment of household wastewater may encompass in-house recycle of treated wastewater either as a separate source of non-potable water for washing and flushing and/or as a source of irrigation water.

Recycled water, if it is suitable for a direct beneficial use, is a valuable resource provided the use of the water will not adversely affect downstream water quality, plant life, fish or wildlife or pose a threat to public health. The effects of physical and chemical parameters for non-potable uses of reclaimed wastewater are, for the most part, well understood and criteria have been established. Health related microbiological limits are more difficult to quantify as evidenced by widely varying standards and guidelines throughout the world. Because domestic sewage is a potential public health concern regulatory controls related to the use of reclaimed water are principally directed at public health protection. As a consequence the required degree of treatment and microbial quality increase as the likelihood of human exposure to the reclaimed water increases.

A high efficiency on-site treatment of residential household wastewater, which includes complete effluent disinfection, should produce an effluent water quality that is safe for on-site, non-potable reuse of reclaimed wastewater. An innovative residential wastewater treatment plant is currently being tested. The treatment process is unique in that excess biomass is periodically decomposed to carbon and inert ash in a thermal processor as opposed to periodic wasting and subsequent disposal in conventional biological treatment systems. Hereby, an effluent with low suspended solids concentrations can be produced without a final filtration step. The residential treatment is monitored and controlled by a computer control system and is maintained by trained service technicians, not the occupant, a practice which represents a departure from conventional on-site residential wastewater treatment.

3. Experimental Facilities

The evaluation was conducted at the University of California, Riverside campus using a residential wastewater treatment unit supplied by MicroSepTec. The test unit was a full-scale residential treatment unit, Enviroserver 600, equipped with an above ground thermal processor and computer control system for local and off-site control and process monitoring. The test facility and principles of operation are described below.

Test Facilities

The test facilities used in this study included a reactor tank with compartments for primary and secondary clarification, compartments for biological oxidation, recirculation and discharge pumps, thermal processor, air compressor and air diffusor pipes, and controls. A schematic of the UCR test facilities is shown in Figure 1a. In the test facility the thermal processor was located above ground and the chlorination contact chamber was installed as a separate tank. In the commercial version of the Enviroserver the chlorination contact chamber is incorporated into the reactor itself and the thermal processor is installed below ground in the first riser, Figure 1b.

All wastewater from the residence enters the inlet to the treatment unit via a 4-inch diameter PVC conduit by gravity feed. Treated effluent was returned to the existing house connection, which is connected to the city wastewater collection network. The Enviroserver 600 treatment unit was constructed of glass-fiber reinforced plastic with an overall volume of 7.6 m^3 (2,000 gal.) with a diameter of 1.5 m (5 ft.) and a length of 3.4 m (11 ft.). The test plant was divided into four equal sections separated by baffles set at an overflow height of 1.21 m (4 ft.). The first compartment, having an effective volume of 1.21 m^3 (320 gal.), was employed to provide primary sedimentation and an anoxic or pre-react zone, mixing incoming wastewater influent with partially treated wastewater and solids. The second and third compartments of the reactor, each with an effective volume of 0.95 m^3 (250 gal.), were individually aerated using air from a compressor supplied by header pipes equipped with membrane diffusers. In addition, each aerated

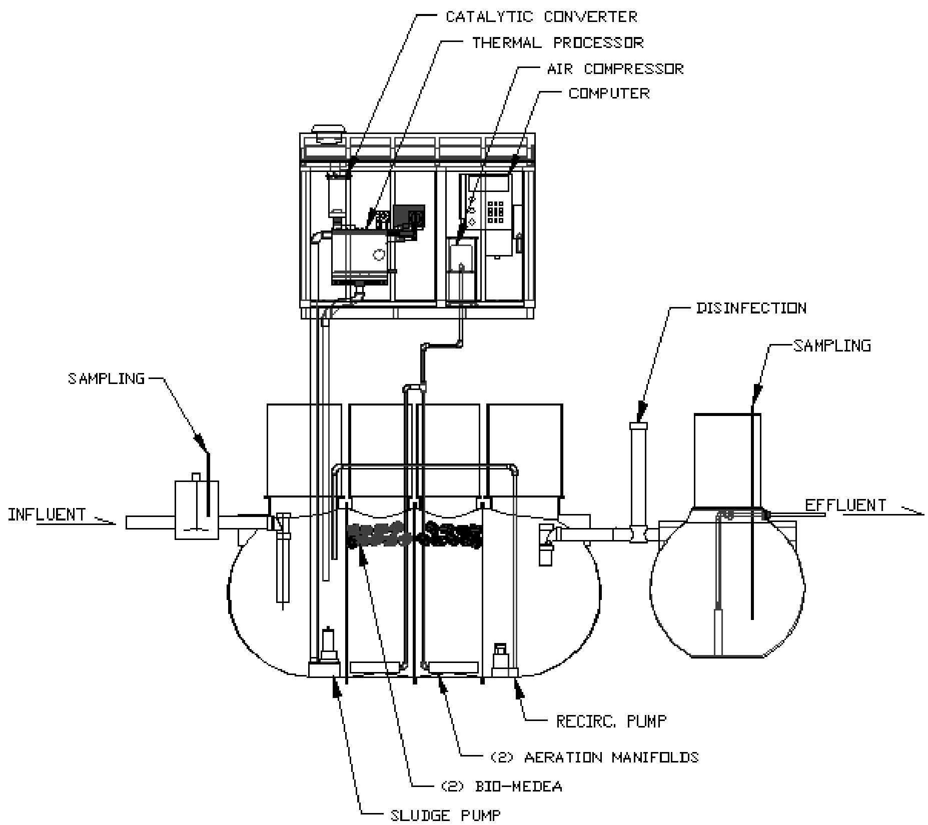

Figure 1a. Schematic rendering of the UCR test facility, an Enviroserver 600 residential treatment unit with separate chlorination tank.

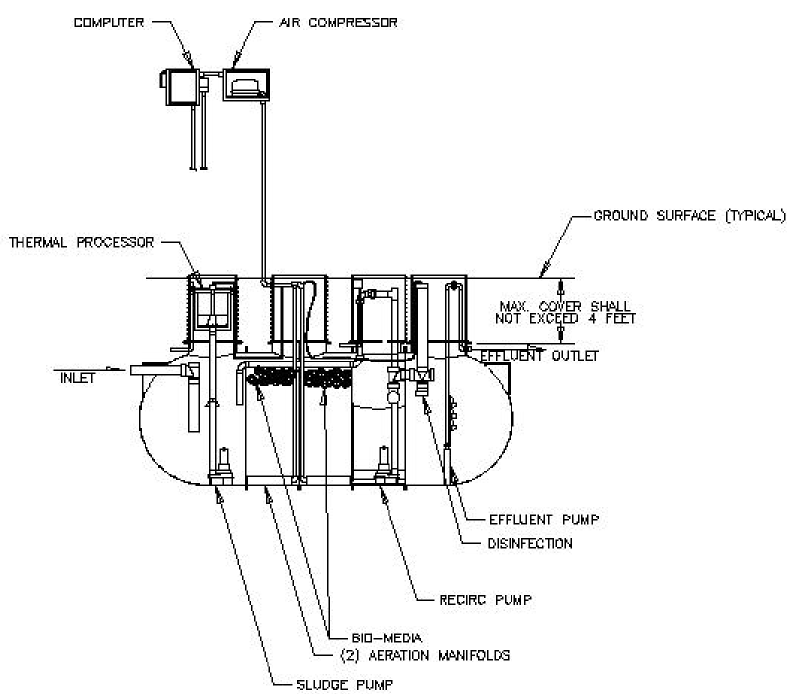

Figure 1b. Schematic rendering of the commercial EnviroServer 600 residential treatment unit.

compartment also contained fixed film support for attached biofilm growth in the shape of cylinders, diameter 90 mm dia (3.5 in.) and length 90 mm (3.5 in.), having a surface area to volume ratio of R=105 m^2/m^3 which provided a total of approximately 50 m^2 of surface area for fixed film growth in each compartment. The fourth compartment, having a volume of 1.21 m^3 (320 gal.), served as the secondary clarifier and temporary storage for excess and sloughed biomass. Treated wastewater was discharged from the secondary clarifier by gravity flow to the flow-through chlorinator for disinfection and held in the chlorination contact tank with an effective volume of 2.14 m^3 (300 gal.) prior to discharge.

Principles of Operation

The Enviroserver unit operates continuously and on demand. The influent feed from the residence is by gravity flow similar to an activated sludge plant. Residential wastewater enters the first compartment where flow equalization and primary clarification takes place. Because the contents of the first compartment is anoxic it also serves as a pre-react zone where soluble CBOD removal is enhanced by adsorption onto existing microbial flocs. Biological CBOD removal and nitrification takes place in the subsequent two aerated compartments. To promote CBOD removal and nitrification both compartments contain fixed media for attached biofilm growth. Depending on bulk oxygen concentration in the aerated compartments and thickness of the attached biofilm it is also possible that some denitrification takes place in the biofilm layers closest to the support where NO_3-N is available as the terminal electron acceptor. Biologically treated wastewater overflows into the fourth compartment reactor where secondary clarification takes place.

Excess biomass including biomass sloughed of the fixed film support is wasted using a thermal process that converts biological solids to a residual consisting of carbon and inert ash. Periodically, a small submersible pump is activated to return settled biomass from the secondary clarifier to the primary clarifier (pre-react zone). Settled biomass from the primary clarifier is periodically pumped from the bottom of the compartment to the thermal processor where the solids are retained by a stainless steel sieve and the water is drained back to the primary clarifier. After a set number of pump cycles the control system initiates the thermal decomposition of the retained solids which includes drying, gasification, and pyrolysis at controlled temperatures. The end product is an inert residual of carbon and ash that is flushed out the next time the primary clarifier recirculation pump is turned on. Recirculation of settled biomass from the secondary clarifier to the primary clarifier in combination with periodic thermal processing also help maintain low effluent TSS concentrations.

Enhanced nitrogen removal also becomes possible when the aerobically treated and nitrified wastewater from compartment two and three is recycled from compartment four to compartment one if a carbon source is readily available and the first compartment is free of dissolved oxygen, e.g. anoxic. The NO_3-N in the aerobically treated wastewater serves as the terminal electron acceptor and the raw wastewater influent entering the first compartment serves as the necessary carbon source for the denitrification reactions. Anoxic conditions are normally maintained throughout the day because the pre-react zone in compartment one is not aerated and because incoming raw wastewater quickly depletes any available oxygen despite the periodic influx of dissolved oxygen that is introduced into the pre-react zone during recycle pumping. The effect of biomass recycle and biomass conversion to ash in the thermal processor on treatment performance and operation strategies for optimizing enhanced nitrogen removal was not studied as part of this evaluation.

The clarified and treated wastewater next flows through a chlorination contact tank , which comprises a flow-through cell with a receptacle containing calcium hypochlorite ($CaCl_2O_2$) tablets. The chlorination contact tank is designed for a hydraulic residence time of 90 minutes for complete coliform destruction.

4. Methods and Procedures

Experiments were conducted at the University of California, Riverside campus, using an Enviroserver 600 treatment unit supplied by MicroSepTec. Evaluation of the Enviroserver treatment unit was carried out from January 1999 to July 1999. At the beginning of the experimental operation, the Enviroserver treatment unit was filled with influent wastewater from the City of Riverside Waste Reclamation Plant and seeded with the fixed film support having attached biofilm growth. The experimental procedures, analysis methods, and wastewater characteristics are described in this section.

Measurement of Physical and Chemical Parameters

Since flowrates and mass loading rates to a residential wastewater treatment unit are highly variable, special provisions were necessary to characterize influent and effluent water quality. A sample well equipped with a mixer to homogenize incoming raw wastewater was installed on the influent line. The sample well volume was matched to the pump capacity and purge volumes of the automatic sampler and to the size of the plastic storage containers used for collecting composite influent wastewater samples at selected time intervals.

A flow meter complete with datalogger was installed on the residential water line to measure the potable water consumption on a continuous basis. Because all water consumed by the residents was discharged to the test facility a representative estimate of wastewater flowrates were obtained assuming that the time delay between usage and discharge did not adversely affect the analysis. Wastewater samples were automatically collected on an hourly basis and a 24-hour composite sample was obtained in the laboratory by manually blending hourly samples in proportion to actual water usage. Samples for water quality analysis were collected from the influent sample port, secondary clarifier (compartment 4), and the chlorination contact tank. The location of sample points is shown in Figure 1a.

All samples were collected in polypropylene bottles designed for use with automatic samplers. All samples were either analyzed directly or stored on ice prior to analysis. In all cases an aliquot was immediately filtered using 0.45 micrometer Millipore filters. Analysis of wastewater constituents was performed according to Standard Methods [1989]. The following parameters were measured routinely during the study: total dissolved solids (TDS), total suspended solids (TSS), total organic carbon (TOC), carbonaceous biological oxygen demand ($CBOD_5$), total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), total phosphorus (TOT-P), reactive phosphorus (PO_4-P), total coliform (COL-T), fecal coliform (COL-F), free chlorine (CHL-F) and total chlorine (CHL-T).

Characterization of Household Wastewater

Grab samples of influent and effluent wastewater to the Enviroserver treatment unit were analyzed during the initial acclimation period to monitor treatment performance. Because of the expected variability of flowrate and wastewater composition 24-hour composite samples were used to provide the required baseline information. Track studies of the Enviroserver operation provided additional information on the variability of influent wastewater flowrates and composition as well as process performance and overall treatment efficiency. Track studies were conducted on four weekdays to capture wastewater discharge during the typical morning and evening peaks. A track study typically included wastewater samples collected every hour during a 24-hour period and analyzed for wastewater constituents. For the 24-hour track studies samples were collected at the inlet sample port and in the chlorination contact chamber using automatic samplers. With simultaneous measurements of water consumption an estimate of wastewater flowrates was obtained and used to calculate mass loading rates of influent and effluent wastewater constituents.

Long-term Evaluation

For the long-term evaluation of treatment efficiency of the Enviroserver treatment unit 24-hour daily composite samples were collected from the influent sample port and chlorination contact chamber during the period 21 May 1999 to 30 July 1999. Four track studies were also conducted during this period where influent and effluent samples were analyzed on an hourly basis to provide a measure of short-term variability of flow- and mass loading rates. Wastewater samples were collected using an automatic sampler and the collected samples were stored in an ice-cooled container prior to analysis.

Extended Loading Study

The long-term evaluation period was terminated by an extended loading study whereby the reactor influent was augmented with a pre-mixed synthetic waste. The study was performed to investigate the effect of a controlled addition of nutrients on overall treatment efficiency. A synthetic wastewater was made by mixing 0.82 g of dark corn syrup (Karo), with COD concentration of 915 g/L, and 94.33 mg of $(NH_4)_2SO_4$, with 1L tap water to yield a synthetic wastewater with a COD concentration of 750 mg/L and NH_3-N concentration of 20 mg/L. The selected synthetic wastewater strength was based on the average of measured COD and NH_3-N concentrations in the influent for the long-term evaluation. The synthetic wastewater was prepared fresh every day. The synthetic wastewater was added to the influent port using a small gear pump operated on a timer. Additions were made during four hours in the morning (6AM-10AM) and four hours in the evening (5PM-9PM) to coincide with the periods of largest daily wastewater flows (Figure 2). Actual flowrates and mass-loading rates of added nutrients are shown in Table 1. Composite 24-hour samples were collected and analyzed in the same manner as described earlier.

Table 1. Flow- and mass-loading rates of added nutrients for Extended Loading Study.

Time Period	AM			PM			Added Volume	Loading Factor
	Flowrate L/hr	COD g/hr	NH_3-N g/hr	Flowrate L/hr	COD g/hr	NH_3-N g/hr	L/day	%
1	22.5	16.875	0.450	30.0	22.500	0.600	210	135 [2)]
2	45.0	33.750	0.900	60.0	45.000	1.200	420	173 [2)]
3	90.0	67.800	1.800	[1)]	[1)]	[1)]	360	160 [2)]

[1)] Pump malfunction.

[2)] Loading factor is the ratio of total volume of influent wastewater to the nominal daily wastewater flow of 600 L/day ([210+600]/600=1.35x100%)

5. Experimental Results

The long-term performance of the Enviroserver treatment unit the influent wastewater flow was characterized both in terms of quality and quantity. In a single household little or no "averaging" of wastewater composition and flowrates take place over time as activities in a single residence are sequential. Consequently, the large variations in wastewater composition, constituent concentrations, and flowrates observed during the acclimation phase, which reflect the diverse activities and varying schedules in a single household, are to be expected. In this section results from the wastewater characterization study, long-term treatment performance, four 24-hour track studies, and the extended loading study are reported.

Characterization of Household Wastewater

The on-site test facility was installed and connected to a single-family residence located on the northeast side of the University of California, Riverside campus. The residence was occupied by a family of four during the evaluation period.

Acclimation Period

Between 22 February 1999 and 31 March 1999 grab samples were collected once per day, usually in the morning, from the primary clarifier and from the chlorination contact tank. The collected data were useful for monitoring the acclimation process of the treatment unit but not sufficiently detailed for performance evaluation. First, the operational requirement of periodic wastewater recycling from compartment four to compartment one effectively diluted the incoming wastewater influent and, as a result, samples collected from the first compartment severely underestimated the strength of influent wastewater. Second, sampling only one time per day was deemed to be inadequate because of highly varying flowrates and composition during the day.

Composite Sampling

Beginning on 21 May 1999 and extending through 31 July 1999, all wastewater samples were collected on a composite basis. A sample well equipped with a mixer to homogenize incoming waste was installed on the influent line. Hourly samples were collected using an automatic sampler and flow averaged 24-hour composite samples were obtained by combining hourly samples weighed with the actual hourly flowrate. Measured concentrations of influent wastewater constituents are found in Table 2.

The importance of flow averaging is shown in Figure 2 where the average and standard deviation of hourly flowrates are plotted. Over a 24-hour period average water usage follows the classical diurnal pattern with a morning and an evening peak but variations from hour to hour and from day to day were considerable. The average hourly flowrates ranged from zero to about 80 L/h (20 gph) during a 24-hour period. The variation of the hourly flowrate from day to day, measured as one standard deviation, was of the same magnitude as the hourly average and is shown in Figure 2 as error bars. In Figure 3 the frequency distribution of hourly flowrates is plotted to provide a quantitative measure of how often a particular flowrate is expected to occur. Based on nearly seven hundred hourly flowrate recordings an influent flow smaller than the average hourly flowrate 6.5 L/hour (1.7 gph) is expected to occur 50 % of the time, a flowrate smaller than or equal to 100 L/hour (26 gph) is expected 94.1 % of the time, and a flowrate smaller than or equal to 235 L/hour (60 gph) is expected 97.7 % of the time. The latter flowrate translates into an expected hydraulic residence time of four hours or more for any of the two 0.95 m^3 (250 gal) Enviroserver reactor compartments or the chlorinator tank. The hydraulic residence time for the maximum flowrate measured during the study, 920 L/hour (245 gph), which corresponds to more than 20 times the hourly average, would be somewhat longer than one hour.

Examination of the chemical analysis data of wastewater constituents in the 24-hour composite samples also revealed large day to day concentration variations. The influent wastewater was characterized by a typical CBOD concentration averaging 212 mg/L but with a standard deviation of 101 mg/L, which testifies to the large variations of

Table 2. Measured concentrations of influent wastewater constituents from on-site residential wastewater treatment study. Samples collected from sample well on influent line. (5/21/99-7/30/99)

Constituent	**Units**	**Average Influent Concentration**	**Std. dev. [N=31]**
Biochemical Oxygen Demand	mg/L	212	101
Chemical Oxygen Demand	mg/L	727	481
Total Organic Carbon	mg/L	121	153
Total Suspended Solids	mg/L	267	185
Total Dissolved Solids	mg/L	653	348
Total Kjeldahl Nitrogen	mg/L as N	43	24
Ammonia	mg/L as N	20	17
Nitrate	mg/L as N	1.1	0.9
Reactive Phosphorus	mg/L	12	6
Total Phosphorus	mg/L	19	8
Fecal Coliform	CFU/100 mL	490,000	180,000
Total Coliform	CFU/100 mL	860,000	230,000
Turbidity	NTU	80	102
Conductivity	µmho/cm	525	77
pH	-----	7.5	0.6

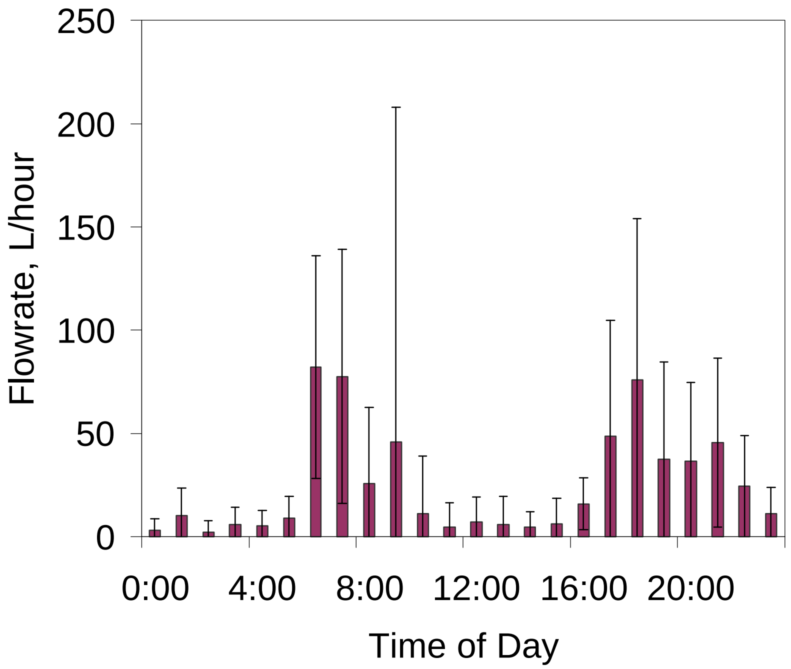

Figure 2. Average hourly flowrates with error bars showing one standard deviation.

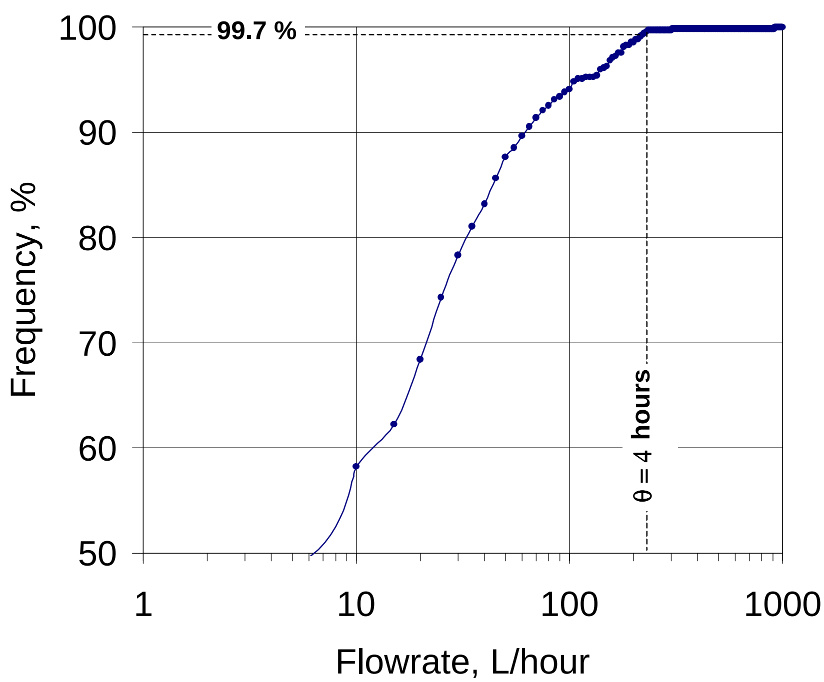

Figure 3. Frequency distribution of hourly flowrates. The hydraulic residence time in a compartment having a volume of 950 L (250 gal) exceeded 4 hours for 99.7 % of the time during the evaluation period.

wastewater strength and composition originating from single households. Nutrients such as nitrogen and phosphorus follow a similar pattern. The large variations in flowrate coupled with large variations in wastewater composition and strength offer no alternative testing methodology other than composite, flow averaged, sampling for evaluating removal efficiency of on-site residential wastewater treatment systems.

Information on typical individual household wastewater quantity and quality is relatively scarce in the literature. For example, a typical water consumption rate between 150 to 190 L/d per person (40 to 50 gpd per person) for households residing in apartments and mobile home parks that include little or no water for landscaping or irrigation is often used for water resources planning purposes. These numbers are comparable to the average flowrates measured in this study. Equally important from a design and performance point of view are data on expected concentration ranges of wastewater constituents. Unfortunately, there appears to be no published data on single household wastewater quality with which to compare findings from this study. In Table 3 typical concentrations of wastewater constituents commonly used for the design of large municipal wastewater treatment plants are listed. Comparison between typical design concentrations and the measured concentrations of wastewater constituents in this study reveal that concentrations are very similar with only phosphorus concentrations being noticeably higher in the present study. Also, coliform counts in typical municipal wastewater are 100-1000 times higher than the number measured in the UCR study. A possible explanation is that growth occurs during transport from the source to a centrally located municipal wastewater treatment plant.

Long-term Evaluation of Treatment Performance

The evaluation of the Enviroserver long-term treatment performance is based on 24-hour composite samples of influent and effluent collected between 21 May 1999 and 30 July 1999. Removal rates for suspended solids, carbon, and nutrients for the Enviroserver operating continuously and on demand are discussed in terms of an average removal efficiency as well as from a frequency analysis to provide a measure of robustness.

Table 3: Typical concentrations of influent household wastewater constituents in residential wastewater [1)]

Constituent	Units	Concentration
Biochemical Oxygen Demand	mg/L	220
Chemical Oxygen Demand	mg/L	500
Total Organic Carbon	mg/L	160
Total Suspended Solids	mg/L	220
Total Dissolved Solids	mg/L	500
Total Kjeldahl Nitrogen	mg/L as N	40
Ammonia	mg/L as N	25
Nitrate	mg/L as N	0
Reactive Phosphorus	mg/L	5
Total Phosphorus	mg/L	8
Total Coliform	CFU/100 mL	10e7 – 10e8

[1)] Tchobanoglous, G.T. and E.D. Schroeder, *Water Quality*, Addison-Wesley

From average influent and effluent concentrations of the measured household wastewater constituents, an average removal efficiency was calculated for each constituent and is tabulated in Table 4.

Table 4. Measured concentrations of effluent wastewater constituents and average removal rates in percent from on-site residential wastewater treatment study. Samples collected from chlorination tank. (5/21/99-7/30/99)

Constituent	Units	Average Eff. Concentration	Std. dev. [N=31]	Average Removal %
Biochemical Oxygen Demand	mg/L	5.7	3.1	97.3
Chemical Oxygen Demand	mg/L	54	21	92.6
Total Organic Carbon	mg/L	18	7.6	85.1
Total Suspended Solids	mg/L	5.9	4.1	97.8
Total Dissolved Solids	mg/L	543	143	-
Total Kjeldahl Nitrogen	mg/L as N	7.0 [1)]	4.6 [1)]	83.7
Total Inorganic Nitrogen [2)]	mg/L as N	2.2	1.5	89.6
Ammonia	mg/L as N	0.1	0.1	-
Nitrate	mg/L as N	2.1	1.5	-
Reactive Phosphorus	mg/L	1.3	0.6	89.2
Total Phosphorus	mg/L	2.0	0.7	89.5
Fecal Coliform [3)]	CFU/100 mL	<2	0.0	-
Total Coliform [3)]	CFU/100 mL	<2	0.0	-
Total Chlorine [3)]	mg/L	12	20	-
Free Chlorine [3)]	mg/L	9	18	-
Turbidity	NTU	5.1	4.6	-
Conductivity	µmho/cm	599	120	-
pH	-----	8.0	0.3	-
Temperature	°C	17.0	3.9	-

1) N (number of samples) = 24.
2) Total Inorganic Nitrogen here defined as NH_3-N + NO_3-N.
3) Results reflect disinfection after modifications were carried out on the through-flow chlorinator. After modification all Total and Fecal Coliform counts were less than or equal to 2 CFU/100 mL.

Carbon and Solids Removal

Average removal for $CBOD_5$ was 97.3 percent and for TSS 97.8 percent with an average effluent concentration of 5.7 and 5.9 mg/L, respectively. Suspended solids and carbon removal efficiencies are summarized in Table 4. Maximum recorded effluent $CBOD_5$ and TSS concentrations were 14.0 mg/L for both constituents. Average influent and effluent TOC, $CBOD_5$, and COD are also plotted in Figure 4 where the error bars indicate one standard deviation. The frequency in percent that a wastewater constituent in the effluent exceeded a specified concentration is shown in Table 5. For example, $CBOD_5$ in the effluent exceeded 5 mg/L in slightly more than half of the 24-hour composite samples analyzed in the long-term study but was greater than 10 mg/L in only twelve percent of the time. Similarly, TSS concentrations in the effluent exceeded 10 mg/L in less than one fifth of the time.

The low TSS concentrations in the effluent is in part due to excellent solids settling characteristics with an average sludge volume index (SVI) in the secondary clarifier being 75 mL/mg and never exceeding 150 mL/mg. (Samples for TSS determinations were collected while the reactor contents were well mixed). The effectiveness of the sludge recycle pumping from the secondary clarifier to the primary clarifier and periodic decomposition in the thermal processor was evidenced by the average TSS concentrations tapering from a high 5,600 mg/L in the first compartment to a low of 450 mg/L in the fourth compartment.

Nutrient Removal

Some nitrogen and phosphorus are removed by assimilation into new cell mass and subsequently removed from the reactor by thermal conversion to ash. Maintaining both aerobic and anoxic zones in the reactor allows for additional amounts of nitrogen to be removed. Nitrogen is biologically removed by nitrification followed by denitrification. In both instances, an organic carbon and energy source are required.

The absence of ammonia in the effluent indicate that complete nitrification was achieved during the study period. The average daily ammonia concentration in the effluent was

Table 5. Frequency, in percent of wastewater constituent concentrations, from on-site residential wastewater treatment study exceeded 20, 15, 10, 5, and 2 mg/L in effluent. 24-hour composite samples collected from chlorination tank. N is the number of samples. (5/21/99 - 7/30/99)

Constituent	**Concentration in mg/L**					
	N	**20**	**15**	**10**	**5**	**2**
Biochemical Oxygen Demand	31	0.0	0.0	12.0	52.0	100.0
Total Suspended Solids	31	0.0	0.0	17.3	62.1	82.8
Total Kjeldahl Nitrogen-N	24	0.0	10.9	17.4	60.9	97.2
Total Inorganic Nitrogen-N	31	0.0	0.0	0.0	2.5	50.0
Ammonia-N	31	0.0	0.0	0.0	0.0	0.0
Nitrate-N	31	0.0	0.0	0.0	2.5	46.7

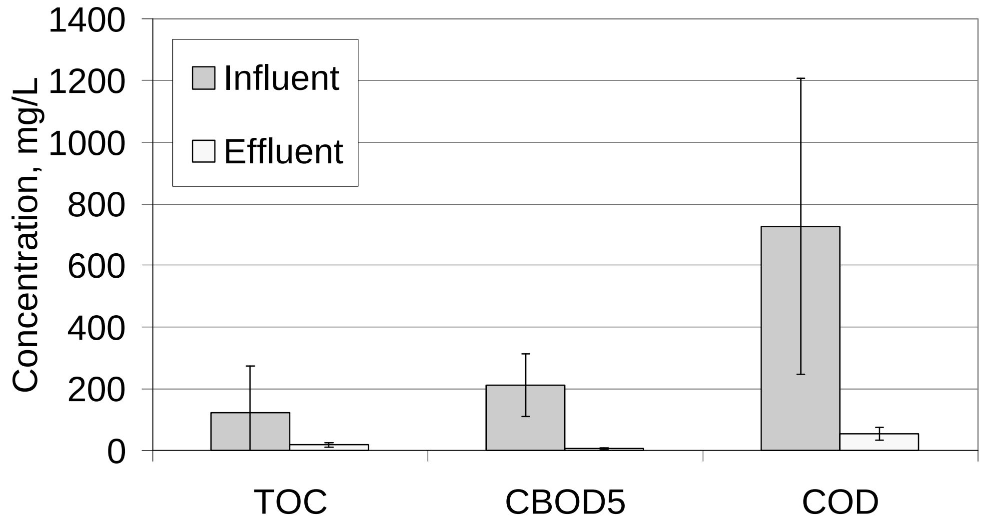

Figure 4. Average influent and effluent TOC, BOD_5, and COD concentrations. Error bars show one standard deviation. (N=31)

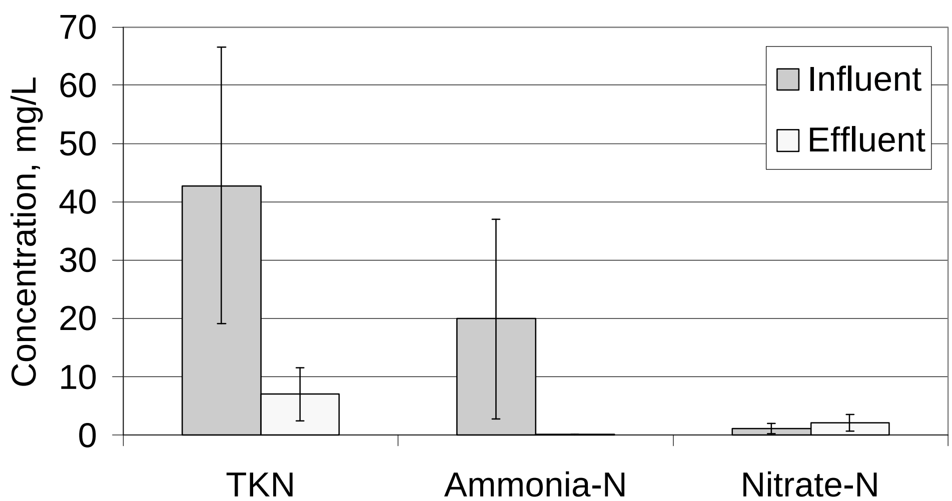

Figure 5. Average influent and effluent TKN, Ammonia-N, and Nitrate-N concentrations. Error bars show one standard deviation. (N=24 for TKN, and N=31 for NH_3 and NO_3)

0.1 mg/L with a standard deviation of 0.1 mg/L and a maximum of 0.2 mg/L. Ammonia oxidation results in nitrate formation but the average nitrate concentration in the effluent was only 2.1 mg/L with a standard deviation of 1.5 mg/L and a maximum of 8.7 mg/l. The inorganic nitrogen, calculated as (NH_3-N + NO_3N), removal efficiency was 89.6 percent (Table 4). The high percentage removal suggests that both nitrification and denitrification reactions take place simultaneously. To achieve simultaneous removal of both ammonia nitrogen and oxidized nitrogen both aerobic and anoxic micro-environments must exist within the reactor.

The pre-react zone is kept anoxic which would permit oxidized nitrogen removal to take place as readily available carbon is continuously being added to the reactor. It is also probable that ammonia oxidation and oxidized nitrogen removal take place within the biofilm in compartments two and three where the thickness of the biofilm could limit oxygen mass transfer and thus render parts of the biofilm anoxic. But the relative importance of the pre-react zone and biofilm is unknown and the relative efficiency is hypothesized to be ultimately controlled by site specific conditions. Influent and effluent TKN, NH_3-N, and NO_3-N concentrations are plotted in Figure 5. Nitrogen removal, measured as TKN, was 83.7 percent with an average concentration of 7.0 mg/L in the effluent.

Phosphorus removal, measured as TOT-P, was nearly 90 percent with an average effluent concentrations for the Enviroserver of 2.0 mg/L with a standard deviation of 0.7 mg/l (Table 4). Such high removal rates were not expected because no operational provisions were made for a "feast-and-famine" strategy to develop and maintain a phosphorus accumulating biomass. Instead, excess biomass was wasted by thermal decomposition at temperatures reaching 600°C which is well above the boiling point for many phosphorus compounds including elemental phosphorus, phosphoric acids, and phosphorus oxide. However, phosphorus removal by evaporation cannot be confirmed until the exhaust gas from the thermal processor is analyzed and a complete mass balance for phosphorus is performed. Until then, reported phosphorus removal rates should be regarded as preliminary only.

Disinfection

The clarified and treated wastewater is disinfected as it passes through a flow-through chlorinator, a receptacle containing calcium hypochlorite ($CaCl_2O_2$) tablets. Disinfection efficiency is a function of both the concentration of the disinfectant (chlorine) and the contact time. During the study the receptacle containing the hypochlorite tablets was clogged by partially dissolved tablets which hindered new tablets from entering the flow-through cell resulting in little or no dissolution of hypochlorite and hence little or no disinfection. Before the problem was identified chlorine concentrations in the chlorination contact chamber were erratic and hence also only partial disinfection. Clogging is now prevented by diverting a small stream of air from the compressor unit to the receptacle holding the hypochlorite tablets. Ample contact time is provided in the 0.95 m^3 (250 gal) chlorination contact chamber. In Figure 3 the frequency distribution of measured hourly flowrates to the wastewater treatment unit is plotted. For example, the hydraulic loading rate smaller than 235 L/h is expected 97.7 percent of the time and which corresponds to an hydraulic residence time in the chlorinator contact chamber of four hours or more.

Disinfection efficiency is measured as the number of colonies of total and fecal coliforms produced per 100 mL of sample after an incubation period. After the modification of the hypochlorite receptacle both total and fecal coliform numbers, measured as CFU/100 mL, were consistently below 2 CFU/100 mL.

Track Studies

To gain a better understanding of the effect of the inherent variability of influent flowrates and wastewater composition on removal efficiency over the short-term 24-hour track studies were performed on four weekdays during the study period. A track study typically included influent and effluent samples collected every hour. Samples were analyzed for the following constituents: total dissolved solids (TDS), total suspended solids (TSS), total organic carbon (TOC), chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), total phosphorus (TOT-P), and reactive phosphorus (PO_4-P).

Average hourly flowrates for the four weekdays (26 May, 8 June, 24 June, and 1 August) are plotted in Figure 6 where the error bars show maximum and minimum values. Maximum recorded hourly flowrate was 212 L/hr compared to a daily average of 17 L/hr. Again, hour to hour variations were large as well as day to day variations which testifies to the importance of composite sampling for the evaluation of residential wastewater treatment processes. In Figures 7-11 influent and effluent wastewater concentrations, COD, TSS, TKN, Ammonia-N, and TOT-P, are plotted as a function of time of day. When high concentrations were found in the influent then effluent concentrations are also somewhat elevated for the same time interval. For example, elevated effluent COD concentrations appear to coincide with high influent concentrations (Figure 7). This observation is consistent with the hydraulic performance of a treatment process with recycle. The recycle stream dilutes incoming wastewater and at the same time disperses the contents of the four compartments to modify effluent water quality in the chlorinator tank and discharge. Even so, average COD concentration in the effluent was 50 mg/L, which corresponds to approximately a $CBOD_5$ concentration of 10 mg/L or less, based on linear correlation of the COD and $CBOD_5$ influent data. Similarly, TSS and TKN concentrations in the effluent were consistently low despite large fluctuations of both influent concentrations and flowrates. The correlation between influent and effluent concentrations is relatively weak for the same time interval and does not appear to affect effluent water quality over subsequent time periods.

Examination of track study results show a strong correlation between high water flowrates and high phosphorus mass loading rates. For example, total phosphorus loading rates exceeding 0.5 g/h were generally associated with high water flowrates, which suggests that the source of phosphorus was washing detergents. If warranted, a simple substitution of household detergents is all that is required to lower phosphorus concentrations in the effluent.

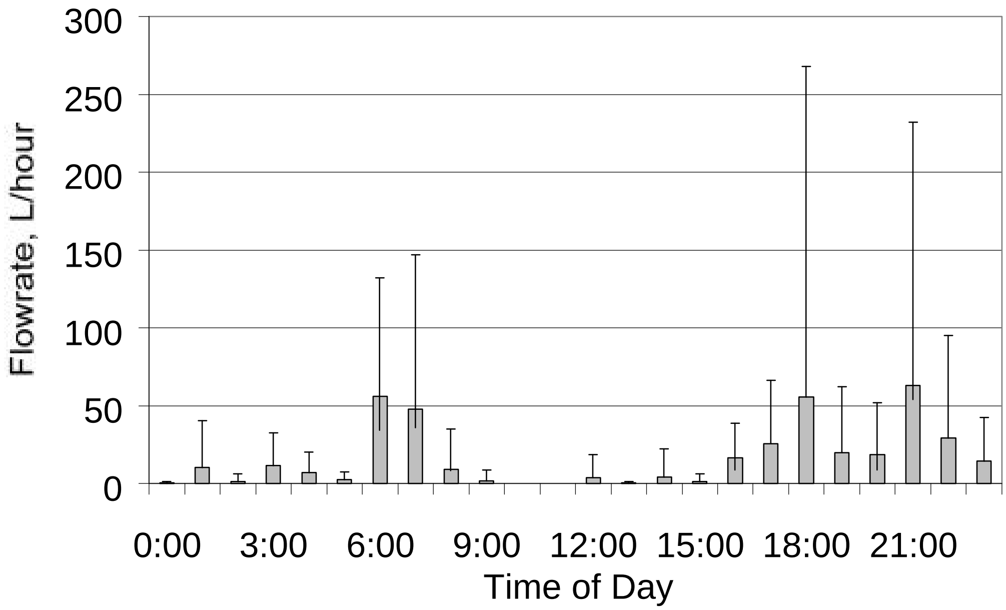

Figure 6. Average hourly flowrates for weekday track study. Error bars show maximum and minimum values. (N=4)

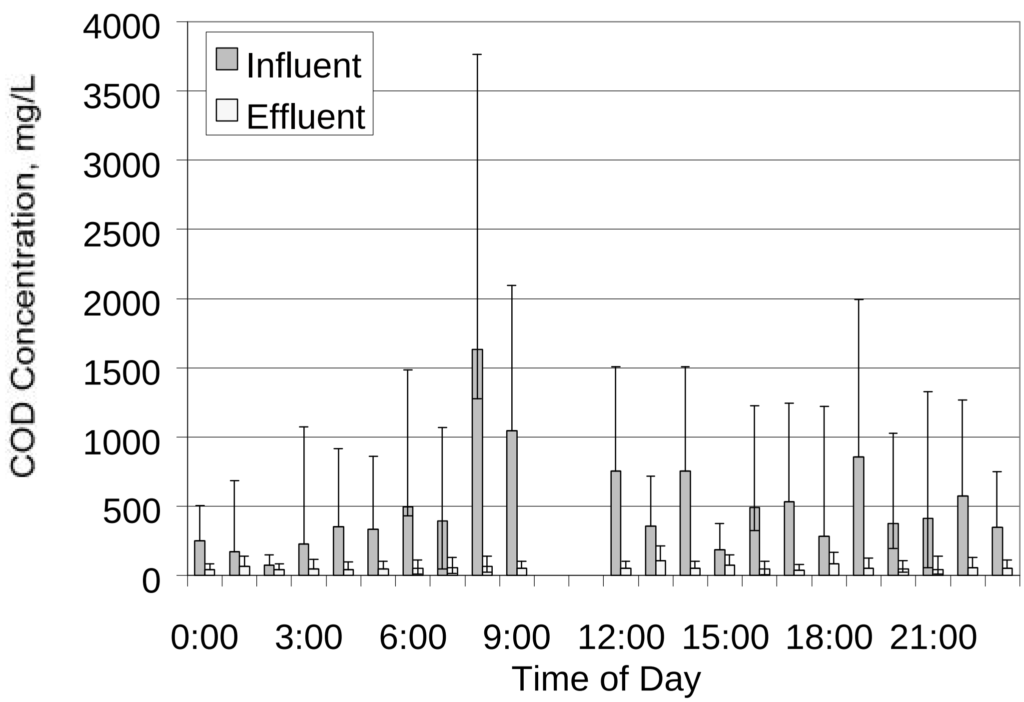

Figure 7. Hourly influent and effluent COD concentrations for weekday track study. Error bars show maximum and minimum values. (N=4)

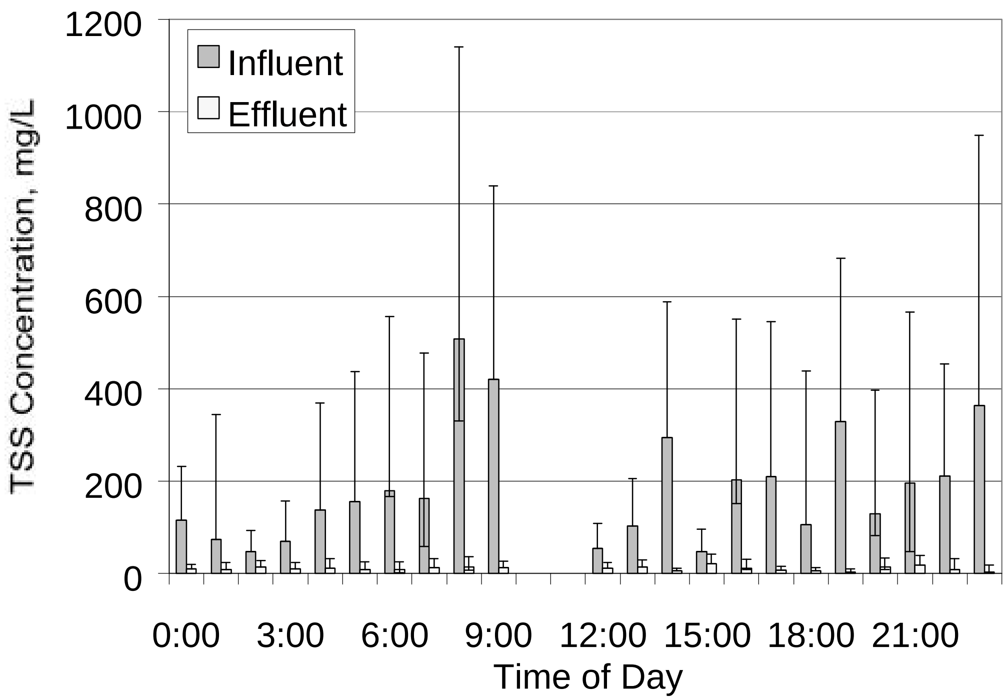

Figure 8. Hourly influent and effluent TSS concentrations for weekday track study. Error bars show maximum and minimum values. (N=4)

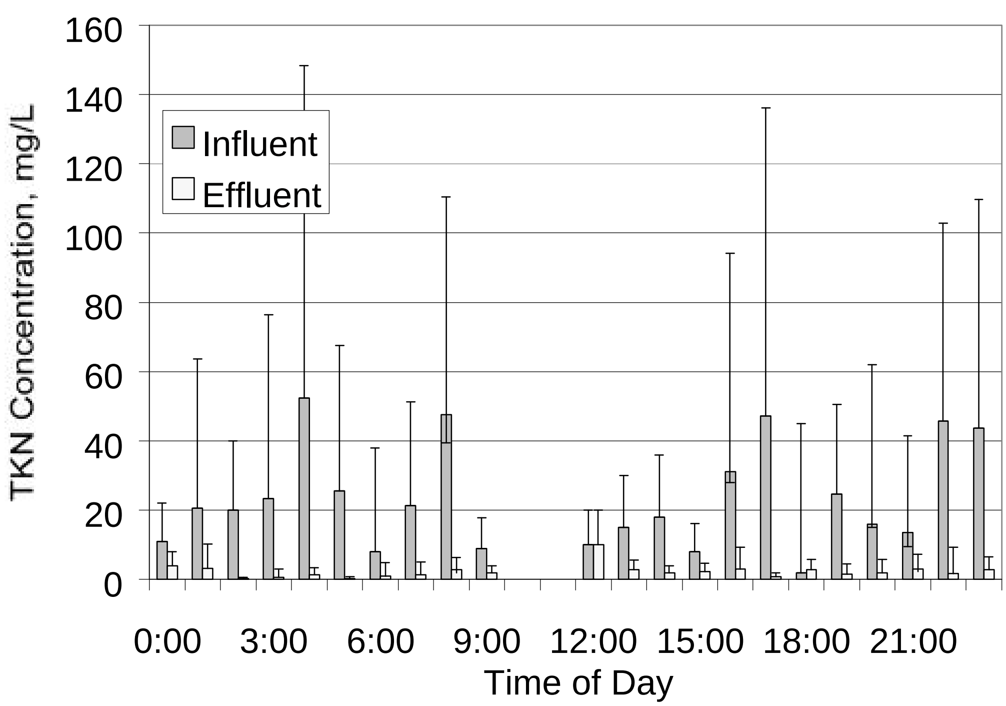

Figure 9. Hourly influent and effluent TKN concentrations for weekday track study. Error bars show maximum and minimum values. (N=4)

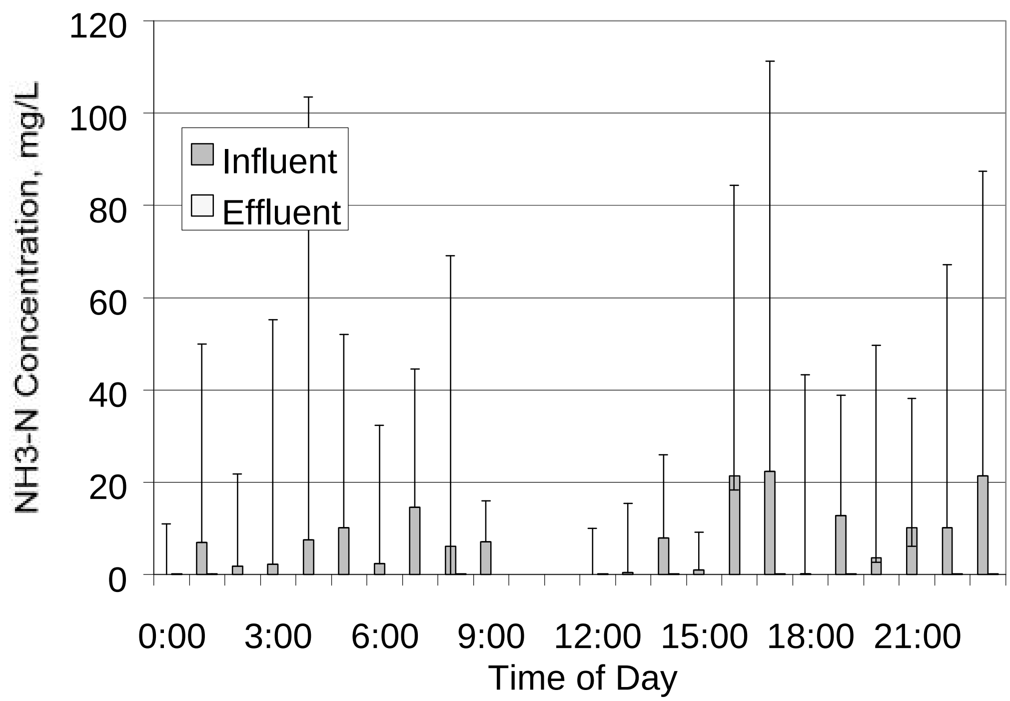

Figure 10. Hourly influent and effluent Ammonia-N concentrations for weekday track study. Error bars show maximum and minimum values. Note, maximum concentration was 0.1 mg/L in effluent. (N=4)

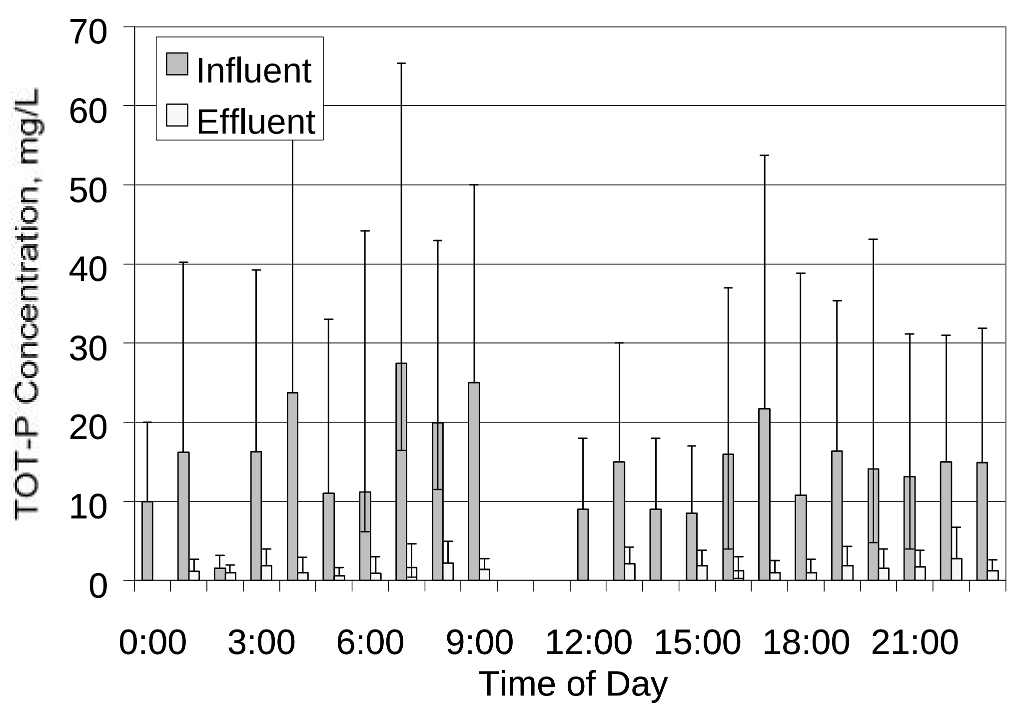

Figure 11. Hourly influent and effluent Total-P concentrations for weekday track study. Error bars show maximum and minimum values. (N=4)

Extended Loading Study

An extended loading study was performed by controlled addition of a synthetic wastewater to investigate the effect of increased mass-loading rates on treatment performance. A synthetic wastewater with a COD concentration of 750 mg/L and a NH_3-N concentration of 20 mg/L was added to the Enviroserver in addition to the normal influent (Table 1).

For comparison daily effluent concentrations for COD and TKN are plotted for the Longterm Evaluation Study and the Extended Loading Study in Figures 12 and 13. Observed effluent concentrations for the extended loading study are comparable with the average effluent concentrations for the longterm evaluation study. Measured effluent concentrations were always below average plus one standard deviation which suggest that the removal efficiency is independent of the extended loading rates investigated.

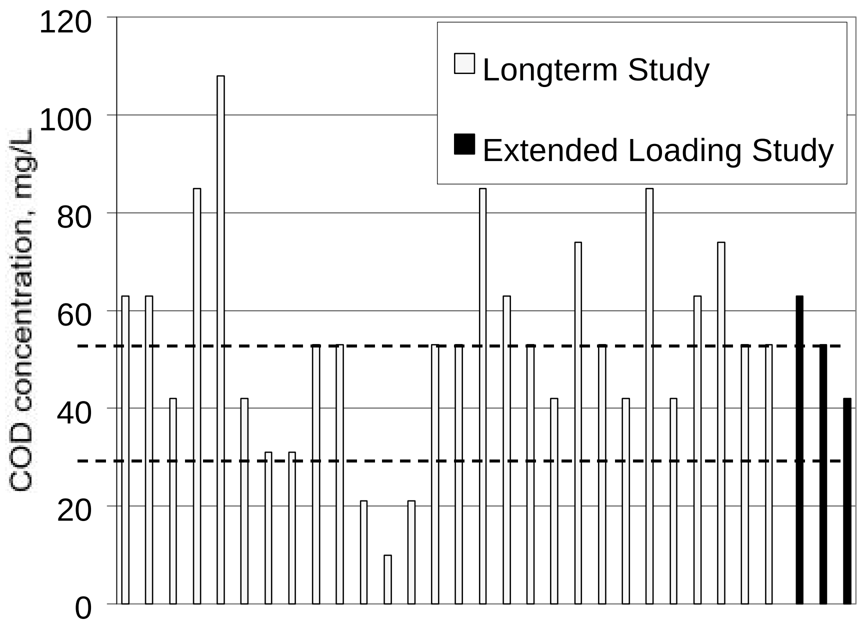

Figure 12. Effluent COD concentration for longterm evaluation study (normal loading) and for extended loading rates of 135%, 160% and 173% based on a nominal daily wastewater flow of 600 L/day. Dotted lines represent average and average plus one standard deviation for effluent COD concentrations for the Longterm Evaluation Study.

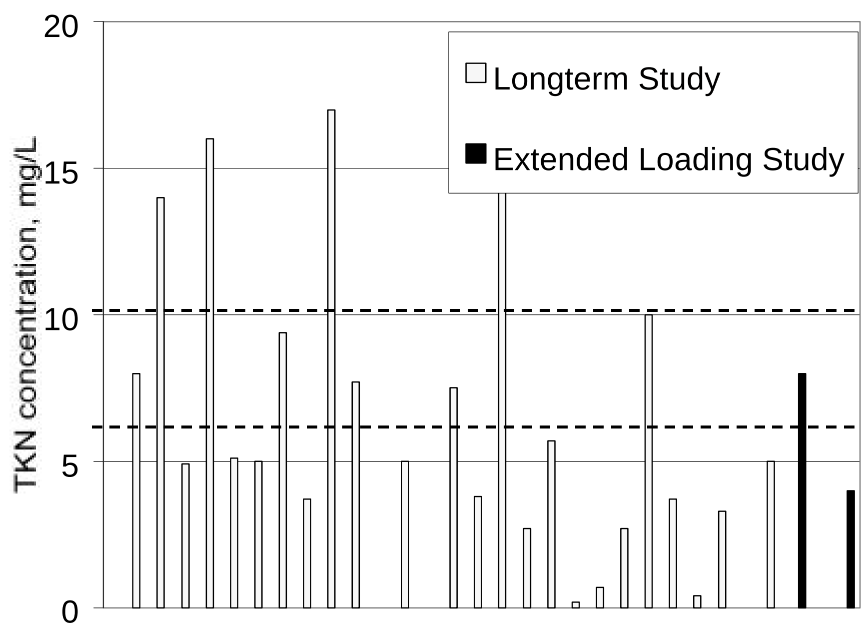

Figure 13. Effluent TKN concentration for longterm evaluation study (normal loading) and for extended loading rates of 135%, 160% and 173% based on a nominal daily wastewater flow of 600 L/day. Dotted lines represent average and average plus one standard deviation of effluent TKN concentrations for the Longterm Evaluation Study.

6. Conclusions

The principal conclusions resulting from the evaluation of the Enviroserver 600 residential wastewater treatment unit are as follows:

1. Average carbon, as BOD_5, and solids, as TSS, removal rates were 97.3 percent and 97.8 percent, respectively.

2. Despite large variations in hydraulic and mass loading rates less than one fifth of all 24-hour composite samples exceeded 10 mg/L for both BOD_5 and TSS.

3. Nearly complete nitrification and denitrification was obtained. Average removal rates for TKN and inorganic nitrogen was 83.7 percent and 89.7 percent, respectively. Simultaneous nitrification and denitrification yielded a total inorganic nitrogen concentration rarely greater than 5 mg/L.

4. The thermal processor combined with recycle pumping of settled solids from the secondary clarifier to the pre-react zone produced a tapered solids concentration from approximately 5,600 mg/L in the first compartment to about 450 mg/L in the fourth compartment with subsequent low TSS concentrations in the effluent.

5. An effluent free of detectable total and fecal coliform, <2 CFU/100 mL, was consistently achieved using a bypass contact chlorinator using calcium hypochlorite in tablet form.

6. Hourly and daily variations of influent flowrates and mass-loading rates had little or no effect on effluent water quality.

7. The Enviroserver 600 treatment unit is capable of handling additional influent flow and mass-loading while maintaing effluent water quality.

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