46 East King Street
Littlestown, Pennsylvania 17340
Phone: (717) 359-5101
Fax: (717) 359-8441
E-Mail Address: littlestown@pa.net

LITTLESTOWN
1765

THE BOROUGH OF LITTLESTOWN

WE'RE GROWING, ONE NEIGHBOR AT A TIME.

GROWING GREENER NEW OR INNOVATIVE TECHNOLOGY GRANT FINAL REPORT

USE OF ULTRAFILTRATION TREATMENT BOROUGH OF LITTLESTOWN, ADAMS COUNTY, PENNSYLVANIA

PROJECT NO. SC00198IT - ME# 351026

I. PROJECT SUMMARY/OVERVIEW

The Littlestown Borough Authority (Authority) constructed a 0.36 MGD Zenon Zeeweed ultrafiltration membrane water treatment plant at Well No. 8, the Authority's previously abandoned quarry. The treatment facility's process units consist of raw water pumping, one membrane ultrafiltration unit, and a baffled chlorine contact tank (finished water storage tank). The Pennsylvania Department of Environmental Protection (PADEP) issued Operational Permit No. 0198502 on June 26, 2001.

Start-up of the water treatment plant occurred on September 26, 2001. Up to that point the facility was operational but recirculated finished water back to the quarry in order that the operators could become more familiar with the operation of the system.

The Zenon Zeeweed system utilizes hydrophilic membranes of proprietary composition operated under a slight vacuum (-4 to -9 psi). The membrane material has nominal and absolute pore sizes of 0.035 and 0.1 microns, respectively. The nominal molecular cutoff weight is 100,000 daltons; the absolute molecular cutoff weight is 120,000 daltons. The membrane is highly chlorine resistant up to concentrations of 3,000 mg/L. Fibers of 0.75 mm interior diameter, 1.95 mm outside diameter and 1.65 m length are suspended in an open membrane process tank. Raw or pretreated water is pumped into the membrane tank and flows by vacuum from outside of the membrane into the lumen. The Zenon system is operated at a constant transmembrane flux rate with monitoring of the corresponding pressure increase needed to maintain that target flux rate over time. A blower also provides a constant supply of filtered air into the bottom of the membrane tank. This air oxidizes organic and inorganic materials and also scours the membrane exterior surface to reduce build-up of solids. Rejected solids remain in the membrane tank. They are disposed of by either batch or continuous wasting.

A clean-in-place (CIP) tank contains permeate which is used to clean the membrane. Permeate from the CIP tank is pumped from the interior of the fiber to the outside to expel any accumulated solids. The frequency, duration and flow rates of this flow reversal are all adjusted by operators to achieve optimal cleaning.

Zenon received National Sanitation Foundation (NSF) certification under Standard No. 61 on October 15, 1998.

II. WATER CHARACTERISTICS AND FLOWS

Water obtained from Well No. 8, the abandoned quarry, was found to be of consistent quality with the following characteristics:

CONTAMINANTS	CONCENTRATIONS	COMMENTS
Turbidity	3.5 NTU	Relatively constant
pH	7.4 - 7.5	
Alkalinity	134 mg/l	
Algae Chlorophyl	4.0 mg/l	
Fecal Coliform	0	
Total Coliform	19/100 ml	
Iron	ND - 1.5 mg/l	
Manganese	0.012 - 0.042 mg/l	
Organic Carbon	3.8 mg/l	Relatively Constant
Particle Counts	3 - 10,000/200 ml	2 - 20 microns

In addition, the peak daily water demand is 340,600 gallons per day, with the average daily water demand being 316,780 gallons per day.

At present, the Borough serves 1,280 water customers. Of that amount, 95.8 percent are residential, 3 percent are commercial, 0.4 percent is municipal and 0.8 percent is industrial.

III. SITE DESCRIPTION

A. History and Ownership

Well No. 8, owned by the Authority, was first approved for public water supply use via Permit No. 8507-W, which was issued in 1955. It is located a few feet from a 90 feet deep limestone quarry that has been inactive for many years and has filled with water. The Authority estimates that the quarry contains 4.8 million gallons of water. All water in the quarry is derived from subsurface sources; there are no surface sources or runoff feeding the quarry. The ultimate yield of the quarry and well is unknown. Well No. 8 was used for 40 years without dewatering. Operators have also conducted extended pump testing of the well at 250 gpm in an unsuccessful effort to draw down the quarry water level.

Well No. 8 was used with only chlorine disinfection until the PADEP reclassified it as a Groundwater Under Direct influence (GUDI) source pursuant to passage of the PA Filter Rule. On May 30, 1990, fecal coliform samples collected from Well No. 8 contained 212 CFU/100 mL, which triggered a mandate to provide filtration by May 30, 1994. The Authority entered into a Consent Order and Agreement on August 9, 1991 which required them to either filter water pumped from the well or take it out of service. A filter plant was not on line by May 30, 1994, so the Authority took the well out of service and it had been idle since.

B. The Pilot Study

During the membrane pilot study, the PADEP learned that construction of Well No. 8 had many years ago been altered to include a horizontal influent pipe that connected the well bore directly to water in the quarry. It was apparently added to increase yields after they had decreased to unacceptable levels. This late discovery confirmed the PADEP's earlier finding of surface water influence.

The Authority had initially intended to utilize a traveling bridge filter and, in preparation, they conducted a year long pilot study. That study provided marginally acceptable results which the Authority chose not to pursue. It also provided, however, sufficient data to allow the PADEP to evaluate the seasonal variations in raw water quality.

Given the relatively stable raw water quality, the PADEP approved a proposal to conduct an eight (8) week membrane pilot study. The pilot was actually operated for eleven (11) weeks from November 13, 1997 to February 3, 1998.

The pilot was conducted utilizing continuous particle and turbidity measurements. Hach model 1900 WPC particle counters and 1720C turbidimeters were used. All results were tracked and recorded on-site using a personal computer. Grab samples were collected for the following additional water quality data: pH, iron, manganese, suspended solids, dissolved solids, aluminum, total and fecal coliforms, total plate count, alkalinity, color, magnesium, calcium, hardness, nitrate, total kjeldahl nitrogen, fluoride, bromide, chloride, orthophosphate, sulfate, barium, beryllium, boron cadmium, chromium, cobalt, copper, lead, magnesium, molybdenum, nickel, phosphorus, potassium, silicon, silver, sodium, strontium, sulfur, thallium, tin, titanium, vanadium, zinc, zirconium, total and dissolved organic carbon, total trihalomethane formation potential and algae.

Daily operational data collected by the Authority included; permeate rate, totalized permeate volume, vacuum after backpulse, vacuum before backpulse, backpulse duration, backpulse frequency, backpulse volume, water temperature, air temperature and bleed rate. Operators also recorded all process changes, cleanings and problems. The study found that the ultrafiltration membrane consistently produced water that met the PADEP's standards.

C. Process and Facilities

This water filtration facility was designed to initially produce 200 gpm from Well No. 8. All portions of the facility were designed and installed, wherever possible, to allow an increase in capacity at a future date.

Well No. 8 was partially reconstructed as part of this project. Schedule 80 PVC pipe was installed inside the existing steel casing to within approximately 2 inches of the existing horizontal intake pipe in an attempt to minimize iron and manganese concentrations which tend to increase as the well sits idle.

The existing well vertical turbine pump was replaced with two Burks, Series WB40-10X, 5HP, horizontal centrifugal pumps. Each pump has a capacity of up to 300 gpm. TDH at 200 and 300 gpm was 15 feet and 26 feet, respectively. Raw water is pumped either to the membrane tank or to waste back into the quarry.

The membrane tank has dimensions of 17.5' by 8.5' by 12.0'd. Approximately 500 ft^2 of membrane surface area is provided in each of 24 ZW-500 modules installed in three 8-module cassettes. Each module contains about 4,700 fibers. The permitted rate of operation is 18.0 gfd when operated at 150 gpm. The Authority provided room in the tank to add at least two more 8-cassette modules. If the Authority decides to increase capacity to 250 gpm, they may do so by adding two modules or adding one and operating at a higher flux rate (22.50 gfd). (The PADEP has advised of the need to obtain prior approval via a permit amendment and the Authority has acknowledged this requirement.)

Air for scouring is provided by one of two blowers each capable of providing 360 scfm (initial) and 600 scfm (ultimate)at 5.0 psi. Each module requires 15 scfm and blower capacity will need to be adjusted whenever the Authority wants to increase the filter plant capacity. Each blower is powered by a 20 HP motor and coupled with an inlet filter, inlet silencers, discharge silencers, pressure relief valve and check valve. The inlet filter is of the dry element type with a washable filter media. Its efficiency is 90%, or better, on 10 micron material with a pressure drop not exceeding 2.8 inches W.C.

Water is drawn through the membranes under vacuum generated by one of two permeate pumps. Goulds Series 3196, Durco Mark 111 pumps fitted with 5.0 HP variable frequency drive motors are used. The pump capacity is 250 gpm at 50 feet TDH and 375 gpm at 30 feet TDH. Permeate was first used to fill the 840 gallon CIP tank. When that tank is full, permeate is routed to the 70,000 gallon filtered water tank.

Due to the low pressures in the permeate system, there is a tendency for air to be released from the water. To prevent the problems associated with air locks in the piping, pump system and on-line instrumentation, an air removal system was installed between the membrane tank and the permeate pumps. Permeate flows from the membranes into a vertical tank receiver. One of two SIHI Model LEMA 20AZ831.0A.0 air extraction pumps applies a vacuum to the top of the receiver. The pumps, powered by 0.75 HP motors, are each capable of moving 13.5 scfm at 18-20" Hg vacuum. The permeate pumps are fed from the bottom of the receiver.

The filtered water tank is an Aqua Store Model 3143-WT, glass-lined, bolted steel structure. It has a nominal diameter of 25 feet and a nominal height of 20 feet. Its floor elevation is at 501.00'. Ancillary tank facilities include one 24-inch access hatch at grade, a roof mounted access hatch, a roof mounted gravity ventilator, a 6 inch overflow with weir box intake, a 6-inch inlet, a separate 6-inch outlet and a removable silt stop. The tank was constructed to increase effective chlorine contact times. The inlet pipe was located at the tank perimeter extended 16' above the tank floor and fitted with a tee to direct flow along the outside of the tank. Six foot and 14 foot square baffles were installed around the tank outlet located in the center of the tank. The baffles were made of PVC or vinyl material constructed over an aluminum framework. Water is forced under the outer baffle (installed 1.0' above the tank floor) and over the inner baffle to reach the outlet. Two drains, one inside and one outside of the baffles, were installed to drain the tank.

Finished water is withdrawn from the tank by one of two finished water pumps. Horizontal, split case, single stage pumps, Peerless 3AE14G units coupled with 20 HP motors are used. The capacity of the pump is 250 gpm at 130' TDH. These constant speed pumps are controlled using water levels in the filtered water storage tank.

Utility water is obtained from the finished water pumps. A double check valve assembly is provided to protect the potable water supply.

The only chemical feed system is for chlorine gas. One hundred fifty pound cylinders are used to supply chlorine solutions automatically to the raw water, automatically to the permeate prior to the filtered water tank and manually to the CIP tank. Two cylinder mounted Capitol Controls, Series 200, 100 pounds per day (ppd) vacuum regulators were installed. The rotameter schedule is : 0-5 ppd for raw water, 0-25 ppd for the CIP tank, 0-5 ppd for permeate. Ancillary facilities include: a two cylinder scale with loss of weight transmitter, an automatic switchover valve, two motorized valves, one manual valve, one Capital Controls 1610B chlorine gas detector, one self-contained breathing apparatus and one 150-pound cylinder emergency repair kit.

Safety equipment provided on site includes safety glasses, an apron, rubber gloves and an eye wash station.

As with all membranes, the Zenon system utilizes two processes for cleaning. The first is a frequent, short duration backpulse of permeate at 6 to 8 psi to flush any solids that have accumulated on the outside of the membranes. (To prevent damage to the membranes, backpulse pressure does not exceed 15 psi). The frequency and duration of the backpulse are variables controlled by the operator; however, Zenon generally recommends that backpulsing be done for 5 to 20 seconds every 10 to 30 minutes. After backpulsing, pressure loss through a clean membrane should be about 1 psi. Backpulses are automatically initiated by a manually adjusted timer. There is no automatic adjustment based on pressure loss or rate of loss accumulation. If additional backpulsing is needed to clean the membrane, the frequency - not duration - of cleaning is typically increased.

Eventually, the membranes will foul with organic or inorganic material and backpulsing will not be sufficient to clean the membranes; headloss after backpulsing may be as high as 10 psi. Zenon recommends cleaning when initial post-backpulse pressure loss reaches 8 psi. At such time, the membrane is cleaned typically with either a 2,000 to 10,000 ppm citric acid solution for inorganics or a 200 to 500 ppm hypochlorite solution for organics. The Zenon membrane can be exposed without damage to water with a pH range of 2 to 10.5 during cleaning. The membrane will be back pulsed followed by use of the extra cleanser. Any cleansers will be added directly to the membrane tank. After a period of reversed recirculation (flow from lumen to outside), the membrane may be soaked or the cleaning solution immediately discharged from the tank. Operators confirm that they've provided adequate cleanser flushing, by checking bulk solution pH in the membrane tank, before returning the system to service. An added measure of protection is provided by the installation of a limit switch on the permeate valve to prevent accidental discharge of cleaning solutions to the clearwell. Cleaning solutions may be discharged to the sanitary sewer system or containerized for reuse during subsequent cleanings. All wastewaters generated from chemical cleaning are ultimately discharged to the Littlestown community sanitary sewer system.

The Zenon membrane will be damaged if allowed to dry. It is shipped with a protective coating of glycerin and sealed in plastic. Once the glycerin is removed, the membrane should not be exposed to air for more than four (4) hours; however, the manufacturer expects that damage will not occur for up to 24 hours. If allowed to dry for more than four hours, the membrane should be soaked for two (2) hours and then pressure tested before return to service.

Site plans for the facility are attached. A process flow diagram can be found in the attached plans on Sheet No. G-11.

IV. Innovative Technology Description

Membrane technology provides an absolute barrier to particulate matter greater than 0.2u in size, thus eliminating the need for chemical flocculants and coagulants and sedimentation. The small pore size ensures the removal of a higher percentage of impurities including some viruses, which are removed by a combination of adsorption onto the solids in the process tank and by membrane filtration. The only chemical utilized in the actual water treatment process is chlorine as a disinfectant. By utilizing this technology, a smaller filtration building was possible thereby reducing the footprint and saving valuable land resources.

The membranes operate under low vacuum created within the hollow membrane fibers by a permeate pump. The treated water is drawn through the membrane by the suction generated by the permeate pump, enters the hollow fibers and is pumped out to the treated water storage tank. Air flow is introduced at the bottom of the membrane module to create a turbulence which scrubs and cleans the outside of the membrane fibers allowing them to operate at a high flux rate. The air also has beneficial side effects of oxidizing iron and organic compounds, resulting in a treated water quality that is better than that provided by ultrafiltration alone.

Ultrafiltration also has added benefits in eliminating the generation of, and the need to deal with a solids disposal waste stream; modifications to this process eliminated the need for mechanical recirculation of the quarry waters thus saving energy.

V. Operational Conditions for Innovative Technology

Flows generally ranged from a low of eighty gallons per minute raw flow, to a high of 160 gallons per minute raw flow. The recirculation rate was set at a twenty-five percent reject back into the quarry. Typically, reject fates are lower; Littlestown uses the reject water for recirculation of the quarry water.

The facility has three points of chlorine application: 1.) raw water chlorination, 2.) backpulse make up water, and 3.) finished water. Raw water chlorination was not used during this past year. Backpulse make up water averaged between 1 - 3 ppm total residual chlorine (TRC). Backpulse water is then fed into the membrane tank (unchlorinated waters) resulting in a very lowered TRC. A portion of this water is then returned to the quarry. The return line to the quarry is equipped with a continuous chlorine analyzer to evaluate returned waters for TRC. Due to low flow conditions, this system is inoperable as it currently exists. However, the operators periodically collect grab samples and have noted that the TRC levels returning to the quarry have not exceeded 0.2 ppm.

Finished water TRC ranged from a low of 0.5 mg/l to a high of 1.5 mg/l. Interestingly enough, the membrane manufacturer has built in a safe set point for finished water TRC of 0.5 mg/l. Readings below this level will cause an alarm condition and shut down the system. The owner/operator is not able to change this set point and at first this created operational issues in that the alarm condition was triggered prior to the build up of adequate TRC (in the finished water) causing system shutdown. After several attempts to resolve this situation, the operators "induced" higher levels of TRC by adding liquid bleach into the finished water storage tank thus elevating the TRC to an acceptable level. They employ this same practice after periodic shutdowns for cleaning, etc.

Vacuum pressure on the membranes ranged from 23 - 29 inches Hg. During the entire operating cycle the backpulse frequency was set at every ten minutes for duration of thirty seconds. This setting appeared to work well for this system. Trans-membrane pressure (TMP) ranged from -3 to -6 indicating relatively clean membranes.

The permitted operating rate is 150 GPM at a membrane flux rate of 18.0 GPD/SF for this specific water filtration system. Turbidity and particles are continuously monitored. Raw water turbidity ranged from 1 NTU to 5 NTU's, particle counts range from 1000 to 10,000 per 200 mls. Finished water requirements include a turbidity of 0/1 NTU's and particle counts (total) of 10 per 100 mls or less.

Routine maintenance of the system includes alternation of duplicate equipment (pumps, blowers - alternation controlled by the PLC), cleaning of monitoring equipment (on-line tubidimeters and particle counters), and periodic cleaning (soaking) of the membranes (approximately quarterly). The periodic cleaning process allows for the neutralization of chlorine with sodium bisulfate. The "spent" solution is then discharged to the sanitary sewer system and the membrane tank is flushed with raw water several times. After several flushings, the unit is brought back on-line and put into service. pH reading are taken when the unit is brought into service and have consistently been in the acceptable permit range. We do not believe that the means of cleaning has caused or will cause operational or water quality issues as long as the operators remain attentive to the process.

The facility maintains a maintenance agreement with HACH Co. to provide routine maintenance service and calibration of the turbidimeters and particle counters. It is evident from the daily graphs when the online tubidimeters tubing needs cleaned, raw water levels drop dramatically. Monthly or more frequent cleaning of the tubing is recommended. The particle counters were sent back to the manufacturer for repair and reinstalled.

The Borough maintains a service agreement with the membrane manufacturer wherein a service technician makes quarterly site visits to the facility. These visits have proven invaluable during the first year and feel that service agreements are a necessary element for inclusion into the final permit.

The filtration system was plagued by chronic breakdown of equipment early on during the first year. The Crispin valve located atop of the air chamber corroded and caused system shut down for several weeks until it was replaced by the manufacturer. Shortly thereafter, the nipple on the air separation chamber cracked and was leaking air, thus causing system shut down again until the manufacturer could replace this item. The solenoid valve on the backpulse line seats improperly causing a "false" Membrane Integrity Test (MIT) failure and system shutdown. Level sensors in the finished water storage tank have frequently read either excessively high (won't allow raw water pump to start) or excessively low (calls for more water when the tank is actually full). Additionally, vacuum pump 92A has been problematic; as the system calls for alternate vacuum pumps. 92A frequently fails during its rotation cycle. The manufacturer was made aware of all of these items and has addressed them to the Borough's satisfaction.

More problematic has been the finished water chlorine analyzer. This equipment was supplied by the general contractor, and service and training for this equipment by the manufacturer's representative has not been positive. We are contacting the manufacture directly and requesting service be provided through a different vendor.

VI. MONITORING AND SAMPLING PLAN FOR INNOVATION TECHNOLOGY PROCESS

This facility is required to continuously measure and record raw water turbidity and particle counts; finished water turbidity, particle counts and total chlorine residual (TCR). On-line instrumentation feeds data to both the Programmable Logic Controller (PLC) for permit compliance and process control and a computer, which utilizes Aqua View software for tracking purposes.

The Authority has maintenance contracts for calibration services; on-line instrumentation includes:

- Turbidity - HACH 1720 C Turbidimeters, both raw water and finish water are continuously sampled.
- Particles - HACH 1900 WPC particle counters are utilized. With a capability of monitoring particles in th e2 to 800 micron size range, and a fifteen channel capacity with Aqua View Software. The channel range is variable from 2 to 20 microns. The maximum particle concentration for this instrument is 20,000/ml (with 10% coincidence). The counter maintains a sample flow rate of 200 ml/min and is continuously sampled.
- Total Residual Chlorine - C1 - 17 chlorine residual analyzers are used to continuously sample finished water daily at the entry point.

A. **CT Capabilities**

This facility is designed to meet the PADEP's design and operational chlorine contact time and residual (CT) requirements. Since there is minimal pre-filtration detention time, all CT capabilities are provided in the filtered water storage tank. CT calculations assumed a minimum temperature of 0.5°C, a pH of 7.5, a maximum flow rate of 250 gpm and a T10/T of 0.6 in the filtered water tank with a minimum volume of 52,700 gallons.

B. **Process Instrumentation and Control**

A programmable logic controller (PLC) is provided. It monitors output from: raw and permeate water particle counters, raw and permeate water turbidimeters, raw and finished water flow meters, air blower discharge, chlorine ejector water supply pressure switch, finished water chlorine analyzer and chlorine gas leak detector. Flow from the raw pumps are constant. The PLC controls flow through the membranes based on levels in the filtered water storage tank (obtained by ultrasonic transducer). It also regulates the speed of the permeate pump to insure that the membranes are continuously submerged. Any excess raw water is wasted back into the quarry to aerate it while reducing solids concentrations within the membrane tank.

Applied vacuums and flux rates are tracked and used to determine appropriate backpulsing and chemical cleaning schedules.

Hach 1900 WPC particle counters are used. They are capable of monitoring particles in the 2 to 800 micron size range and have 15 channel capability when using Aqua+ software (to be provided). The channel range is variable from 2 to 20 microns. The maximum particle concentration for this instrument is 20,000/mL (with 10% coincidence). The counter includes a constant head device, to maintain a sample flow rate of 300 to 1000 mL/min, and a spike calibration kit.

Hach 1720D trubidimeters and C1-17 chlorine residual analyzers are also used. Turbidimeters are installed to sample raw and permeate water. One chlorine analyzer was installed to sample finished water at the Entry Point and another to monitor the bleed water returned to the quarry from the membrane tank. The PADEP's Water Management Program concurred with discharge of concentrate back into the quarry provided an on-line chlorine analyzer, with recorder, was installed to monitor the amount of chlorine in the discharge.

Two air compressors are provided to operate the pneumatic control valves. Each of the 3.0 HP units is capable of providing 12 scfm at 100 psig thru an 80 gallon receiver.

C. **Ancillary Facilities**

A natural gas powered generator was provided. It is a 3 phase unit capable of operating 54.0 HP of essential equipment required to insure continuous operation of the Well No. 8 facilities. The generator automatically starts and stops as needed and includes an automatic load transfer control.

D. **Equipment Start-up**

In addition to providing construction assistance, Zenon provided five days of operational training to Authority personnel. Three additional days of training were devoted to membrane cleaning and maintenance. Afterward, the Borough entered into a service agreement with the membrane manufacturer wherein a service technician makes quarterly site visits to the facility. These visits have proven invaluable during the first year.

VII. ANALYTICAL RESULTS

The main factor influencing operations this past year was the chronic break down of equipment (see above). There were no water finished water quality issues at the facility this past year. There were no unusual operating conditions (other than maintenance issues) this past year. The only time the MIT failed was as a result of the malfunctioning solenoid valve; all other MIT's were acceptable. There were no other problems noted with operations and monitoring this past year.

Raw water pH average was 8.6; minimum turbidity was 0.8 NTU's; maximum turbidity was 3.88 NTU's; minimum particle counts were 4,854; maximum was 22,156 counts per ml. Finished water turbidity ranged from a minimum of 0.0 (non detected) to a maximum of 0.22 NTU's, particle counts ranged from a minimum of 0 counts to a maximum of 8.77 counts per ml. Log removal ranged from a minimum of 3.53 to a maximum of 6.01. All of this data was collected during normal operating conditions. It should be noted that data generated after a prolonged period of shutdown sometimes took longer than anticipated to stabilize. Frequent cycling off and on of the unit (shut down due to vacuum pump malfunction, finished water storage tank level sensor malfunction) appears to have detrimental effects on the generation of the data.

Oddly enough, finished water turbidity levels and particle counts did not appear to have seasonal affects. Finished water turbidity levels remained nearly constant throughout the year. Particle counts appear to be more affected by shutdown than by seasonal changes as well. We had a concern in that regard as to the quality of the raw quarry waters (algae) during warmer months; however little if any affect was noted in the particle counts during this time. We believe that the constant recirculation of the quarry itself has helped tremendously in maintaining a more consistent raw water quality.

Organic fouling was not an issue; TMP's were not noticeably reduced during the course of operations. Operators routinely chose convenient times for the periodic cleaning as opposed to the need (TMP) for cleaning. Membranes did not appear to have been fouled by organic material, backpulse occurred primarily every 10 minutes for 30 seconds and as such seemed to provide adequate cleaning based on the steady TPM.

Attached is the report on the CT tracer testing. In addition:

- Appendix A provides data regarding the background fluoride analysis and the test data sheets.
- Appendix B provides the flowrate data sheets.
- Appendix C provides the data analysis and determination of T_{10}.
- Appendix D provides the analysis of inactivation of Giardia cysts.

VIII. <u>COST OF TECHNOLOGY</u>

Appendix E provides the final capital costs for the completed Littlestown Water Filtration Facility. These costs include equipment, installation and start-up. To summarize:

- Contract 99-1 with Zenon Environmental Systems, Inc., in the amount of $495,205.00, covered the actual filtration system, installation, quality control, start-up and additional training.

- Contract 99-2 with Conewago Enterprises, Inc., in the amount of $646,604.03, covered the renovation and expansion of the facilities, the storage tank, pumps, piping, generators, particle counters, turbidimeter, etc.

- Contract 99-3 with Monacacy Valley Electric, in the amount of $97,055.61 covered the electrical portion of the project.

- Contract 99-4 with Herre Bros. Inc., in the amount of $58,311.92, covered the HVAC portion of the project.

The total project cost was <u>$1,297,176.56</u>. What made this project even more beneficial was that, thanks to two state appropriations totaling one million dollars, and a $100,000 Growing Greener Innovative Technology Grant, the Borough's cost was only $197,176.56. For a small municipality with many on fixed incomes, this was very important.

IX. CONCLUSIONS

The main goals of the plant were successfully met. Foremost was the demonstration of the equipment producing a filtered product that met or exceeded the requirements of Chapter 109. The plant also proved to be relatively easy to operate and monitor.

The Zenon system was successful without the need of coagulant chemicals. The plant illustrated that conventional flocculation, coagulation and settling were not necessary to treat this water. Because of the elimination of these processes the plant operator's job was lessened, in that jar testing, mixing of chemicals and monitoring of chemical feed pumps all are unnecessary with this unit.

The results indicate that facility is successful in providing a high quality filtered drinking water for the residents of Littlestown.

REPORT ON CT TRACER TESTING

LITTLESTOWN BOROUGH AUTHORITY

OCTOBER 9, 2002

Purpose

The primary purpose of this tracer study was to determine chlorine contact times of the finished water tank through demonstration as a requirement of the PADEP Operational Permit No. 0198502. For the purpose of determining compliance with the disinfection requirements, the contact time of basins used in calculating contact time should be the detention time at which 90 % of the water passing through the basin is retained in the basin. The tracer study performed at the Littlestown Borough Authority Water Treatment Facility on July 25, 2002 was conducted to determine contact time.

Test Procedure

The tracer study protocol was developed from the EPA's Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources. The facility's process units consist of raw water pumps, membrane filtration process tanks, chlorination system, finished water storage tank and finished water pumps.

Fluoride was utilized as the tracer due to its availability and ease of introduction into the system. A 23 % concentration of hydrofluosilicic acid was introduced into the system after the membrane filtration process tank and before the chlorine injection point. The dosing rate for the test was calculated based on achieving a 1.70 mg/L fluoride concentration throughout the facility. In the original study protocol the dosing rate was set to achieve a 2.0 mg/L concentration, however the dosing equipment, a peristaltic pump, required significant time to calibrate and could not accurately deliver the dose at such a low flow rate. Therefore, the fluoride solution was diluted to 50% of the original concentration using deionized water and the dose was delivered at twice the original rate. This dosing rate was measured until a constant rate was achieved and the anticipated final concentration adjusted to this rate.

Background fluoride analysis of the raw water was completed at the start of the test and every 30 minutes thereafter. The results of this analysis and the test data sheets are presented in Appendix A.

Samples in the chlorination room for conformational purposes and after the finished water pumps were taken at 10-minute intervals throughout the test. Sheet 1 provides a guide to the location of sampling points. The samples were capped and transported to the laboratory on site. The SPADNS method for fluoride analysis was utilized. Sample bottles were labeled prior to the test.

The test was conducted at 91% of the facility flow rate of 150 GPM or 137 GPM. Flow was regulated through the plant by adjustment at the PLC board and the filter to waste valve. The filter to waste valve required periodic attention and manipulation in order to maintain the test flow however the flow stabilized midway through the test. Flow rates were recorded every 10 minutes at sample intervals and if the rate deviated from the target value of 137 GPM flow rates were then adjusted. The study was conducted with the membrane filter unit operating however the backpulse was set to 2-hour intervals. Appendix B provides a record of flowrates through the plant on the test date.

During the test the finished water chlorine analyzer was adjusted such that the Cl_2 level would not drop sufficiently to automatically shut down the finished water pumps. Hydrofluosilicic acid was introduced into the water stream via a metering pump before the chlorination system and traveled via a 6" connection line to the finished water storage tank. The water entered the finished water tank 16 feet from the floor, split between two 90° bends to circulate around the exterior of the first baffle, passed between the floor and the first baffle, passed over a second baffle, and exited through a 6" line at the center of the tank. The water then flowed out of the finished water storage tank to the finished water pumps and into the quarry via a 4" connection hose. Permission was obtained from the DEP Water Quality Division to discharge water to the quarry under the above conditions, as opposed to discharging into the distribution system.

The weather on July 25 was clear skies, morning through afternoon and warm. The test began at approximately 9:00 a.m. and was completed at 5:00 p.m. Most of the test occurred during sunny conditions at 90 degrees F. The tracer team consisted of three samplers, one laboratory worker and the plant operator.

Results

Tables with recorded fluoride concentrations, prepared during lab analysis are provided in Appendix A. Appendix C contains the data analysis and determination of T10 for the finished water storage tank. The data was analyzed numerically. The concentration of fluoride entering the basin (Co) divided by the concentration leaving the basin (C) was plotted against time (t). T10 is obtained at the 0.1 C/Co value. The numerical method involves a linear regression of the log (1-C/Co) versus t/T; where t is the time of sampling and T is the theoretical detention time of the basin to obtain the slope (m) and the y-intercept (b). The slope and intercept values allow for the determination of T10 utilizing the following equation:

$$T10 = T * ((\log (1-0.1) - b)/m))$$

The equation used for the numerical evaluation of T10 is assumed to be accurate if the correlation coefficient indicates a good statistical fit (0.9). It should be noted that a correlation coefficient above 0.9 was achieved in the evaluation.

The T10 values can be used for more than the calculation of necessary chlorine concentrations as it also represents the time 90 % of the water is retained in the basin for processing.

Analysis

The results of the tracer study were analyzed to better understand the data and any deficiencies at the facility. The analysis is based upon the following:

- The detention time, T10, can be estimated for the finished water storage tank from the known detention time and estimated basin factors. This allows for a comparison of estimated T10 values and the calculated T10 values.

A numerical evaluation of the finished water storage tank provided a T10 value of 109 minutes at the 137 GPM flow rate.

Conclusion

The Environmental Protection Agency recommends that a water treatment facility achieve at least a 3-log removal/inactivation of *Giardia* cysts. At the current raw water characteristics with a T10 value of 110 minutes and a finished water chlorine residual of 1.0 mg/L, the finished water storage tank is capable of providing the necessary detention time to meet these standards. Appendix D contains the calculations and charts necessary to demonstrate these disinfection levels.

Recommendation

Given that under current operating standards the finished water tank can provide adequate detention time, no modifications are necessary for the system and it should continue to operate under current standards.

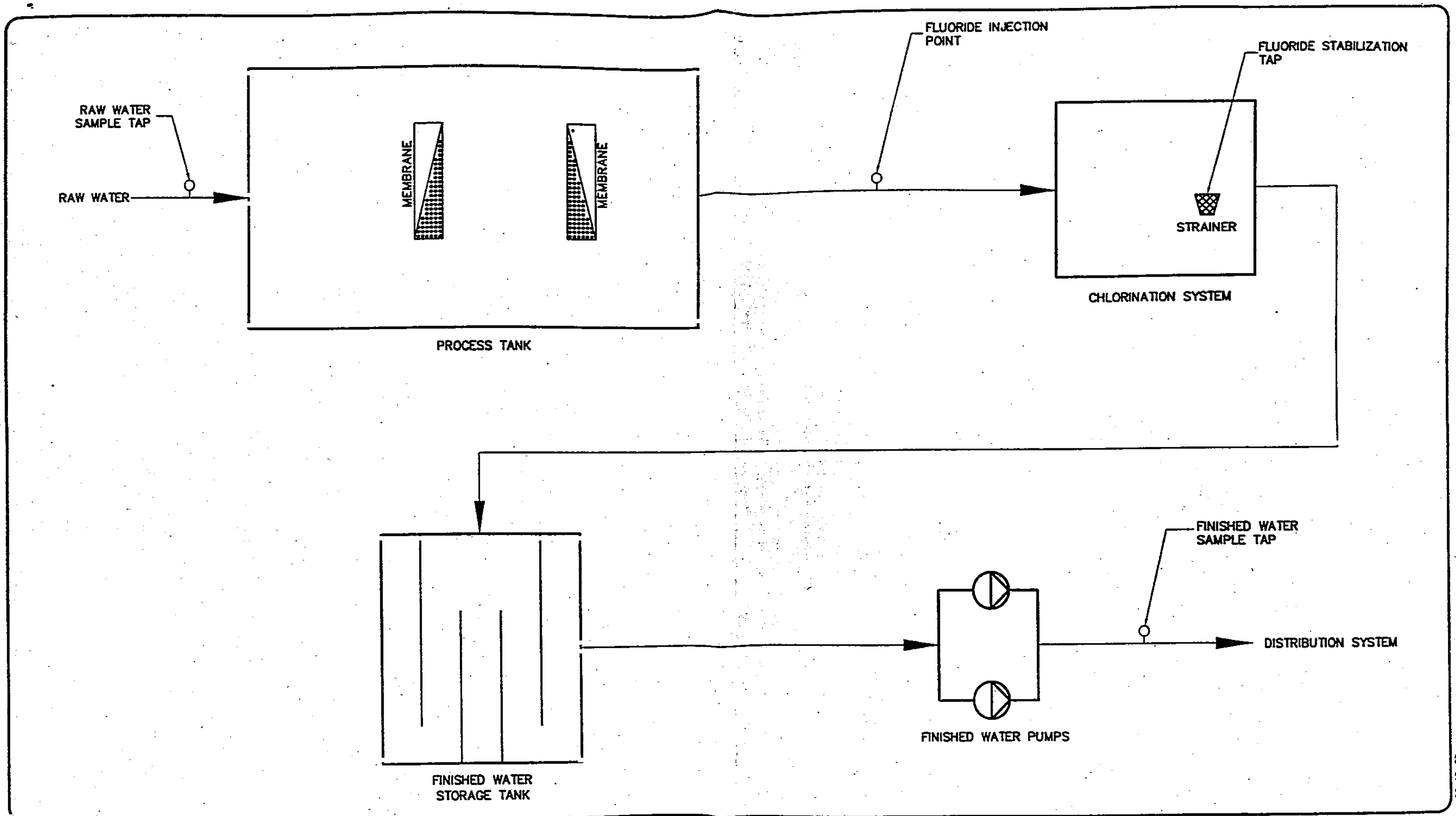
APPENDIX A

BACKGROUND FLUORIDE ANALYSIS
&
TEST DATA SHEETS

Applied F (mg/L)	1.53

T10 (min) =	90
T (min) =	467
T10/T (min) =	19%

Time	Raw (mg/L)	Stabilized (mg/L)	Stabilized (Adjusted, mg/L)	Finished (mg/L)	Finished (adjusted, mg/L)
0	0.17	1.38	1.21	0.23	0.06
10	0.17	2.11	1.94	0.23	0.06
20	0.17	1.49	1.32	0.26	0.09
30	0.26	1.25	0.99	0.27	0.01
40	0.26	1.53	1.27	0.25	-0.01
50	0.26	1.64	1.38	0.26	0.00
60	0.29	1.52	1.23	0.30	0.01
70	0.29	1.72	1.43	0.31	0.02
80	0.29	1.63	-	0.31	0.02
90	0.14	1.53	1.39	0.31	0.17
100	0.14	1.71	1.57	0.36	0.22
110	0.14	1.66	1.52	0.43	0.29
120	0.34	1.63	1.29	0.42	0.08
130	0.34	1.75	1.41	0.42	0.08
140	0.34	1.67	1.33	0.48	0.14
150	0.27	1.77	1.50	0.49	0.22
160	0.27	1.68	1.41	0.46	0.19
170	0.27	1.75	1.48	0.50	0.23
180	0.27	1.64	1.37	0.52	0.25
190	0.27	1.75	1.48	0.54	0.27
200	0.27	1.60	1.33	0.66	0.39
210	0.26	1.73	1.47	0.62	0.36
220	0.26	1.72	1.46	0.69	0.43
230	0.26	1.64	1.38	0.72	0.46
240	0.29	1.64	1.35	0.68	0.39
250	0.29	1.68	1.39	0.76	0.47
260	0.29	1.43	1.14	0.76	0.47
270	0.25	1.42	1.17	0.82	0.57
280	0.25	1.40	1.15	0.84	0.59
290	0.25	1.57	1.32	0.88	0.63
300	0.27	1.64	1.37	0.91	0.64
310	0.27	1.66	1.39	0.89	0.62
320	0.27	1.45	1.18	0.86	0.59
330	0.36	1.37	-	0.91	0.55
340	0.36	1.29	0.93	0.96	0.60
350	0.36	1.51	1.15	1.01	0.65
360	0.32	1.67	1.35	1.00	0.68
370	0.32	1.45	1.13	1.01	0.69
380	0.32	1.11	0.79	1.01	0.69
390	0.32	1.65	1.33	1.04	0.72
400	0.32	1.93	1.61	1.08	0.76
420	0.32	1.23	0.91	1.16	0.84
440	0.32	1.53	1.21	1.23	0.91
460	0.32	1.49	1.17	1.23	0.91



HRG
Herbert, Rowland & Grubic, Inc.
Engineering & Related Services

116 Baltimore Street
Gettysburg, PA 17325
(717) 337-9684
Fax (717) 337-9394
Email - gbg@hrg-inc.com
Website - www.hrg-inc.com
Harrisburg • Lancaster • State College • Gettysburg • Pittsburgh • Stroudsburg

BOROUGH OF LITTLESTOWN
46 EAST KING STREET
LITTLESTOWN, PENNSYLVANIA 17340

WELL No. 8
WATER FILTRATION FACILITY
FLUORIDE SAMPLING DIAGRAM

PROJ. MGR. – PM	
DESIGN–	
CADD–	AMR
CHECKED–	
SCALE–	NO SCALE
DATE–	06-19-02

SHEET NO. 1
DRAWING NO. 1 OF 1
PROJECT 0599.105

APPENDIX B

FLOWRATE DATA SHEETS

① Start up plant goes thru backpulse then every 2 hrs.

Background @ 9:15

Fl2 on @ 9:20:00 217

Littlestown Borough Authority Water Filtration Plant
CT Test Data

Fluoride Concentrations (mg/L)						Fluoride Concentrations (mg/L)					
Time (mins)	Raw Water	Stabilized Fluoride	Finished Water	Tank Elev	Flow	Time (mins)	Raw Water	Stabilized Fluoride	Finished Water	Tank Elev	Flow
0				217"	137	360				229.4	137
30 10				216"4	137	370				230.3	137
40 20				217'8	137	380				230.1	136
50 30				219'	134	390				230.3	140
00 40				220'.4	138	400					
10 50				222"	140	410					
20 60				223'.7	138	420					
30 70				225	137	430					
40 80				226'.3	134	440					
50 90				224	102	450					
00 100				224.6	135	460				230.6	139
10 110				225.6	140	470					
20 120				226.3	135	480					
30 130				226.9	139	490					
40 140				227.5	135	500					
50 150				227.8	137	510					
10 160				227.9	136	520					
10 170				228.2	138	530					
20 180				228.5	136	540					
30 190				228.6	139	550					
40 200	*			228.9	137	560					
50 210	Backpulse right before			227.9	128	570					
00 220				227.9	140	580					
10 230				227.8	137	590					
20 240				227.8	142	600					
30 250				228.3	137	610					
40 260				228.5	141	620					
50 270				228.8	138	630					
00 280				228.9	141	640					
0 290				229	135	650					
10 300				229.2	136	660					
20 310				229.2	140	670					
30 320				229.6	136	680					
40 330				229.1	132	690					
50 340				229.2	138	700					
350				229.5	138	710					

TMP @ 50" = −4 + −5.1 TMP @ 180 = −4.3 + −5.4

" " 100 = −6 + −3.9

150 = 5.3 + −4.2

Shutdown @ 10:44 due to lo Cl2

Start up @ 10:44:30 = backpulse

Prepared by **HRG, Inc.**
1 July 2002

Backpulse @ 12:4

APPENDIX C

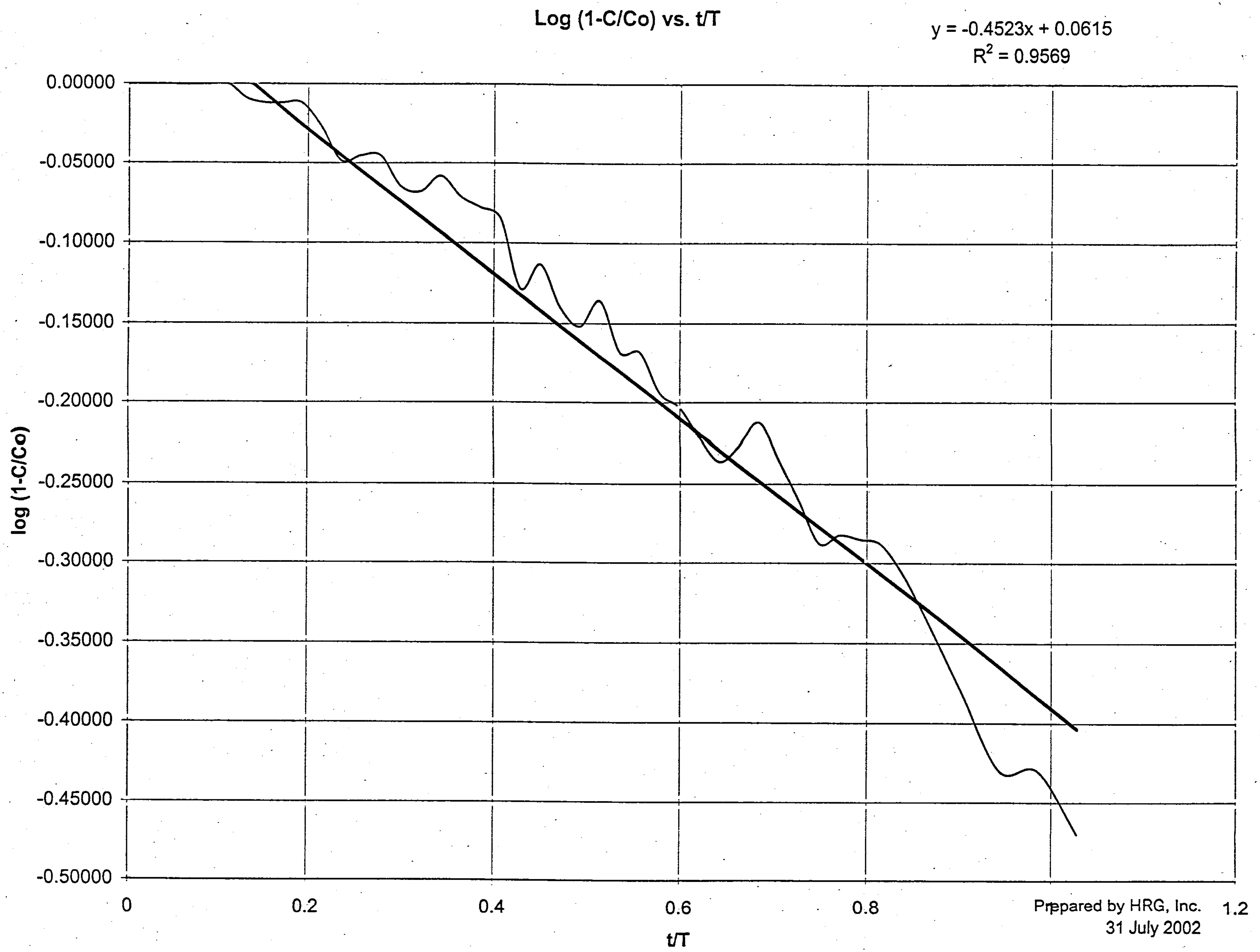
DATA ANALYSIS & DETERMINATION OF T_{10}

Littlestown Borough Authority Water Treatment Plant - Study Results

Avg. Background F (mg/L)	0.27		T10 (min) =	109
Applied F (mg/L)	1.80		T (min) =	467
Adj. Applied (mg/L)	1.53		T10/T (min) =	23%

Time	Raw (mg/L)	Stabilized (mg/L)	Stabilized (Adjusted, mg/L)	Finished (mg/L)	Finished (adjusted, mg/L)	C/Co	Log (1-C/Co)	t/T
0	0.17	1.38	1.11	0.23	-0.04	0%	0.00000	0
10		2.11	1.84	0.23	-0.04	0%	0.00000	0.0214133
20		1.49	1.22	0.26	-0.01	0%	0.00000	0.0428266
30	0.26	1.25	0.98	0.27	0.00	0%	-0.00044	0.0642398
40		1.53	1.26	0.25	-0.02	0%	0.00000	0.0856531
50		1.64	1.37	0.26	-0.01	0%	0.00000	0.1070664
60	0.29	1.52	1.25	0.30	0.03	2%	-0.00905	0.1284797
70		1.72	1.45	0.31	0.04	3%	-0.01195	0.1498929
80		-	-	0.31	0.04	3%	-0.01195	0.1713062
90	0.14	1.53	1.26	0.31	0.04	3%	-0.01195	0.1927195
100		1.71	1.44	0.36	0.09	6%	-0.02679	0.2141328
110		1.66	1.39	0.43	0.16	11%	-0.04846	0.235546
120	0.34	1.63	1.36	0.42	0.15	10%	-0.04530	0.2569593
130		1.75	1.48	0.42	0.15	10%	-0.04530	0.2783726
140		1.67	1.40	0.48	0.21	14%	-0.06462	0.2997859
150	0.27	1.77	1.50	0.49	0.22	14%	-0.06793	0.3211991
160		1.68	1.41	0.46	0.19	13%	-0.05809	0.3426124
170		1.75	1.48	0.50	0.23	15%	-0.07126	0.3640257
180	0.27	1.64	1.37	0.52	0.25	16%	-0.07800	0.385439
190		1.75	1.48	0.54	0.27	18%	-0.08485	0.4068522
200		1.60	1.33	0.66	0.39	26%	-0.12837	0.4282655
210	0.26	1.73	1.46	0.62	0.35	23%	-0.11338	0.4496788
220		1.72	1.45	0.69	0.42	28%	-0.13997	0.4710921
230		1.64	1.37	0.72	0.45	30%	-0.15189	0.4925054
240	0.29	1.64	1.37	0.68	0.41	27%	-0.13607	0.5139186
250		1.68	1.41	0.76	0.49	32%	-0.16830	0.5353319
260		1.43	1.16	0.76	0.49	32%	-0.16830	0.5567452
270	0.25	1.42	1.15	0.82	0.55	36%	-0.19415	0.5781585
280		1.40	1.13	0.84	0.57	37%	-0.20312	0.5995717
290		1.57	1.30	0.88	0.61	40%	-0.22163	0.620985
300	0.27	1.64	1.37	0.91	0.64	42%	-0.23605	0.6423983
310		1.66	1.39	0.89	0.62	41%	-0.22638	0.6638116
320		1.45	1.18	0.86	0.59	39%	-0.21227	0.6852248
330	0.36	-	-	0.91	0.64	42%	-0.23605	0.7066381
340		1.29	1.02	0.96	0.69	45%	-0.26121	0.7280514
350		1.51	1.24	1.01	0.74	48%	-0.28791	0.7494647
360	0.32	1.67	1.40	1.00	0.73	48%	-0.28244	0.7708779
370		1.45	1.18	1.01	0.74	48%	-0.28517	0.7922912
380		1.11	0.84	1.01	0.74	48%	-0.28791	0.8137045
390		1.65	1.38	1.04	0.77	50%	-0.30476	0.8351178
400		1.93	1.66	1.08	0.81	53%	-0.32829	0.856531
420		1.23	0.96	1.16	0.89	58%	-0.37956	0.8993576
440		1.53	1.26	1.23	0.96	63%	-0.42999	0.9421842
460		1.49	1.22	1.23	0.96	63%	-0.42999	0.9850107
480		1.40	1.13	1.28	1.01	66%	-0.46997	1.0278373

Prepared by HRG, Inc.
20 Aug 02



Log (1-C/Co) vs. t/T
y = -0.4523x + 0.0615
R2 = 0.9569
0.00000
-0.05000
-0.10000
-0.15000
-0.20000
-0.25000
-0.30000
-0.35000
-0.40000
-0.45000
-0.50000
log (1-C/Co)
0
0.2
0.4
0.6
0.8
1.2
t/T
Prepared by HRG, Inc.
31 July 2002

HERBERT, ROWLAND & GRUBIC, INC.
369 East Park Drive
Harrisburg, PA 17111
(717) 564-1121

JOB 0599.105
SHEET NO. ______ OF ______
CALCULATED BY AVR DATE 31 JULY 02
CHECKED BY ______ DATE ______
SCALE ______

NUMERICAL ANALYSIS OF T_{10}

EQUATION OF $\text{LOG}(1-C/C_0)$ VS. t/T : $y = -0.4523x + 0.0615$
(CORRELATION COEFF. = 0.96)

FOR T_{10} : $C/C_0 = 0.1$

$$\text{LOG}(1-0.1) = -0.4523(t/467) + 0.0615$$

$$\therefore t = 111 \text{ MIN}$$

PRODUCT 204-1 (Single Sheets) 205-1 (Padded) NEBS Inc. Groton Mass 01471 To Order PHONE TOLL FREE 1 800 225 6380

APPENDIX D

ANALYSIS OF INACTIVATION OF GIARDIA CYSTS

HRG
Herbert, Rowland & Grubic, Inc.
Engineering & Related Services

JOB 0599.105 - CT STUDY
SHEET NO. ______ OF ______
CALCULATED BY AMR DATE ______
CHECKED BY ______ DATE ______
SCALE ______

PROPERTIES OF INFLUENT FLOW*

pH - AVG. 7.0

TEMP. - MAX. = 20° C
MIN. = 10° C

Cl_2 RESIDUAL - 1.0 mg/L (MINIMUM)

- INACTIVATION OF GIARDIA CYSTS (T_{10} = 110 MIN.)

10° C → CT = (1.0 mg/L)(110 MIN) = 110

FROM TABLE E-3 @ pH = 7.0 → LOG INACTIVATION ≈ 3.0

20° C → CT = 110

FROM TABLE E-5 @ pH = 8.5 → LOG INACTIVATION = > 3.0

* FROM DAILY OPERATIONS LOG SHEETS 4/01 - 5/02

PRODUCT 204-1 (Single Sheets) 205-1 (Padded)

10°C, pH 7.0

TABLE E-3
CT VALUES FOR INACTIVATION
OF GIARDIA CYSTS BY FREE CHLORINE
AT 10 C (1)

CHLORINE CONCENTRATION (mg/L)	pH<=6 Log Inactivations						pH=6.5 Log Inactivations						pH=7.0 Log Inactivations						pH=7.5 Log Inactivations					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	12	24	37	49	61	73	15	29	44	59	73	88	17	35	52	69	87	104	21	42	63	83	104	125
0.6	13	25	38	50	63	75	15	30	45	60	75	90	18	36	54	71	89	107	21	43	64	85	107	128
0.8	13	26	39	52	65	78	15	31	46	61	77	92	18	37	55	73	92	110	22	44	66	87	109	131
→ 1	13	26	40	53	66	79	16	31	47	63	78	94	19	37	56	75	93	112	22	45	67	89	112	134
1.2	13	27	40	53	67	80	16	32	48	63	79	95	19	38	57	76	95	114	23	46	69	91	114	137
1.4	14	27	41	55	68	82	16	33	49	65	82	98	19	39	58	77	97	116	23	47	70	93	117	140
1.6	14	28	42	55	69	83	17	33	50	66	83	99	20	40	60	79	99	119	24	48	72	96	120	144
1.8	14	29	43	57	72	86	17	34	51	67	84	101	20	41	61	81	102	122	25	49	74	98	123	147
2	15	29	44	58	73	87	17	35	52	69	87	104	21	41	62	83	103	124	25	50	75	100	125	150
2.2	15	30	45	59	74	89	18	35	53	70	88	105	21	42	64	85	106	127	26	51	77	102	128	153
2.4	15	30	45	60	75	90	18	36	54	71	89	107	22	43	65	86	108	129	26	52	79	105	131	157
2.6	15	31	46	61	77	92	18	37	55	73	92	110	22	44	66	87	109	131	27	53	80	107	133	160
2.8	16	31	47	62	78	93	19	37	56	74	93	111	22	45	67	89	112	134	27	54	82	109	136	163
3	16	32	48	63	79	95	19	38	57	75	94	113	23	46	69	91	114	137	28	55	83	111	138	166

CHLORINE CONCENTRATION (mg/L)	pH=8.0 Log Inactivations						pH=8.5 Log Inactivations						pH<=9.0 Log Inactivations					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	25	50	75	99	124	149	30	59	89	118	148	177	35	70	105	139	174	209
0.6	26	51	77	102	128	153	31	61	92	122	153	183	36	73	109	145	182	218
0.8	26	53	79	105	132	158	32	63	95	126	158	189	38	75	113	151	188	226
1	27	54	81	108	135	162	33	65	98	130	163	195	39	78	117	156	195	234
1.2	28	55	83	111	138	166	33	67	100	133	167	200	40	80	120	160	200	240
1.4	28	57	85	113	142	170	34	69	103	137	172	206	41	82	124	165	206	247
1.6	29	58	87	116	145	174	35	70	106	141	176	211	42	84	127	169	211	253
1.8	30	60	90	119	149	179	36	72	108	143	179	215	43	86	130	173	216	259
2	30	61	91	121	152	182	37	74	111	147	184	221	44	88	133	177	221	265
2.2	31	62	93	124	155	186	38	75	113	150	188	225	45	90	136	181	226	271
2.4	32	63	95	127	158	190	38	77	115	153	192	230	46	92	138	184	230	276
2.6	32	65	97	129	162	194	39	78	117	156	195	234	47	94	141	187	234	281
2.8	33	66	99	131	164	197	40	80	120	159	199	239	48	96	144	191	239	287
3	34	67	101	134	168	201	41	81	122	162	203	243	49	97	146	195	243	292

Notes:
[illegible] for 3 log inactivation [illegible]

From "EPA Guidance Manual for Compliance with the Filtration & Disinfection Requirements for Public Water Systems Using Surface Water Sources, March 1991 Edition"

20°C, pH 7.0

TABLE E-5
CT VALUES FOR INACTIVATION
OF GIARDIA CYSTS BY FREE CHLORINE
AT 20 C (1)

CHLORINE CONCENTRATION (mg/L)	pH <= 6 Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0	pH = 6.5 Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0	pH = 7.0 Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0	pH = 7.5 Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	6	12	18	24	30	36	7	15	22	29	37	44	9	17	26	35	43	52	10	21	31	41	52	62
0.6	6	13	19	25	32	38	8	15	23	30	38	45	9	18	27	36	45	54	11	21	32	43	53	64
0.8	7	13	20	26	33	39	8	15	23	31	38	46	9	18	28	37	46	55	11	22	33	44	55	66
1	7	13	20	26	33	39	8	16	24	31	39	47	9	19	28	37	47	56	11	22	34	45	56	67
1.2	7	13	20	27	33	40	8	16	24	32	40	48	10	19	29	38	48	57	12	23	35	46	58	69
1.4	7	14	21	27	34	41	8	16	25	33	41	49	10	19	29	39	48	58	12	23	35	47	58	70
1.6	7	14	21	28	35	42	8	17	25	33	42	50	10	20	30	39	49	59	12	24	36	48	60	72
1.8	7	14	22	29	36	43	9	17	26	34	43	51	10	20	31	41	51	61	12	25	37	49	62	74
2	7	15	22	29	37	44	9	17	26	35	43	52	10	21	31	41	52	62	13	25	38	50	63	75
2.2	7	15	22	29	37	44	9	18	27	35	44	53	11	21	32	42	53	63	13	26	39	51	64	77
2.4	8	15	23	30	38	45	9	18	27	36	45	54	11	22	33	43	54	65	13	26	39	52	65	78
2.6	8	15	23	31	38	46	9	18	28	37	46	55	11	22	33	44	55	66	13	27	40	53	67	80
2.8	8	16	24	31	39	47	9	19	28	37	47	56	11	22	34	45	56	67	14	27	41	54	68	81
3	8	16	24	31	39	47	10	19	29	38	48	57	11	23	34	45	57	68	14	28	42	55	69	83

CHLORINE CONCENTRATION (mg/L)	pH = 8.0 Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0	pH = 8.5 Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0	pH <= 9.0 Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	12	25	37	49	62	74	15	30	45	59	74	89	18	35	53	70	88	105
0.6	13	26	39	51	64	77	15	31	46	61	77	92	18	36	55	73	91	109
0.8	13	26	40	53	66	79	16	32	48	63	79	95	19	38	57	75	94	113
1	14	27	41	54	68	81	16	33	49	65	82	98	20	39	59	78	98	117
1.2	14	28	42	55	69	83	17	33	50	67	83	100	20	40	60	80	100	120
1.4	14	28	43	57	71	85	17	34	52	69	86	103	21	41	62	82	103	123
1.6	15	29	44	58	73	87	18	35	53	70	88	105	21	42	63	84	105	126
1.8	15	30	45	59	74	89	18	36	54	72	90	108	22	43	65	86	108	129
2	15	30	46	61	76	91	18	37	55	73	92	110	22	44	66	88	110	132
2.2	16	31	47	62	78	93	19	38	57	75	94	113	23	45	68	90	113	135
2.4	16	32	48	63	79	95	19	38	58	77	96	115	23	46	69	92	115	138
2.6	16	32	49	65	81	97	20	39	59	78	98	117	24	47	71	94	118	141
2.8	17	33	50	66	83	99	20	40	60	79	99	119	24	48	72	95	119	143
3	17	34	51	67	84	101	20	41	61	81	102	122	24	49	73	97	122	146

From "EPA Guidance Manual for Compliance with the Filtration & Disinfection Requirements for Public Water Systems Using Surface Water Sources, March 1991 Edition"