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FEASIBILITY OF WASTEWATER REUSE AT THE NATIONAL SPINNING COMPANY, INC. IN WASHINGTON, NORTH CAROLINA

by
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ABSTRACT

The City of Washington, North Carolina, and the National Spinning Company, Inc. are considering a unique wastewater reuse scheme. Upon upgrading of the wastewater facility at the City of Washington with a denitrification filter, it is proposed that 1.3 mgd of tertiary treated wastewater be routed for use as process water in textile dyeing operations. The reclaimed wastewater would be stored at two abandoned City of Washington clearwells prior to use by National Spinning Company. The objective of this research was to evaluate the quality of the reclaimed wastewater that could be produced after treatment by the City of Washington and after passage through the existing treatment used at National Spinning Company for its process water.

A pilot-plant was constructed at the University of North Carolina to simulate the City of Washington treatment plant upgrade and the present process water treatment scheme at the National Spinning Company (a groundwater source). Several large grab samples of City wastewater were collected and processed through the pilot plant. The reclaimed water was analyzed to determine the feasibility for use as process water.

The results indicated that the reclaimed wastewater is of very high quality based on conventional measures (chemical oxygen demand, biochemical oxygen demand and dissolved organic carbon) and on specific chemicals required for analysis in Safe Drinking Water Act (SDWA) Compliance Monitorings. With the exception of trihalomethanes (THMs), all volatile organic chemicals (VOCs) that are required to be monitored by EPA in drinking water sources were below detection limit. Analysis of the entire list of non-volatile organics and inorganics for SDWA Compliance Monitoring revealed that phthlates were in excess of the MCL (0.1482 mg/l compared to MCL of 0.004 mg/l). The high concentration of phthalates may have been due to contact with plastic within the pilot plant units. Other chemicals that were found above detection limit but below their MCLs were: atrazine (0.000143 mg/l); copper (0.006 mg/l); fluoride (0.63 mg/l); nitrate/nitrite (1.08 mg/l); and sulfate (50 mg/l). THMs were well below the current maximum contaminant levels (MCLs). Without further chlorination before storage of the reclaimed wastewater and possibly after storage, regrowth of microorganisms is expected. Although regrowth may be eliminated, a more important concern is the possibility that the reclaimed wastewater will stain the National Spinning Company fabrics. Coagulation-flocculation-sedimentation of the stored water was shown to reduce the staining significantly; however, some staining potential is still evident. Other treatment options may be worth exploring if and when the City of Washington and National Spinning Company decide to pursue wastewater reclamation further.

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SUMMARY AND CONCLUSIONS

The City of Washington, North Carolina, and the National Spinning Company, Inc. are considering a unique wastewater reuse scheme. Upon upgrading of the wastewater facility at the City of Washington with a denitrification filter, it is proposed that 1.3 million gallons per day of tertiary treated wastewater be routed for use as process water in textile dyeing operations. The reclaimed wastewater would be stored at two abandoned City of Washington clearwells prior to use by National Spinning Company.

This research was undertaken to evaluate the technical feasibility of the proposed wastewater reclamation plan from the standpoint of producing a water that was acceptable to National Spinning Company for yarn dyeing and that compared favorably to its existing groundwater supply. The use of reclaimed municipal wastewater as process water in textile dyeing operations has not been documented in the literature. Reclaimed water used for this purpose must be of very high quality to meet the process needs of the industry and to minimize the potential impacts on human health by inadvertent exposures.

Pilot plant treatment units were constructed to simulate the additional treatment recommended to the City of Washington by its consultant and to simulate the existing processes used by National Spinning Company to produce process water from their groundwater supply. Unlike typical pilot plant studies, these pilot plant units were operated in batch-wise mode rather in a continuous mode due to the fact that the pilot plant was located at the University of North Carolina in Chapel Hill and 55 gallon samples had to be shipped from the City of Washington for processing.

A total of five batches of wastewater from the City of Washington over a span of 8 months (April to November 1993) were processed through the pilot plant. The reclaimed wastewater was generally of very high quality based on conventional measures of organic compounds, i.e., chemical oxygen demand, biochemical oxygen demand, total organic carbon. However, regrowth of microorganisms was noted during the 15 h storage period after treatment by the City of Washington and before treatment by National Spinning Company. Thus bacteria can be expected in the treatment units used to produce process water at the National Spinning Company. Bacterial regrowth could be eliminated or minimized by application of additional chlorination after the storage step and dechlorination just prior to use of the process water for yarn dyeing.

A potentially difficult problem is staining of yarn goods by use of the reclaimed wastewater. The standard jar test was used to

determine if additional treatment of the wastewater by coagulation (with Riverclear 3103 polymer)would reduce the staining problem. Although staining was reduced greatly,some discoloration was still evident. The cause of this staining is not known.

A comparsion was also made of reclaimed wastewater quality and existing groundwater quality. Samples were subjected to analyses required by the Safe Drinking Water Act (SDWA) Compliance Monitoring program. The only volatile organic chemicals detected were trihalomethanes (chloroform, bromodichloromethane, and chlorodibromomethane). Trihalomethanes were less than 20 µg/l and well below the current maximum contaminant level (MCL). Of the list of non-volatile organics and inorganics analyzed in SDWA Compliance Monitoring, phthalates were 0.1482 mg/l, which is considerably above the MCL of 0.004 mg/l; however, it is possible that phthalates are an artifact of the experiment.

In addition, the following chemicals were detected but were below their MCLs: atrazine (0.000143 mg/l); copper (0.006 mg/l); fluoride (0.63 mg/l); nitrate/nitrite (1.08 mg/l); and sulfate (50 mg/l). No MCLs exist for iron and manganese but their concentrations were 0.5 and 0.055 mg/l, respectively.

The results of this investigation suggest that use of reclaimed wastewater would be feasible for yarn dyeing if the staining problem could be solved. More research is needed on alternative treatment technologies that could reduce staining. These treatment technologies are available, e.g. oxidation by ozone, improved coagulation and/or microfiltration.

RECOMMENDATIONS

Further process research is recommended to convince both the City of Washington and the National Spinning Company that wastewater reclamation is feasible. The most important issue is whether needs for process water by National Spinning Company can continue to be met by its existing groundwater supply.

Some of the technical problems of wastewater reclamation found in this study can be easily overcome. Microbial regrowth in the reclaimed wastewater is easily eliminated by additional chlorination at the clear well storage facility. Dechlorination after storage is equally feasible at little cost. The more difficult problem is the possible staining of fabric. Several options could be explored to eliminate staining. For instance, coagulation of the wastewater is an option given that the treated wastewater from the City of Washington would first be sent to the old water treatment plant for storage in the clear well. Coagulant could be added in the pipeline leading from the City of Washington's wastewater treatment facility; there may be enough energy dissipation to promote flocculation without further treatment. The floc could then be allowed to settle in the clear well which would then necessitate periodic cleaning. Another option is to consider a new strategy for water treatment at National Spinning Company that includes microfiltration after the existing treatment by ion exchange and greensand beds.

The process water presently used by National Spinning Company is a groundwater that is not subject to any regulation by the State of North Carolina because it is not used for water supply. However, use of reclaimed wastewater would force regulation by the State of North Carolina in some form yet to be determined. Undoubtedly minimum standards would have to be met to protect the health of National Spinning Company employees. Moreover, National Spinning Company may be concerned about its responsibility in making sure that the National Pollutant Discharge Elimination System (NPDES) permit is not violated given that it would be discharging wastewater that originated from the City of Washington. National Spinning Company also needs to consider other implications that are not answered by science or engineering. These implications have to do with public perception and customer concerns about the yarn products that have been dyed with this process water. The decision to reuse wastewater, therefore, should be made cautiously with the full cooperation and knowledge of the responsible agencies and with the highest level of management at the National Spinning Company.

The experience and regulatory guidance on wastewater reuse is very limited in North Carolina and thus policy issues remain. Moreover, the lack of universal regulatory standards, limited

experience, and the general public's less than favorable opinion towards wastewater reuse (which is based on potable and not on non-potable applications) may concern National Spinning Company about potential legal issues. It is, therefore recommended that the State of North Carolina work to develop a framework to regulate reuse projects as in other states (i.e., California). Undoubtedly, more innovative uses of reclaimed wastewater will be developed in the future in order to conserve water resources. Both the State and industry must look for reuse opportunities and develop the necessary technical framework to manage these projects effectively.

Specific recommendations for research to improve the technical information on wastewater reuse for the yarn dyeing industry follow from this study. A continuous-flow, pilot plant treatment of the wastewater effluent from the City of Washington would yield more reliable data than the batch studies conducted herein and would answer questions about process reliability during the normal course of variations in effluent quality. The major technical problem to be overcome appears to be staining of the yarn and thus more research would be needed to identify the cause and/or find treatment processes that will remove the responsible staining agents. This research showed that chemical coagulation reduced the staining potential but more work is needed to find the optimum coagulant and dose. The abandoned water treatment plant at the City of Washington could be adapted to provide for coagulation of the wastewater effluent. In addition, microfiltration either following coagulation or instead of coagulation may reduce staining.

INTRODUCTION

The City of Washington, North Carolina, and National Spinning Company, Inc. are considering a unique wastewater reuse scheme. Upon upgrading of the wastewater treatment facility at the City of Washington with a denitrification filter (Tetra Filtration System), it is proposed that 1.3 million gallon per day (mgd) of the 2.5 mgd tertiary treated wastewater be routed for use as process water in textile dyeing operations. The proposed reuse plan is shown schematically in Figure 1. Treated wastewater would be pumped 1,900 feet to existing effluent storage reservoirs (the two clear wells of the abandoned water treatment facility for the City of Washington) and then pumped a total distance of about 3,400 feet to the existing water treatment facility at the National Spinning Company, Inc.

Clearly, the proximity of the City's wastewater treatment facility and the industry and existing storage reservoirs make this proposal attractive. Moreover, the final point of wastewater discharge for a large percentage of the City's flow will be shifted from Kennedy Creek to the Tar River. This shift will provide a larger dilution factor and possibly relieve the City of the need to construct a new outfall of its own to the Tar River.

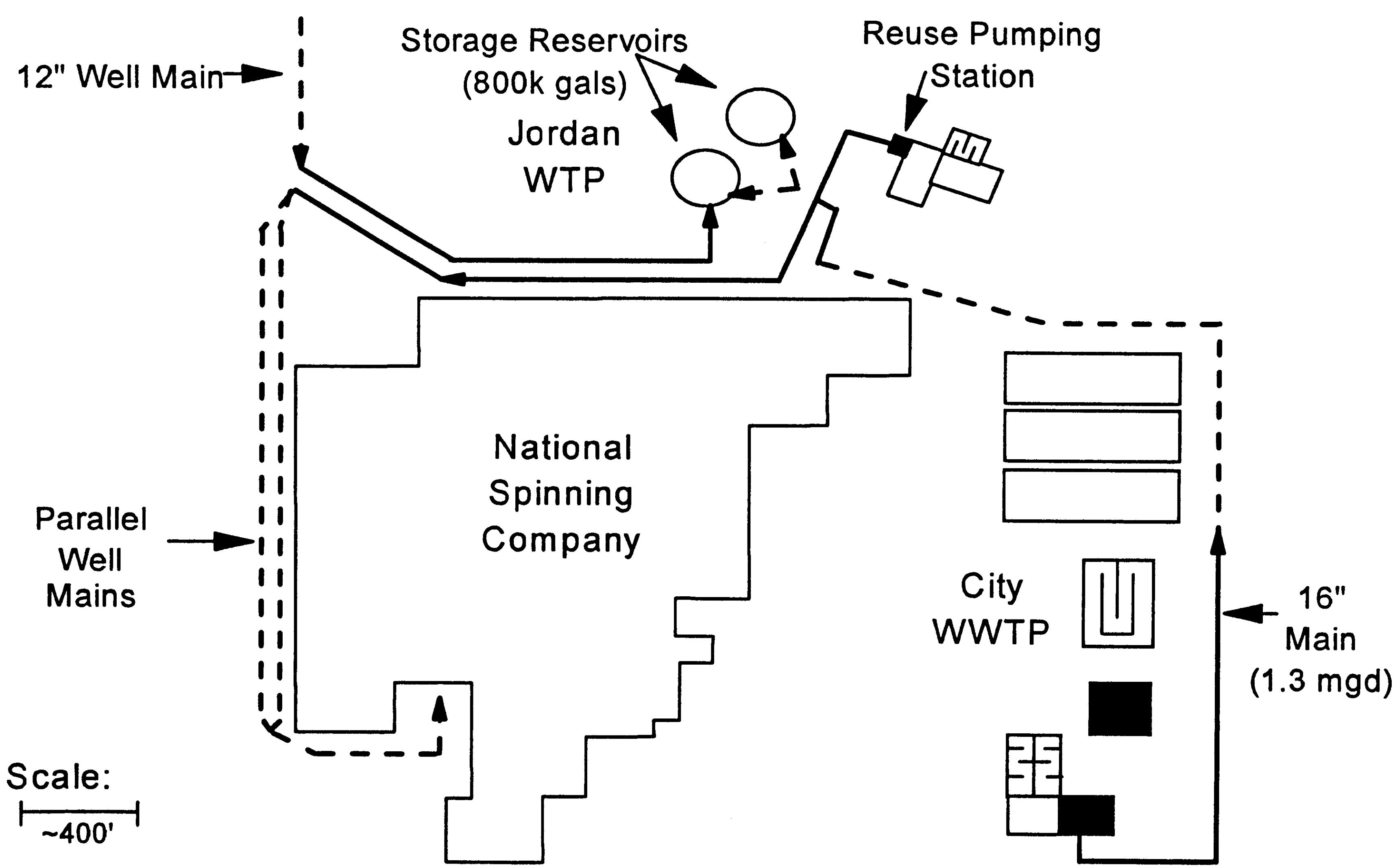
The reclaimed water will be used in yarn dyeing operations. At present the National Spinning Company uses a groundwater supply for process water. This water is not used as a source of potable water at the facility and is, therefore, not regulated. Consequently, there is no concern at the facility about employee exposure or contact with the present process water. The conversion to reclaimed wastewater will likely heighten employee awareness at the facility as well as require the National Spinning Company to regulate this water source.

The proposed wastewater reuse plan, which involves cooperation between a municipality and an industry would be unique in North Carolina and would require special evaluation by State regulatory agencies. Presently, the regulation of potable water sources in North Carolina is governed by the Division of Environmental Health while the regulation of wastewater discharge is governed by the Division of Environmental Management.

The research objectives of this project were to:

- determine if the reclaimed wastewater quality meets process water requirements at the National Spinning Company, Inc.
- compare the quality of the reclaimed water to the current groundwater supply used by National Spinning Company, Inc.

Figure 1. Proposed wastewater reuse scheme by National Spinning Company in City of Washington, NC



BACKGROUND

U.S. EXPERIENCE WITH WASTEWATER REUSE

Reclaimed water can replace potable water for many uses that do not require water of potable quality, including crop and landscape irrigation; non-potable urban uses such as residential lawn irrigation and toilet flushing; industrial cooling and process water; and groundwater recharge. Several states have been at the forefront of wastewater reuse technology. In California, water shortages have dictated the need for water conservation and reuse. As early as 1932, the Golden Gate Park in San Francisco began using reclaimed water for large-scale landscape irrigation. Since 1976, reclaimed water has been injected directly into groundwater aquifers to prevent salt water intrusion in the coastal areas and as a means of supplementing potable water supply sources(Crook, et al., 1993).

Over the past twenty years, the State of Florida has implemented a number of reuse projects. The driving force in Florida has been the need to limit effluent discharges into low-flowing, shallow surface water sources (York and Crook, 1991). Also, population growth in coastal areas has resulted in some salt water intrusion into local drinking water aquifers. Florida has developed programs that encourage the reuse of reclaimed wastewater throughout the state. In 1977, St. Petersburg began using a dual water system in which reclaimed water was supplied for industrial use and irrigation of golf courses, parks, and individual home sites (Crook, et al., 1993). Reclaimed water has also been used extensively in Florida for crop irrigation as well as other non-potable residential uses (York and Crook, 1991).

In North Carolina, wastewater reuse has not been as common due to the abundance of water supplies. However, tighter regulations on wastewater discharges may lead communities to consider the reuse of wastewater effluent to offset demands for non-potable water. This is particularly true for cases where the existing water supply is limited, is of poor quality, or where the reduction of treated effluent discharge may result in reduced pollutant loadings on receiving streams (Miles and Ridge, 1993).

Industrial Applications

The most common industrial use of reclaimed wastewater has been as a source of cooling water, either as as cooling tower make-up or as a primary source of once-through cooling water (EPA, 1992). The Bethlehem Steel plant in Sparrows Point, Maryland, has used secondary effluent for once-through and direct metal cooling since 1942. In Oklahoma, Farmland Industries has been using the City of Enid's municipal wastewater effluent since 1974, and in California, the City of Burbank power plant has used tertiary municipal effluent since 1967 (Crook, et al., 1993 and EPA, 1992).

The use of reclaimed wastewater for industrial process water has been less extensive. The acceptability of reclaimed water for this use is dependent on the specific application and is highly variable. In some instances, relatively low-quality secondary effluent may be used for applications such as the manufacture of concrete (Crook, et al., 1993). However, higher quality water is required for other industrial applications, e.g., textile or paper mill process water (EPA, 1992). Two paper mills use tertiary treated effluent from the Los Angeles County Sanitation District's Pomona Water Reclamation Plant as process water. The Garden State Paper Company uses 3 mgd of reclaimed water for newsprint reprocessing, and the Simpson Paper Company uses 1 mgd for the manufacture of high quality paper for stationery and wrappings. The tertiary treatment at the Pomona plant includes carbon adsorption for color removal (Crook, et al., 1993).

Water Quality in Process Water for Textile Dyeing

Water used in the textile industry must be non-staining; hence, it must be low in turbidity, color, iron, and manganese. In addition, chlorine and other oxidizing agents must be absent to avoid reaction with dyes. A list of requirements for process water in the textile industry is shown in Table 1. The reclaimed wastewater from the City of Washington is intended to be used directly in the application of dyeing yarns at the National Spinning Company.

Because dyeing is done at high temperature, another important issue is whether reclaimed wastewater will cause problems in heat exchangers. Water quality criteria to meet industrial cooling water requirements have been developed. These recommended limits are shown in Table 2. These parameters were selected to minimize the effects of scaling, corrosion, fouling and biological growth in these systems (Sundberg, et al., 1991 and EPA, 1992). A search of the literature did not reveal that any similar applications had been attempted.

Table 1. Textile Process Water Quality Requirements

Parameter	Textile Uses: Sizing suspension	Textile Uses: Scouring, bleach & dye
Cu, mg/l	0.01	N/A
Fe, mg/l	0.3	0.1
Mn, mg/l	0.05	0.01
Hardness, mg/l	25	25
TDS, mg/l	100	100
TSS, mg/l	5	5
Color	5	5

Source: Water Pollution Control Federation, 1989

Table 2. Recommended Cooling Water Quality Requirements

Parameter[a]	Recommended Limit[b]
Cl	500
TDS	500
Hardness	650
Alkalinity	350
pH[c]	6.9-9.0
COD	75
TSS	100
Turbidity[c]	50
BOD[c]	25
Organics[d]	1.0
NH_4-N[c]	1.0
PO_4[c]	4
SiO_2	50
Al	0.1
Fe	0.5
Mn	0.5
Ca	50
Mg	0.5
HCO_3	24
SO_4	200

[a] All values in mg/l except pH.
[b] Water Pollution Control Federation, 1989.
[c] From Goldstein, *et al.*, 1979.
[d] Methylene blue active substances

Federal and State Regulations

At present, the process water used by National Spinning Company (a groundwater source) is not used for potable water and is not regulated. However, conversion of this process water to reclaimed wastewater will undoubtedly require National Spinning Company to meet some minimal standards to protect employee health.

Currently, no federal regulations exist governing water reclamation and reuse in the United States (Crook, et al., 1993). Many states, however, have adopted some form of water reclamation and reuse regulations or guidelines. In a number of states these regulations vary with the intended reclaimed wastewater usage. The variation in regulations for the State of California are shown in Table 3 (Crook, et al., 1993).

Only six states have adopted restrictions directed at industrial use of reclaimed water. These regulations are displayed in Table 4. In North Carolina few regulations have been developed that address wastewater reclamation. Regulations developed in 1993 (Crook, et al., 1993) contain some requirements for land application of domestic wastewater on golf courses and other public access areas. However, no state regulations presently exist that would govern the use of reclaimed wastewater proposed at the National Spinning Company. The application at National Spinning Company would be a unique situation. The North Carolina Division of Environmental Management has stated its willingness to review reuse applications other than those listed in the present state guidelines on a case-by-case basis (Personal Communication: Coleen Sullins, staff member of NC Division of Environmental Management, October 19, 1993).

DENITRIFICATION AND IMPLICATIONS FOR WASTEWATER REUSE

Although denitrification is not essential for wastewater reclamation, the City of Washington is planning to upgrade its wastewater treatment plant to include a biological denitrification filter. This process is made necessary by state regulations that will further restrict nutrient discharges in the Pamlico River basin. Denitrification will be required regardless of whether a portion of the effluent is to be recycled as process water at the National Spinning Company.

The engineering consultant has already selected a down-flow, attached growth system provided by Tetra Technologies, Inc. to provide biological denitrification for the City of Washington (Black & Veatch, 1992). This denitrification system consists of packed bed of a small gravel medium that allows for microorganism attachment. In order for the microorganisms to reduce the nitrogen compounds, an exogenous carbon supply must be provided.

Table 3. California Treatment and Quality Criteria for Reuse

Type of Use	Total Coliform Limits	Treatment Required
Fodder, Fiber, and Seed Crops Surface Irrigation of Orchards and Vineyards	---	Primary
Pasture for Milking Animals Landscape Impoundments Landscape Irrigation (Golf Courses, Cemeteries, etc.)	23/100 ml	Oxidation & Disinfection
Surface Irrigation of Food Crops Restricted Recreational Impoundments	2.2/100 ml	Oxidation & Disinfection
Spray Irrigation of Food Crops Landscape Irrigation (Parks, Playgrounds, etc.) Nonrestricted Recreational Impoundments	2.2/100 ml	Oxidation, Coagulation, Clarification, Filtration, & Disinfection
Groundwater Recharge	Case-by-Case Evaluation	Case-by-Case Evaluation

Source: Crook, et al., 1993

Table 4. State Standards for Industrial Reuse

	Arizona	Hawaii	Nevada	Oregon	Texas	Utah
Reclaimed Water Quality and Treatment Requirements	• Determined on a case-by-case basis	• Oxidized and disinfected • Total coliform < 23/100ml (7-day mean) < 240/100ml (2 consecutive samples)	• Secondary treatment with disinfection • Fecal coliform < 200/100ml (mean) < 400/100ml (single sample)	• Biological treatment and disinfection • Total coliform < 240/100ml (2 consecutive samples), < 23/100ml (median)	•30 mg/L BOD with treatment using pond system •20 mg/L BOD with treatment other than pond system • Fecal coliform not to exceed 200/100ml	• Advanced treatment • BOD<10 mg/L at any time • TSS<5 mg/L at any time • Total coliforms < 3/100ml at any time

Source: EPA/625/R-92/004 "Guidelines for Water Reuse", 1992.

Typically, the source of carbon used for this purpose is methanol (CH_3OH). Methanol serves as the electron donor and nitrate as the electron acceptor in the biological oxidation process as illustrated below(Jeris and Owens, 1975):

$$3NO_3^- + CH_3OH \rightarrow 3NO_2^- + CO_2 + 2H_2O$$
$$2NO_2^- + CH_3OH \rightarrow N_2 + CO_2 + H_2O + 2OH^-$$

$$\text{Net: } 6NO_3^- + 5CH_3OH \rightarrow 3N_2 + 5CO_2 + 7H_2O + 6OH^-$$

A number of facultative bacteria, including *Pseudomonas* and *Bacillus*, are able to convert oxidized forms of nitrogen to elemental nitrogen gas (N_2). Simultaneous with denitrification, the downflow filter also serves to remove suspended solids, most of which are due to sloughing of attached biomass from the filter medium. The Tetra system has been installed successfully at a number of wastewater plants (Upton, et al., 1993). For example, it has been in operation since the mid 1970's at the Hooker's Point Wastewater Treatment Plant in Tampa, Florida, and at the Altamonte Springs Advanced Wastewater Plant in Altamonte Springs, Florida, since the mid 1980's.

The stoichiometry of the reaction presented above shows that five moles of methanol are required to reduce six moles of nitrate-nitrogen to elemental nitrogen. This stoichiometric ratio is equivalent to 1.9 mg of methanol for each mg of nitrate-nitrogen. McCarty, et al. (1969) found that an additional 30% of methanol was needed to satisfy the growth requirements of the microbes and this requirement has been verified experimentally by others (Jeris and Owens, 1975 and Upton, et al. 1993). The equation used to determine the total methanol requirement is:

$$C_m = 2.47\ (NO_3\text{-}N) + 1.53\ (NO_2\text{-}N) + 0.87\ (DO)$$

where,

C_m = required methanol concentration, mg/l

NO_3-N = influent nitrate-nitrogen concentration, mg/l

NO_2-N = influent nitrite-nitrogen concentration, mg/l

DO = influent dissolved oxygen concentration, mg/l

Biological denitrification may have a negative impact on the quality of the reclaimed wastewater. For example, it will be important to control the feed of methanol to prevent the addition of excess methanol which will not be utilized with the reactor. This excess methanol can have two effects: (1) creation of additional oxygen demand that must be satisfied to avoid delivering an anaerobic water for reuse and (2) side reactions with chlorine (added after denitrification for disinfection) to produce potentially chlorinated organic compounds that may be of health concern.

EXPERIMENTAL PROCEDURES

EXISTING WASTEWATER TREATMENT AT CITY OF WASHINGTON

The City of Washington operates a biological wastewater treatment facility which was built in 1988 with a capacity of 2.12 mgd. At the time of this study, The Stanadyne Company was the one source of industrial waste. Stanadyne makes fuel injectors and is a potential source of trace metals although control measures are in place. Treatment at the City of Washington consists of the following: bar screens; oxidation ditch with a hydraulic residence time of 21 hours; two clarifiers in parallel (overflow rate of 320 gallons per day per square foot at 2.12 mgd); two chlorine contact chambers in parallel; dechlorination by injection of sulfur dioxide into the effluent of the chlorine contact chambers; and a reaeration basin prior to discharge to Kennedy Creek. The plant operates well and presently complies with its permit limits for an advanced secondary effluent with a 5-day biochemical oxygen demand (BOD_5) of 15 mg/l and ammonia-nitrogen (NH_3-N) of 4 mg/l (the oxidation ditch is very effective at denitrification). The Annual Pollutant Analysis Monitoring (APAM) required by the State of North Carolina, which includes measurement of EPA's list of priority pollutants, indicates that none of these targeted pollutants is above detection limit (Personal Communication: Jerry Cutler, Superintendent of Treatment Facilities, City of Washington, January 4, 1995).

Plans for expansion include converting an existing aerobic digestor to an anoxic zone as part of the oxidation ditch facility to achieve some denitrification. More denitrification would then be provided in the Tetra Technologies Inc. filter (see Denitrification Filter for more description).

GENERAL DESCRIPTION OF PILOT PLANT UNITS

A pilot plant was constructed at the Wastewater Research Center of the University of North Carolina in Chapel Hill. A schematic of the layout of the treatment units is given in Figure 2. The pilot plant can be divided conveniently into two separate process trains: (1) treatment units that were proposed for addition to the existing treatment plant at the City of Washington to achieve the goal of wastewater reclamation (denitrification-chlorination-dechlorination-reaeration-effluent storage) and (2) treatment units already in operation at National Spinning Company that are used to treat the existing groundwater supply before use as process water (greensand, ion-exchange and cartridge filter).

A summary of design parameters pertinent to the proposed City of Washington treatment scheme is given in Table 5.

DETAILS OF EACH PILOT PLANT UNIT

Denitrification Filter

A schematic of the Tetra Technologies Inc. filter is provided in Figure 3. Both the nitrate and methanol solutions were pumped (Ismatek pump, model no. 7610-20) into the top of the denitrification filter continuously in the experimental runs.

Pump flow rates were measured at regular intervals and adjustments were made to maintain the required concentrations. The filter was designed to achieve the same empty bed contact time (EBCT) and application rate as the full-scale plant. To achieve these design criteria, a reactor was constructed with a diameter of 1-7/8 in. The filter medium was provided by Tetra Technologies, Inc. The depth of the filter medium was 64 in. to simulate full-scale operations; a six-inch layer of gravel was used to support the medium. The filter column was constructed of Plexiglas and sampling ports were installed at 18 in. intervals down the length of the column.

The column was initially seeded with organisms from the Orange Water and Sewer Authority (OWASA) wastewater plant return sludge. Approximately seven to ten days was needed to achieve a viable population. The population was maintained between batch runs by continuous feed of dechlorinated tap water and nutrients. A cartridge-type filter containing activated carbon (Fulflow, model No. WT-6) served to dechlorinate the tap water. The source of nitrogen for denitrification was potassium nitrate and the electron donor was methanol.

During denitrification, nitrogen gas is produced as nitrate is reduced. Accumulation of nitrogen gas within the media caused significant headloss across the filter. Headloss was allowed to increase in the filter column until such time as necessary to degas the filter by backwashing; this degassing process is referred to as "bumping". Bumping took place every 12 h by pumping (Dayton pump, model no. 6K581A) treated water from the storage reservoir in the upflow direction through the filter for approximately 20 s.

Table 5. Design Parameters for Treatment Processes to be Used by the City of Washington, NC (Source: Black & Veatch, Design Memorandum, 1992)

Treatment Unit	Design Parameter	Value
Denitrification	Empty Bed Contact Time (EBCT in min)	20
	Application Rate (gpm/sq ft)	2
	Influent NO_3-N (mg/l)	10
	Carbon Source	Methanol
Chlorination	Hydraulic Retention Time (min)	31
	Effluent Total Chlorine (mg/l as Cl_2)	1
Dechlorination	Effluent Total Chlorine	0
	Hydraulic Retention Time (h)	15
Storage[1]	Hydraulic Retention Time (min)	28

[1]Storage Prior to Pumping to National Spinning Company

Figure 2. Schematic of pilot plant treatment units to simulate proposed wastewater reuse scheme

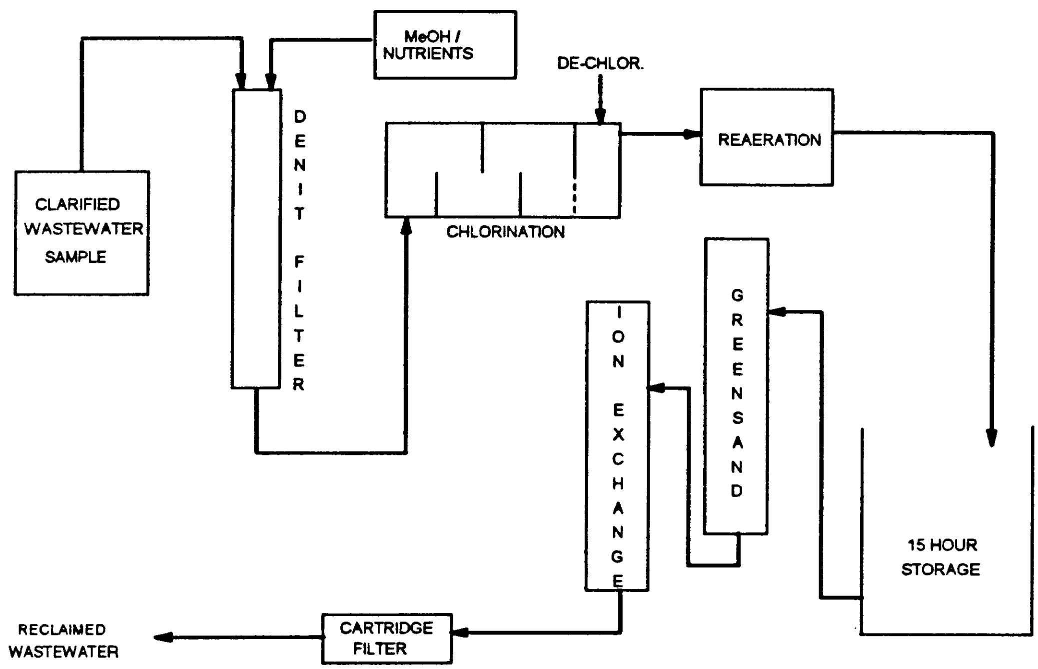
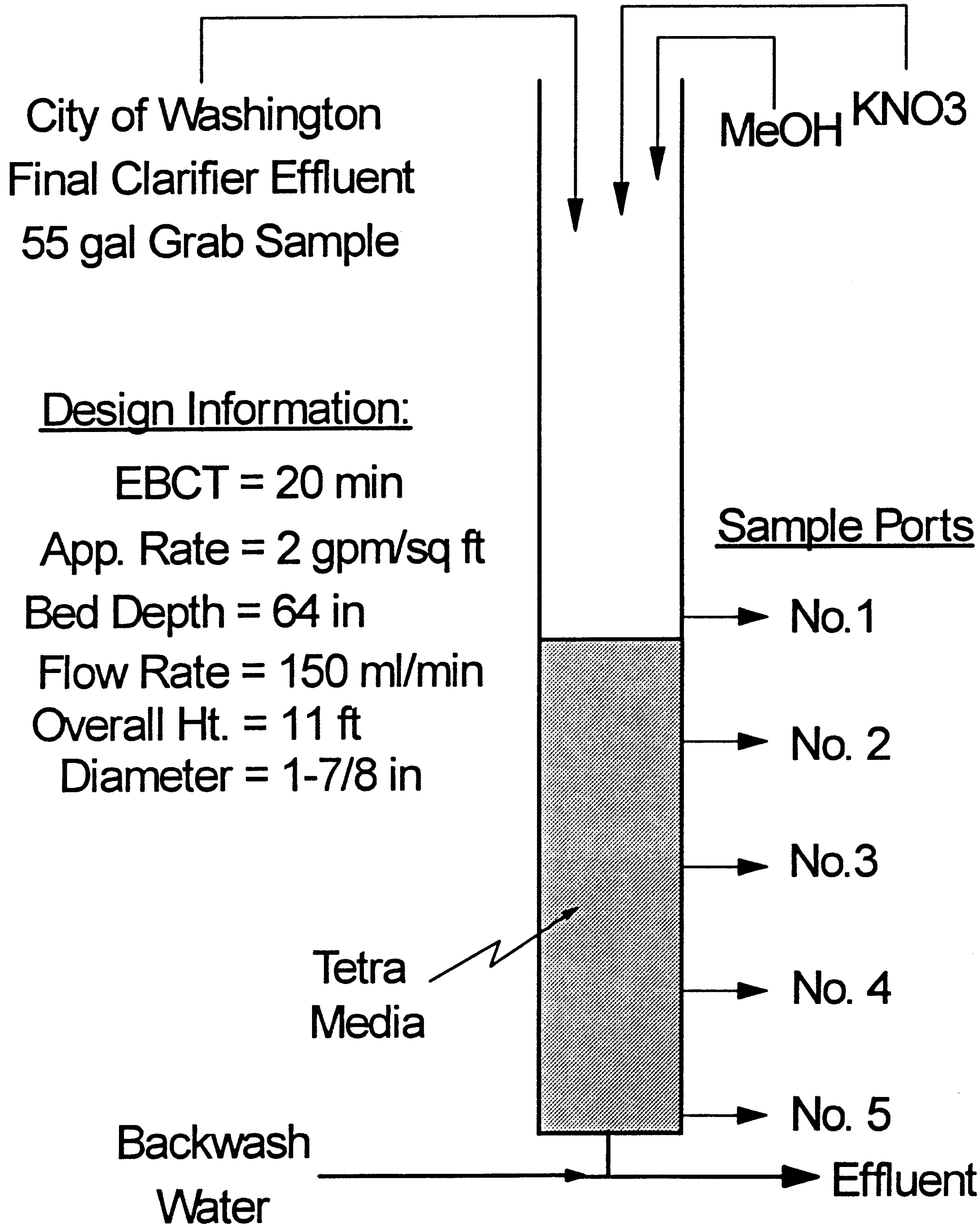


Figure 3. Schematic of denitrification filter used in pilot plant



Chlorination-Dechlorination

Following denitrification, the effluent was chlorinated and then dechlorinated. The chlorine contact chamber was designed to achieve a hydraulic detention time of 31 min and a residual total chlorine concentration of 1 mg/l as Cl_2. Approximately 10 mg/l as Cl_2 was added to the influent to achieve this chlorine residual. A chlorine solution (750 mg/l as Cl_2) was prepared using household bleach (Clorox). This solution was pumped (Ismatik pump, model no. 7610-20) at a continuous rate of 2 ml/min into the chlorination reactor to achieve 10 mg/l.

Dechlorination was accomplished in a separate reactor downstream of the chlorination reactor. A stock solution of sodium thiosulfate was pumped (Ismatik pump, model no. 7610-20) into the reactor to reduce the chlorine concentration to analytical zero (as Cl_2).

Aeration

Following dechlorination, the wastewater was aerated. A diffuser stone was used to bubble air into a reactor that was stirred continuously by a stir bar. A hydraulic detention time of 28 min provided a dissolved oxygen concentration of approximately 7 mg/l.

Storage

Following dechlorination and aeration, the water was stored for 15 h in a 50 gal (190 l) plastic tank. After storage, the water was pumped (Masterflex model No. 7553-20 pump and Masterflex model No. 7017-20 pump head) to the simulated National Spinning Company treatment processes.

Greensand Column

A greensand filter is used by National Spinning to remove insoluble iron and manganese. In the pilot-plant, the filter was constructed of a plastic, 1.75 in. diameter column packed with 24 in. of greensand. Greensand was provided by the National Spinning Company and was of the same type used in their process. This system was operated at a continuous flowrate of approximately 100 ml/min which gave an EBCT of 9.5 min.

Ion Exchange Column

The ion exchange process was simulated in the pilot-plant using a plastic column of the same type used for the greensand filter. Ion exchange resin was provided by the National Spinning Company. Effluent from the greensand filter flowed by gravity to the influent of the ion exchange filter. This system was also operated at a continuous flow of approximately 100 ml/min and a bed depth of 24 in which gave an EBCT of 9.5 min.

Cartridge Filter

A 5-micron cartridge filter is used by the National Spinning Company downstream of the ion exchange filter to remove any residual suspended matter from the process water. A Cuno filter housing, model No. 1B1, and 5-micron element were provided by the National Spinning Company for use in the pilot process.

DESCRIPTION OF PILOT-PLANT RUNS

The effluent from the existing wastewater treatment facilities at the City of Washington served as the feed water. A large grab sample (55 gal) was collected from the outlet of the final clarifier (before chlorination) and delivered to Chapel Hill on the day of each run. The pilot-plant was operated in a continuous-flow mode for approximately 23 h in each run. Prior to each of these runs, dechlorinated tap water that was amended with nitrate and methanol was fed to the denitrification column to establish a biofilm for a period of days or weeks. This procedure assured that steady-state denitrification was achieved prior to introduction of the wastewater from the City of Washington.

A total of five batches of the City of Washington wastewater were processed through the pilot-plant. Effluent samples were taken from the denitrification column over time of feeding each batch (grab sample) of wastewater. The complete list of parameters measured in one or more of these runs is provided in Table 6. The specific parameters measured in each run are given in Table 7 along with the dates on which each batch (grab sample) was collected.

The treated wastewater received from the City of Washington was amended with potassium nitrate to achieve a concentration of 10 mg/l NO_3-N. This concentration was selected because it represents the worst-case situation expected in actual operation. Methanol (Baxter, industrial grade) was also added to the influent stream as the carbon source (i.e., the electron donor) for the microorganisms. According to the stoichiometry of the denitrification reaction in Equation 1, it is necessary to use a weight ratio of 2.5:1.0 methanol to NO_3-N ratio; thus the concentration of methanol was set at 25 mg/l.

The microorganisms were considered acclimated when the nitrate-nitrogen concentration in the denitrification filter effluent was less than about 2 mg/l. After initiation of each run, approximately one hour was needed for the population of microorganisms in the denitrification filter to acclimate to the new source. Adjustments in the chlorine and sodium thiosulfate dosings were required to achieve a steady chlorine residual in the chlorination effluent and no measurable chlorine in the dechlorination effluent. These adjustments usually required from 3-5 hours.

Upon achieving a dechlorinated effluent, the wastewater was routed to the aeration tank and then to the storage reservoir. After 15 h of continuous storage, the stored water was pumped to the inlet of the simulated National Spinning Company treatment process.

ANALYTICAL METHODS

Total Suspended Solids (TSS)

Suspended solids were measured in accordance with Standard Method 2540 D (APHA, 1992). Samples were passed through a Whatman Filter GF/F with a particle retention size of 0.7µm. Standard Method 2540 D describes a filter with a particle retention of 1.2µm. Samples were dried in a Fisher, Isotemp Oven, and weighed using a Mettler Instrument Corporation balance, Type H15.

Turbidity

Turbidity measurements were performed using a Hach Ratio Turbidimeter, model No. 18900-00. The turbidimeter was calibrated prior to each set of samples analyzed. Results are expressed in nephelometric turbidity units (NTUs).

Table 6. Parameters Analyzed in Pilot-Plant

Constituent	Measured Parameter
Particulates	Total Suspended Solids
	Turbidity
	Scanning Electron Microscopy
Biodegradable Organics	5-day, Biochemical Oxygen Demand
	Chemical Oxygen Demand
	Total Organic Carbon
Volatile Organics	Those listed in SDWA[1] for compliance monitoring
Other Organics	Those listed in SDWA[1] for compliance monitoring
Nutrients	Nitrate-nitrogen
Staining Elements	Iron
	Manganese
	Fabric Staining Test
Biological Quality	Total Coliforms
	Fecal Coliforms
	Heterotrophic Plate Count
Residual Chlorine	Total Chlorine, as Cl_2
Inorganics	Hardness
	Sulfite
	Those listed in SDWA[1] for compliance monitoring
Other	pH
	Dissolved Oxygen

[1] SDWA = Safe Drinking Water Act

Table 7. Pilot-Plant Runs and Parameters Measured

Run No./ Date Started	Parameters Measured	
Run 1/April 21,1993	• Nitrate-nitrogen	• Chemical oxygen demand
	• pH	• Volatile organic chemicals[1]
	• Total chlorine	• Dissolved oxygen
	• Total suspended solids	
Run 2/May 21, 1993	• Nitrate-nitrogen	• Volatile organic chemicals[1]
	• pH	• Dissolved oxygen
	• Total chlorine	• Iron
	• Total suspended solids	• Manganese
	• Chemical oxygen demand	• Hardness
	• 5-day biochemical oxygen demand	• Sulfite
Run 3/July 7, 1993	• Nitrate-nitrogen	• Volatile organic chemicals[1]
	• pH	• Turbidity
	• Total Chlorine	• Dissolved oxygen
	• Total suspended solids	• Iron
	• Chemical oxygen demand	• Manganese
	• 5-day, biochemical oxygen demand	• Hardness
		• Sulfite
Run 4/July 30, 1993	• Nitrate-nitrogen	• Biological parameters
	• pH	• Iron
	• Total Chlorine	• Manganese
	• SDWA[1] parameters	• Total organic carbon
	• Turbidity	• Scanning electron microscopy
Run 5/November 7, 1993	• Total organic carbon	• Coagulation studies
	• Staining Tests	

[1] compliance monitoring parameters in Safe Drinking Water Act

Scanning Electron Microscopy (SEM)

Scanning Electron Microscopy was performed by Vicki Madden at the University of North Carolina Pathology Department. The procedure involved passing 10 ml of the sample water through a Poretics, 0.2-micron unipore filter. The filter was then mounted on aluminum stubs with colloidal silver paste and coated with Au/Pd alloy.

5-Day Biochemical Oxygen Demand (BOD_5)

BOD tests were performed in accordance with Standard Method 5210 B (APHA, 1992). A Hach Nutrient Buffer solution, catalog No. 14160-66 and a Hach Nitrification Inhibitor, catalog No. 2533-35 were used for each test. Dissolved oxygen measurements were obtained using the procedure mentioned above.

Chemical Oxygen Demand (COD)

COD measurements were performed using a Hach COD Reactor, model 45600, in accordance with Standard Method 5220 D (APHA, 1992). Samples were preserved with concentrated sulfuric acid and refrigerated prior to analysis.

Dissolved Organic Carbon (DOC)

DOC analyses were performed in accordance with Standard Method 5310 (APHA, 1992). A OI Corporation Model No. 700 TOC (total organic carbon)Analyzer was used. Samples were preserved with concentrated sulfuric acid and refrigerated prior to analysis. To obtain DOC, the samples were filtered through a 0.45 µm membrane filter prior to analysis.

Methanol

Methanol measurements were performed by Oxford Laboratories, Inc. located in Wilmington, North Carolina. Samples were refrigerated and express-mailed to the testing laboratory.

Safe Drinking Water Act Regulated Chemicals

The list of chemicals required by the Safe Drinking Water Act (SDWA) for compliance monitoring were analyzed by Oxford Laboratories, Inc., in Wilmington, North Carolina. These chemicals included the 55 volatile organic chemicals (VOC's) listed as well as the complete list of organic and inorganic chemicals. All samples were refrigerated immediately after sampling and express-mailed to the testing laboratory.

Nitrate-nitrogen

Nitrate-nitrogen was measured using an Orion Research nitrate probe, model No. 701A/digital ionalyzer in accordance with instructions provided by the supplier. A calibration curve was developed daily during each experimental run.

Total Iron

Total iron measurements were performed using the Phenanthroline Method, Standard Method 3500-Fe D (APHA, 1992). Photometric determinations were made using a Hitachi, U-2000 spectrophotometer, at a wavelength of 510 nm. A calibration curve was developed for each test using standard solutions of ferrous ammonium sulfate. Iron tests for batch runs 2 and 3 were performed by Mr. Paul Savard.

Manganese

Manganese measurements were performed using the Persulfate Method, Standard Method 3500-Mn D (APHA, 1992). Photometric determinations were made using a Hitachi, U-2000 spectrophotometer, at a wavelength of 525 nm. A calibration curve was developed for each test using standard solutions of potassium permanganate. Manganese tests for batch runs 2 and 3 were performed by Mr. Paul Savard.

Fabric Staining Analysis

The test used to determine the acceptance of the reclaimed water from a staining stand point was developed by National Spinning Company. The procedure was to pass 500 ml of sample water through a Whatman GF/C filter and to visually inspect the filter for evidence of staining. A quantitative value was applied to each sample by utilizing a Zellweger Uster, High Volume Instrument (HVI) at the College of Textiles of North Carolina State University, in Raleigh. Analyses were performed by Ms. Jan Pegram and involved the measurement of the "whiteness" and "yellowness" of the sample filter. Measured values were then compared using a Cotton Color Grade Chart, a chart used to differentiate grades of cotton.

Microbiological Quality

All microbiological tests (Heterotrophic Plate Counts, Total Coliforms and Fecal Coliforms) were analyzed by outside laboratories. Webb Technical, located in Raleigh, NC, analyzed all of the samples with the exception of one groundwater sample taken from the well supply of the National Spinning Company. This sample was analyzed by the City of Washington.

Dissolved Oxygen (DO)

Dissolved oxygen measurements were made using a YSI, model No. 54A oxygen meter in accordance with Standard Method 4500-O G. Samples were collected in 300 ml standard BOD bottles and the meter was calibrated prior to each set of analyses.

Hardness

Hardness was measured using the EDTA Titrimetric Method, Standard Method 2340 C (APHA, 1992). All measurements were performed by Mr. Paul Savard.

pH

The pH was measured using a Fisher Accumet pH meter, model No. 610. Calibration was performed a minimum of once daily during each experimental run.

Total Chlorine Residual

Total chlorine measurements were performed using the DPD Ferrous Titrimetric Method, Standard Method 4500-Cl F (APHA, 1992). Both free and combined chlorine were determined using this method.

EXPERIMENTAL RESULTS

DENITRIFICATION PROCESS

Measurement of nitrate concentrations and pH in the influent and effluent of the Tetra denitrification filter for the first four experimental runs are shown in Figures 4 and 5. The results indicate that denitrification reached a steady state very quickly, in most cases within one hour after beginning to feed wastewater from the City of Washington. Variations in NO_3-N and pH were only minor during the pilot test suggesting that the denitrification process was stable. The data from the final experimental run are not included in Figures 4 and 5 due to a limited number of samples; however, the results were similar to those obtained in the first four runs.

The values of various process parameters related to nitrate removal within the filter are shown in Table 8. Nearly all of the nitrate was removed in the top 10 in. thus showing that the fixed-film system is very effective. Consistent with the denitrification process, DO decreased sharply with depth in the filter. The decrease in COD and DOC with depth is also expected due to utilization of methanol by the attached microorganisms during denitrification.

CHANGES IN WASTEWATER QUALITY THROUGH RECLAMATION PROCESSES

Changes in wastewater quality were measured both by conventional water quality parameters used to evaluate the effectiveness of wastewater treatment and by other, non-traditional parameters that relate to evaluation for the specific purpose of wastewater reuse.

General Water Quality Parameters During Treatment

General measures of water quality at each stage of treatment are given in Table 9. The results listed for DO, COD and BOD_5 in Table 9 are average values of grab samples taken during the first three experimental runs; DOC was measured in Run No. 5. The increase in COD and BOD_5 from the secondary clarifier effluent to the influent to the denitrification column was

Figure 4. Removal of nitrate in denitrification filter during each pilot plant run (solid symbol = influent and open symbol = effluent)

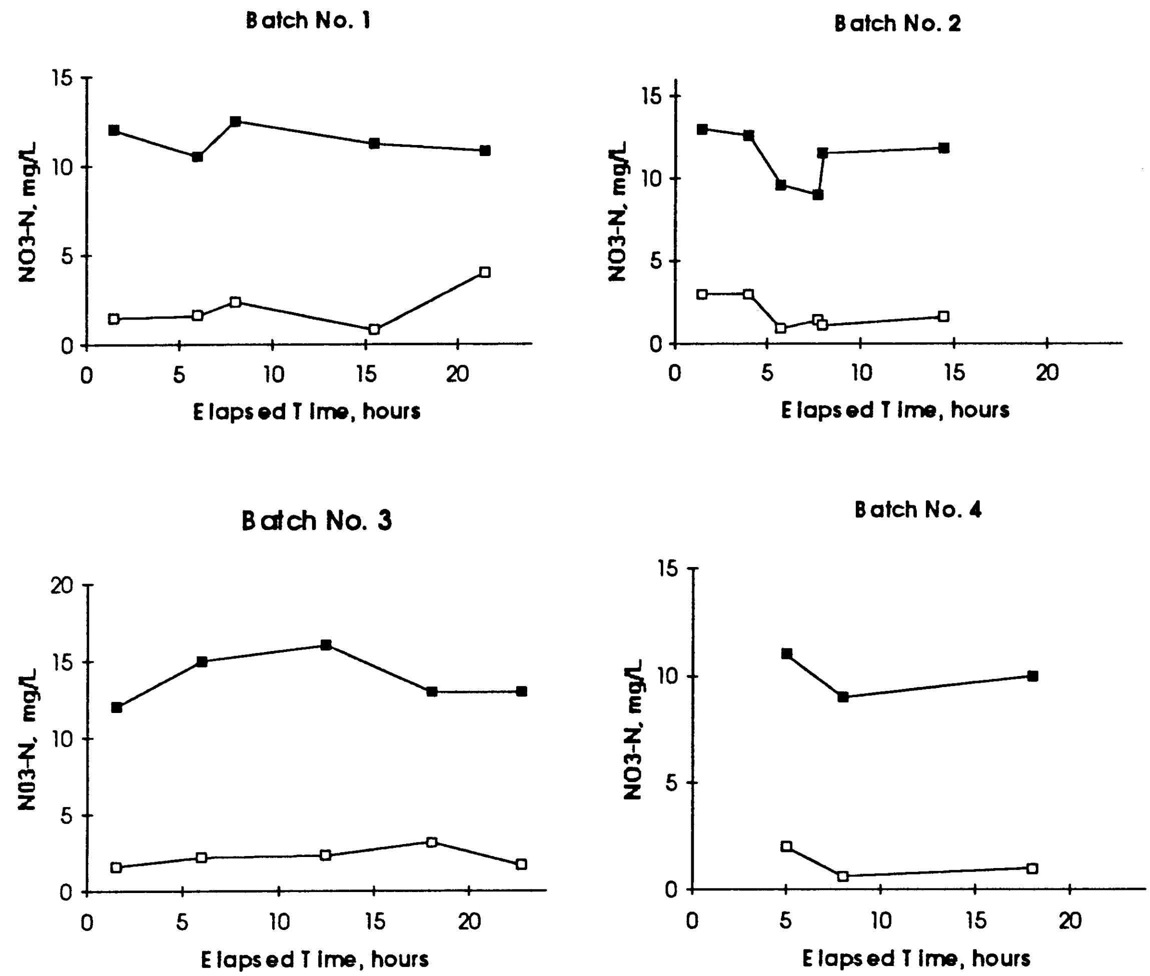


Figure 5. Variability in influent and effluent pH during each pilot plant run of denitrification filters

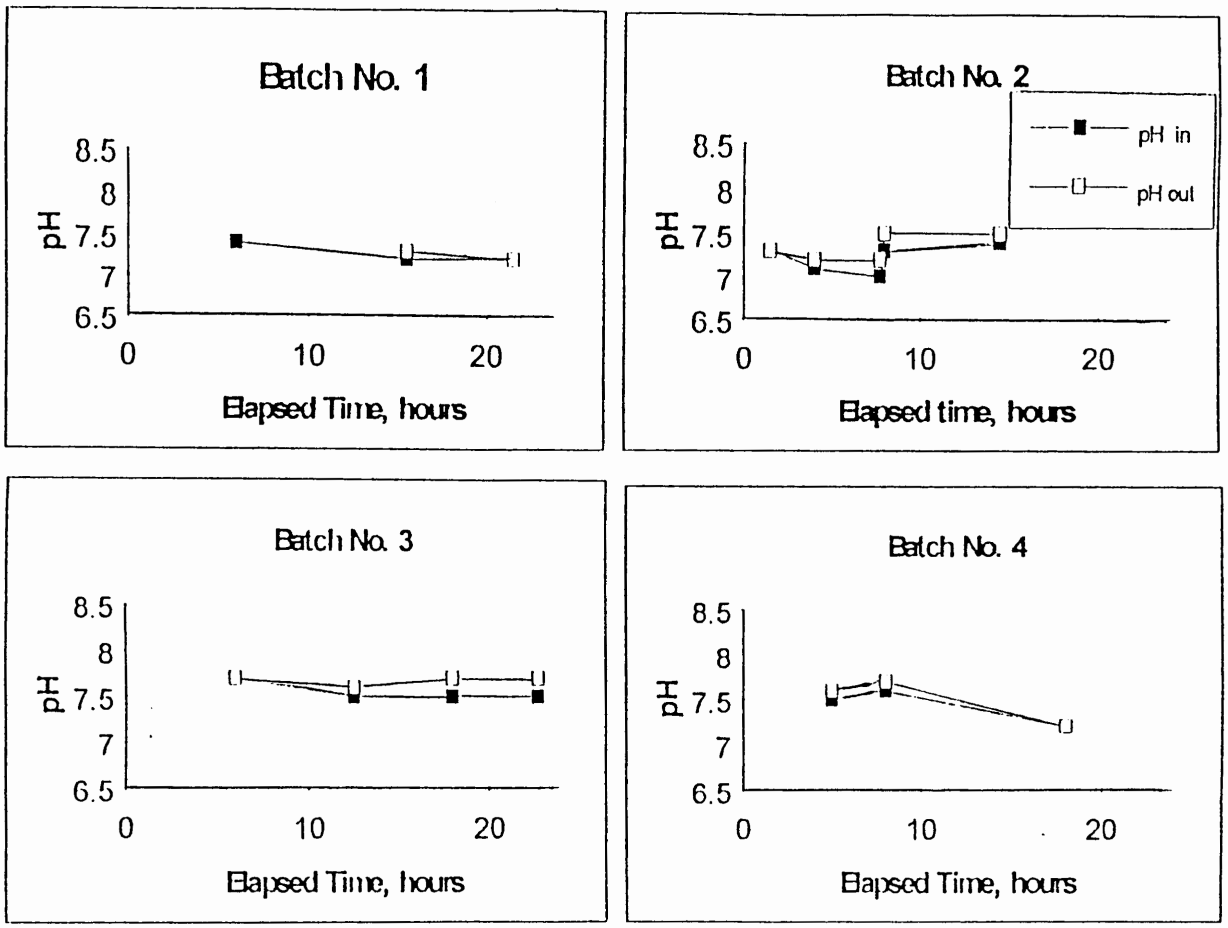


Table 8. Denitrification Filter Profile

Sample Port	Depth of Media (in)	DO (mg/l)	NO_3-N, (mg/l)	pH	COD (mg/l)	DOC (filtered) (mg/l)
1	-8	4.6	8	7.4	54.2	23.0
2	10	0.8	1.3	7.4	17.8	14.7
3	28	1.2	1	7.4	18.8	7.4
4	46	0.8	1	7.4	20.4	8.3
5	64	0.9	1.2	7.3	15	6.5

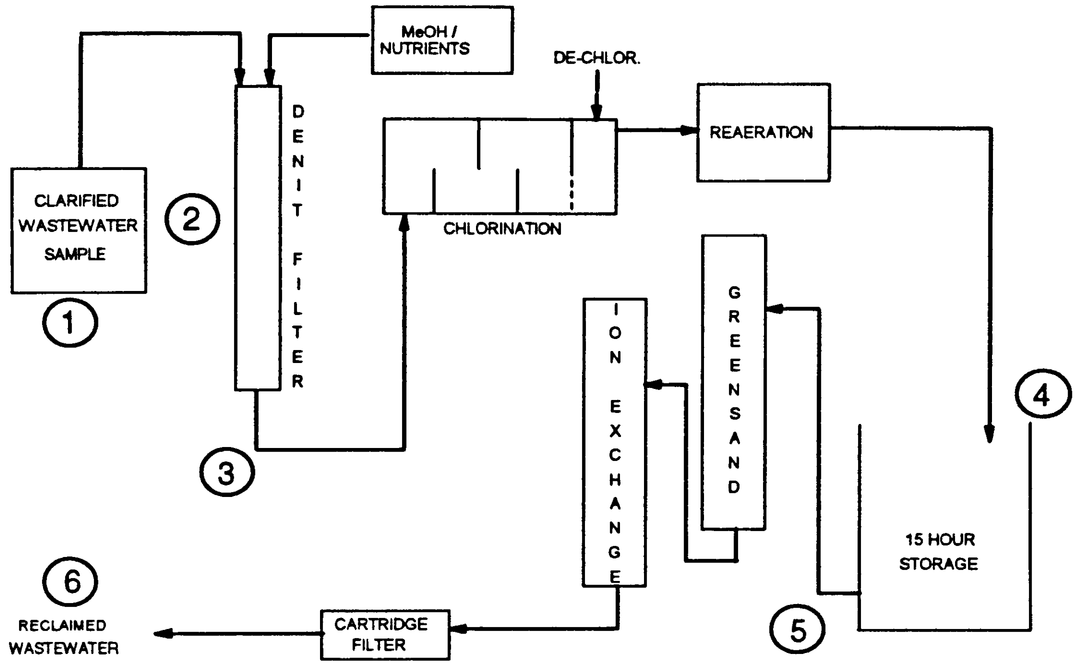


Table 9. General Water Quality Parameters at Various Stages of Treatment

Sample Location	Description	DO (mg/l)	COD (mg/l)	BOD_5 (mg/l)	DOC (mg/l)
1	City of Washington Secondary Clarifier Effluent	not measured	15.3	0.9	54[1]
2	Denitrification Filter Influent	4.6	56.1	38.1	23
3	Denitrification Filter Effluent	0.8	20.9	3.3	6.5
4	Pre Storage	7.6[2]	not measured	not measured	7.1
5	Post Storage	6.4	14.2	2.1	13.2
6	Reclaimed Wastewater	not measured	10.0	2.0	8.5

[1] unfiltered sample
[2] reaeration increased DO

caused by the addition of methanol into the system. Almost all of the biodegradation takes place in the denitrification filter as evidenced by the lack of further change in BOD_5 after this process. Further evidence for the biological stability of the reclaimed wastewater is provided by the relatively small decrease in DO (from 7.6 to 6.4 mg/l) that occurred during the 15 h of storage. The increase in DOC during storage may be an artifact of the analtical procedure; i.e., filtration of samples to remove suspended matter that may contribute to organic carbon has been observed to cause leaching of organics from the filter thus increasing DOC. The COD (10 mg/l), BOD_5 (2.0 mg/l) and DOC (8.5 mg/l) in the reclaimed wastewater were fairly low as should be expected for a well-operated conventional, biological treatment system.

Bacteriological Examination

Standard bacteriological indicators were compared for the reclaimed wastewater and the existing process water used by National Spinning Company (Table 10). These results were obtained during only one experiment (Run No. 4) and are thus of limited value in making generalizations about the process.

Table 10. Comparison of Bacteriological Results

	Fecal Coliforms	Total Coliforms	Heterotrophic Plate Count
National Spinning Company Process Water	< 1/ml	< 2/ml	11/ml
Reclaimed Wastewater	< 1/ml	9/ml	57,000/ml

The fecal and total coliform results were within limits adopted by other states for industrial reuse applications. Although only one sample was measured, it is evident that the reclaimed wastewater was of poorer quality than the existing process water when based on total coliforms and heterotrophic bacteria. Because the wastewater had been chlorinated, the results indicate that regrowth may have occurred during reaeration or the 15 h storage period.

Treatment of the City of Washington wastewater includes dechlorination and reaeration processes in order to meet effluent toxicity and dissolved oxygen discharge limits. These two conditions will encourage microbial activity and thus further changes in quality of wastewater before use by the National Spinning Company. A significant regrowth of microorganisms could result in a deteriorated water quality and fouling of treatment units at National Spinning Company. Regrowth of microorganisms should always be expected during the storage of dechlorinated, reaerated wastewater regardless of the extent of treatment. The simplest solution to this problem would be to rechlorinate at the storage reservoirs, either on a continuous or intermittent basis. However, it will be necessary to add a reducing agent to eliminate chlorine before the yarn dyeing operations to avoid oxidation of dyes that gives imperfections in color.

Tests for the presence of viruses and individual pathogens were not conducted as part of this study. Analysis of these microorganisms would likely be required to determine potential health risks to employees that may accidently ingest the process water. The fact that water is heated to temperatures in excess of 180°F during the dyeing process, however, should provide good disinfection. Nevertheless, testing would be needed to confirm the elimination of microorganisms of concern.

Measurement of SDWA Regulated Chemicals

Process water at the National Spinning Company is used in open vat dyeing operations. Consequently, there is concern about employee exposure to volatile organic chemicals (VOCs) remaining in the reclaimed wastewater. Analyses of 55 VOCs were performed on the wastewater after storage but before treatment in the process water scheme used by National Spinning Company. Grab samples were taken during Run Nos. 1-3 after the pilot-plant had reached stable operation. The 55 VOCs analyzed for are the same required for quarterly compliance monitoring by water utilities in accordance with the Safe Drinking Water Act Amendments (SDWA).

Results of VOC analyses are given in Table 11. These results are average values of one grab sample in each of Run Nos. 1-3. The only compounds that were present in concentration exceeding the detection limit of 0.5 parts per billion (ppb) were chloroform (11.4 ppb), bromodichloromethane (5.4 ppb) and chlorodibromomethane (0.9 ppb). These comprise the trihalomethanes (THMs) that are regulated in drinking water. They are expected as a result of chlorination at the City of Washington water treatment plant and in the pilot plant process. The total concentration of the trihalomethanes (17.7 ppb) was well below the current drinking water standard of 100 ppb.

Run No. 4 was conducted to compare the quality of the reclaimed wastewater directly with that presently being obtained by treatment of groundwater for process water at the National

Table 11. Analysis of Treated and Stored Wastewater for 55 VOCs Contained on SDWA Compliance List. Reported Values are Averages for Run Nos. 1-3.

VOC	ppb	VOC	ppb
Trihalomethanes		1,1,2-Trichloroethane	< 0.5
Chloroform	11.6	Tetrachloroethylene	< 0.5
Bromodichloromethane	5.54	1,3-Dichloropropane	< 0.5
Chlorodibromomethane	0.85	Chlorobenzene	< 0.5
Bromoform	< 0.5	Ethylbenzene	< 0.5
Compounds	< 0.5	1,1,1,2-Tetrachloroethane	< 0.5
Dichlorodifluoromethane	< 0.5	Total Xylenes	< 0.5
Chloromethane	< 0.5	Styrene	< 0.5
Vinyl Chloride	< 0.5	Isopropylbenzene	< 0.5
Bromomethane	< 0.5	1,1,2,2-Tetrachloroethane	< 0.5
Chlorethane	< 0.5	1,2,3-Trichloropropane	< 0.5
Fluorotrichloromethane	< 0.5	n-Propylbenzene	< 0.5
1,1-Dichloroethylene	< 0.5	Bromobenzene	< 0.5
Dichloromethane	< 0.5	1,3,5-Trimethylbenzene	< 0.5
trans-1,2-Dichloroethylene	< 0.5	o-Chlorotoluene	< 0.5
1,1-Dichloroethane	< 0.5	p-Chlorotoluene	< 0.5
2,2-Dichloropropane	< 0.5	tert-Butylbenzene	< 0.5
cis-1,2-Dichloroethylene	< 0.5	1,2,4-Trimethlybenzene	< 0.5
Bromochloromethane	< 0.5	sec-Butylbenzene	< 0.5
1,1,1-Trichloroethane	< 0.5	p-Isopropyltoluene	< 0.5
1,1-Dichloropropene	< 0.5	1,3-Dichlorobenzene	< 0.5
Benzene	< 0.5	1,4-Dichlorobenzene	< 0.5
1,2-Dichloroethane	< 0.5	n-Butylbenzene	< 0.5
Trichloroethylene	< 0.5	o-Dichlorobenzene	< 0.5
1,2-Dichlorolpropane	< 0.5	1,2,4-Trichlorobenzene	< 0.5
Dibromomethane	< 0.5	Hexachlorobutadiene	< 0.5
1,3-Dichloropropene	< 0.5	Napthalene	< 0.5
Toluene	< 0.5	1,2,3-Trichlorobenzene	< 0.5

Spinning Company. As a means of comparison, both samples were analyzed for the presence of all those contaminants required by the Safe Drinking Water Act for compliance monitoring with the exception of the 55 VOCs. This latter group had been analyzed in previous samples and found (with the exception of THMs) to be absent (see Table 11).

The objective of the SDWA analysis was to compare the two waters and not to determine whether the reclaimed wastewater met criteria as a drinking water source. Oxford Laboratories, in Wilmington, North Carolina, performed the chemical analysis on both waters. Table 12 shows the results obtained along with the maximum contaminant level (MCL) for each chemical (Pontius, 1992). Only phthalates are above. This group of chemicals derive from plasticizers which are often found in analysis of wastewater effluents. In addition, contact of water with plastic materials used in the pilot plant could also produce phthalates and thus give an artifactual result.

A few other chemicals were found above the detection limit (designated by <) but well below the MCL. These are atrazine (0.000143 mg/l), copper (0.006 mg/l), fluoride (0.63 mg/l), nitrate/nitrite (1.08 mg/l) and sulfate (50 mg/l).

Required Process Water Quality

Process water at National Spinning Company is used directly in the application of yarn dyeing. The process water, therefore, must not contain significant concentrations of any element that might result in staining of the yarns.

Measurements of iron and manganese were taken after storage of the treated wastewater. These values are compared with levels in the existing National Spinning Company groundwater supply in Table 13. The highest iron measurement recorded for the treated wastewater (0.16 mg/l) is very low. The values of iron and manganese obtained in the pilot-plant process were determined to be acceptable by National Spinning Company standards for these elements.

Total suspended solids and turbidity were measured at several locations in the pilot-plant treatment process. A summary of these results is shown in Table 14. In each instance, the measurements were less than 5 mg/l, including the City of Washington clarified water sample. The turbidity (1.03 NTU) is considerably greater than that of the present process water (0.18 NTU) used at National Spinning. Turbidity is a more important parameter than suspended solids as a criterion for accepable process water because its presence suggests small

Table 12. Chemicals on SDWA Compliance Monitoring List for Existing Process Water at National Spinning Company (NSC) and for Reclaimed Wastewater.

Contaminant	MCL[1] (mg/l)	Reclaimed Water (mg/l)	NSC Process Water (mg/l)
Organics			
Adipates	0.5	<0.0006	<0.0006
Alachlor	0.002	<0.0002	<0.0002
Aldicarb	0.003	<0.0005	<0.0005
Aldicarb Sulfone	0.002	<0.0008	<0.0008
Aldicarb sulfoxide	0.004	<0.0005	<0.0005
Aldrin		<0.00002	<0.00002
Atrazine	0.003	0.000143	<0.0001
Benzo(a) pyrene		<0.00002	<0.00002
Butachlor		<0.00015	<0.00015
Carbofuran	0.04	<0.0008	<0.0008
Chlordane	0.002	<0.0002	<0.0002
2,4-D	0.07	<0.0001	<0.0001
Dalapon	0.2	<0.001	<0.001
Dibromo-chloro-propane	0.0002	<0.00002	<0.00002
Dieldrin		<0.00001	<0.00001
Dicamba		<0.0001	<0.0001
Dinoseb	0.007	<0.0001	<0.0001
Diquat	0.02	<0.0004	<0.0004
Endothall	0.1	<0.009	<0.009
Endrin	0.002	<0.00001	<0.00001
Ethylene dibromide	0.00005	<0.00001	<0.00001
Pentachloro-phenol	0.001	<0.00004	<0.00004
Phthalates	0.004	0.1482	<0.0006
Picloram	0.5	<0.0001	<0.0001
Propachlor		<0.00005	<0.00005
PCB's	0.0005	<0.0001	<0.0001
Simazine	0.004	<0.00007	<0.00007
Toxaphene	0.005	<0.001	<0.001
2,4,5-TP	0.05	<0.0002	<0.0002
Inorganics			
Antimony	0.01/ 0.005	<0.001	<0.001
Arsenic	0.05	<0.005	<0.005
Asbestos	7 MFL		
Barium	2	<0.020	0.085
Beryllium	0.001	<0.001	<0.001
Cadmium	0.005	<0.002	<0.002
Chromium	0.1	<0.005	<0.005
Copper	1.3	0.006	<0.003
Cyanide	0.2	<0.005	<0.005
Fluoride	4	0.63	1.08
Iron		0.500	0.015
Lead	-	<0.003	<0.003
Manganese		0.055	0.020

Table 12. (continued)

Contam-inant	MCL[1] (mg/l)	Reclaimed Water (mg/l)	NSC Process Water (mg/l)	Contam-inant	MCL[1] (mg/l)	Reclaimed Water (mg/l)	NSC Process Water (mg/l)
Glyphosate	0.7	<0.006	<0.006	Mercury	0.002	<0.0002	<0.0002
Heptachlor	0.0004	<0.00004	<0.00004	Nickel	0.1	<0.005	<0.005
Heptachlor epoxide	0.0002	<0.00002	<0.00002	Nitrate, as N	10	1.08	<0.1
Hexachloro-benzene	0.001	<0.0001	<0.0001	Nitrite, as N	1	<0.1	<0.1
Hexachloro-cyclo-pentadiene	0.05	<0.0001	<0.0001	Nitrate + Nitrite, as N	10	1.08	<0.2
3-Hyroxycarbo-furan		<0.0006	<0.0006	Selenium	0.05	<0.005	<0.005
Lindane	0.0002	<0.00002	<0.00002	Sulfate	400/500	50	46
Methomyl		<0.0005	<0.0005	Thallium	0.002/0.001	<0.001	<0.001
Methoxychlor	0.04	<0.0001	<0.0001	pH (lab)		7.6	8.85
Metolachlor		<0.00025	<0.00025				
Metribuzin		<0.0002	<0.0002				
Oxamyl	0.2	<0.002	<0.002				

[1] MCL (maximum Contaminant Level) as given by Pontius (1992)

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Table 13. Comparison of Iron and Manganese in Existing National Company Raw (Groundwater) Water and Treated Wastewater After 15 h Storage.

	Iron (mg/l)	Manganese (mg/l)
National Spinning Company Groundwater, Before Treatment	0.10	0.07
Treated Washington Wastewater, Before National Spinning Company Treatment		
Run No. 1	0.16	0.12
Run No. 2	< 0.05	<0.05
Run No. 3	< 0.05	<0.05

Table 14. Removal of Turbidity (NTU)Total Suspended Solids (TSS)and in the Pilot-Plant.

Sample Description	TSS (mg/l)	Turbidity (NTU)
Washington Secondary Clarifier Effluent	< 5.0	0.87
Tetra Denitrification Filter, Influent	< 5.0	0.92
Tetra Denitrification Filter, Effluent	< 5.0	1.24
Pre Storage	< 5.0	1.25
Post Storage	< 5.0	1.28
Reclaimed Wastewater	< 5.0	1.03
Existing National Spinning Company Process Water	Not Measured	0.18

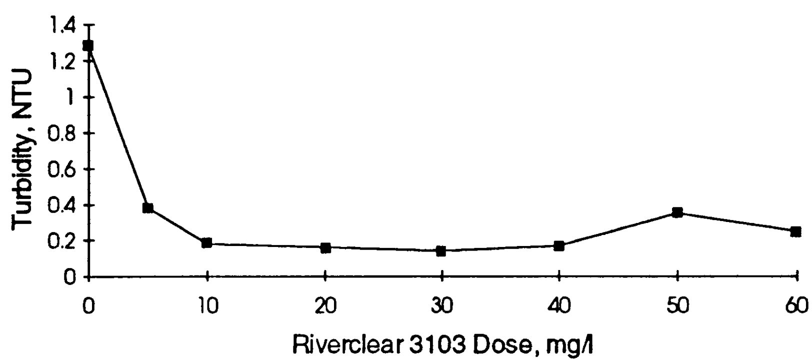
stable particles that may pass through the treatment units at National Spinning Company.

Coagulation Study

Coagulation of the post-storage water was performed during Run No. 5 to determine whether turbidity of the reclaimed wastewater could be further reduced. A conventional coagulation jar test - rapid mix, flocculation, and sedimentation - was used to evaluate the effectiveness of a commercially available polymer (River Clear 3103) in reducing turbidity of the effluent after the 15 h storage period.

Riverclear polymer was selected from the many polymers available because the City of Washington had already conducted jar tests and found this coagulant to be very effective compared to others. Results of the coagulation tests are shown in Figure 6. A dosage of 10 mg/l was needed to reduce turbidity to a minimum of 0.18 NTU. This compares closely with the turbidity of the existing National Spinning Company process water (0.14 NTU).

Figure 6. Coagulation of secondary effluent after denitrification-chlorination-dechlorination-reaeration and 15-hours of storage



Staining Potential

The staining potential test is routinely performed by National Spinning to determine the suitablity of process water for yarn dyeing. The test consists of passing 500 ml of water through a 1.2 µm glass-fiber filter and then visually examining the filter for staining. As shown in Figure 7a-c, a considerable amount of staining was noted when this test was performed on the reclaimed wastewater; by contrast, very little if any staining was noted when the existing process water was tested. Coagulation of the treated wastewater with Riverclear at a near optimal dosage of 30 mg/l removed much of the residual staining; however, the filter exposed to the coagulated water still showed more staining than that exposed to National Spinning Company process water.

An attempt was made to quantify the amount of staining on each filter. Using a Zellweger Uster, High Volume Instrument (HVI) at the North Carolina State University College of Textiles a comparison was made of each sample using a Cotton Color Grade Chart. These results are displayed in Table 15. In this test, higher values indicate more color on the filter, thus a greater potential for fabric staining. The filter sample of the existing process water showed less staining than all of the coagulated water samples. In fact, it was equivalent to a filter sample of Chapel Hill tap water.

Table 15. Comparative Analysis of Staining Potential for Existing National Spinning Company Process Water and Treated Wastewater using a Cotton Color Grade Chart.

Sample Description	Riverclear Dose (mg/l)	Whiteness	Yellowness
National Spinning Company Process Water[1]	0	5.2	7.8
Reclaimed Wastewater[2]	0	6.9	9.7
Storage Effluent[3]	20	6.0	8.4
Storage Effluent[3]	30	5.8	8.3
Storage Effluent[3]	40	5.7	8.0
Chapel Hill, Tap Water	0	5.3	7.8

[1] after greensand-ion exchange-cartridge filter treatment
[2] after greensand-ion ion exchange treatment
[3] coagulation performed on storage effluent

Scanning Electron Microscopy

Further investigation into the nature of the particles remaining in the reclaimed wastewater was performed using scanning electron microscopy (SEM). This procedure involved passing 10 ml of a sample water through a 0.2 µm unipore filter. The filter was then mounted on aluminum stubs with colloidal silver paste and coated with Au/Pd alloy. The filter was viewed under an electron microscope. Scanning electron micrographs are shown in Figures 8a-c. These results can only be qualitatively interpreted. The reclaimed wastewater contained more particles than the existing process water. Coagulation of the treated wastewater reduced the number of particles significantly; however, more particles were found than in the existing process water.

Higher magnification of a typical particle from the reclaimed wastewater without coagulation is shown in Figure 9. An energy dispersive X-ray analysis was performed on this particle and the results are shown in Figure 10. The primary elements found in the particle (iron, manganese, and silica) did not suggest anything atypical about the particle's composition.

Figure 7a.Fabric staining potential of existing process water at National Spinning Company

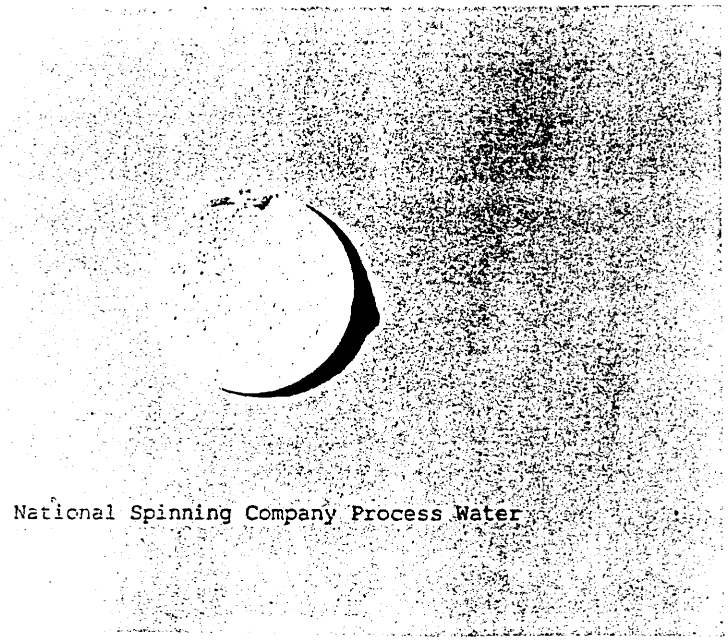


Figure 7b.Fabric staining potential of reclaimed wastewaer without coagulation

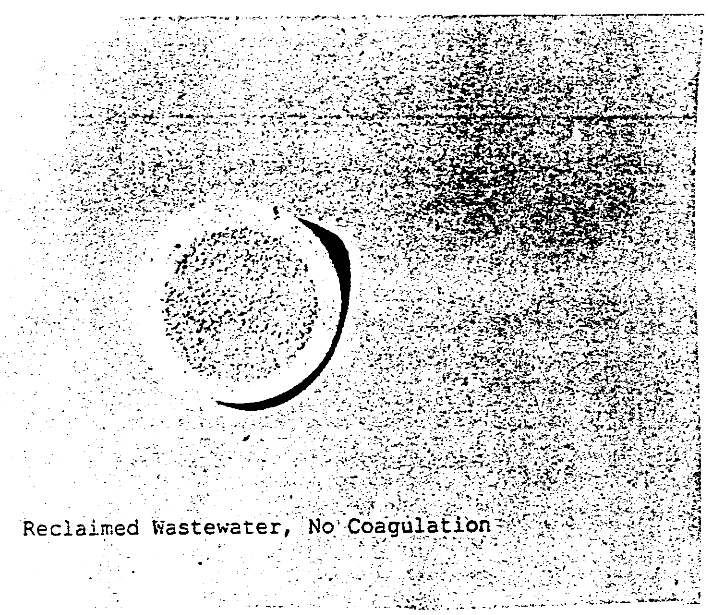


Figure 7c.Fabric staining potential of reclaimed wastewater with coagulation (30 mg/L Riverclear 3103)

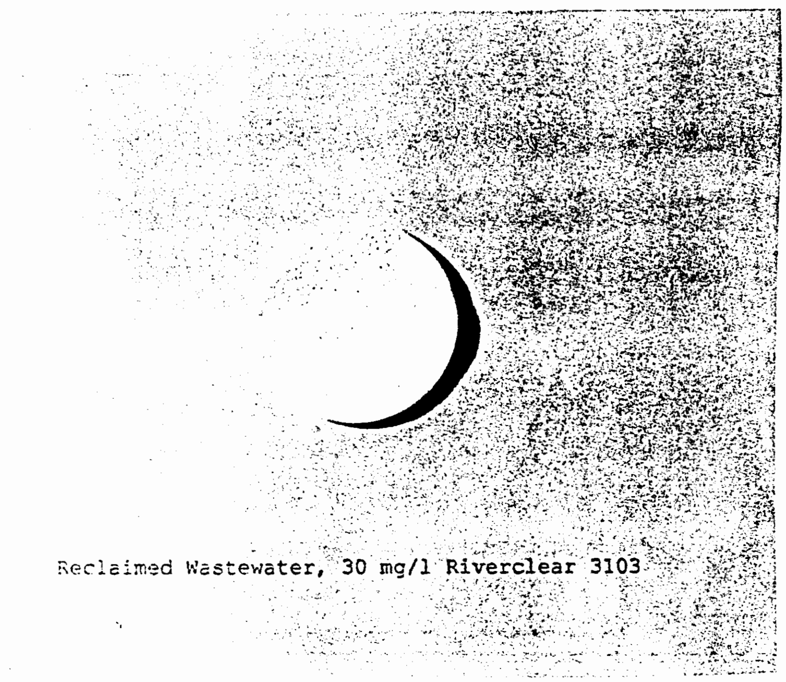


Figure 8a. SEM of existing process water at National Spinning Company

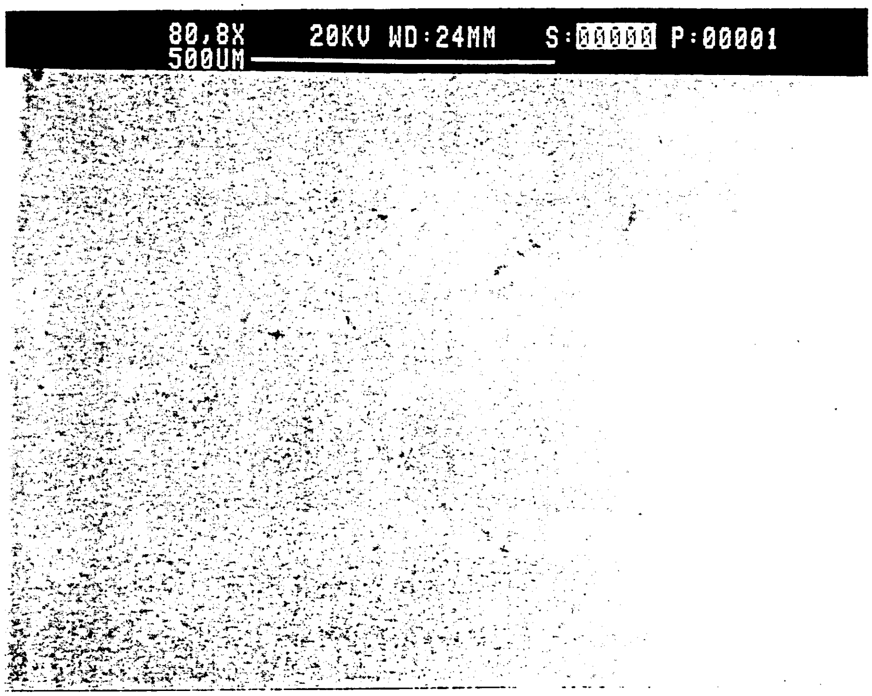


Figure 8b.SEM of reclaimed wastewater without coagulation

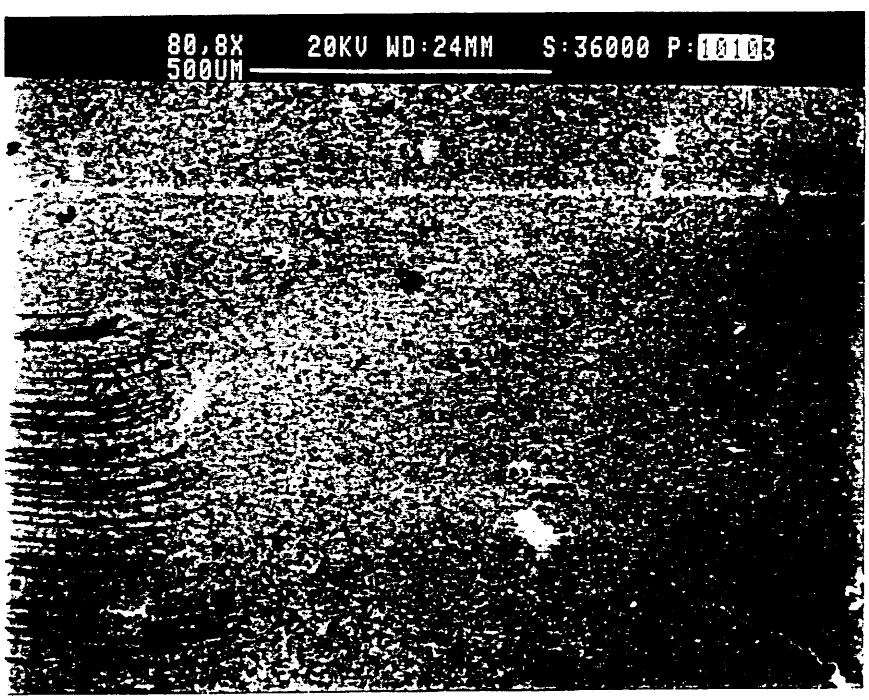


Figure 8c. SEM of reclaimed wastewater with coagulation (12.5 mg/L Riverclear 3103)

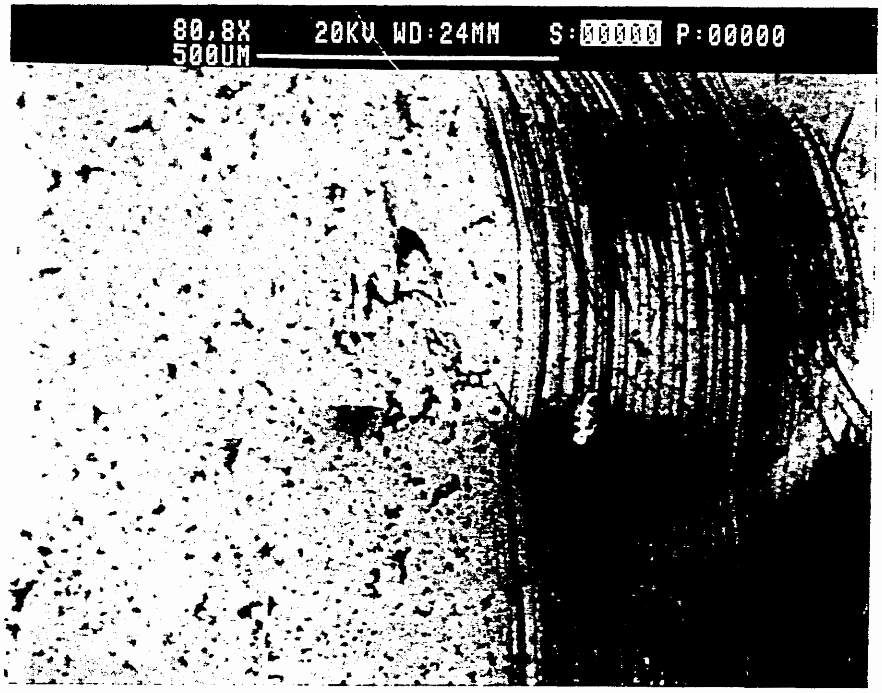


Figure 9. SEM of 5 times greater scale of reclaimed wastewater without coagulation showing one particle

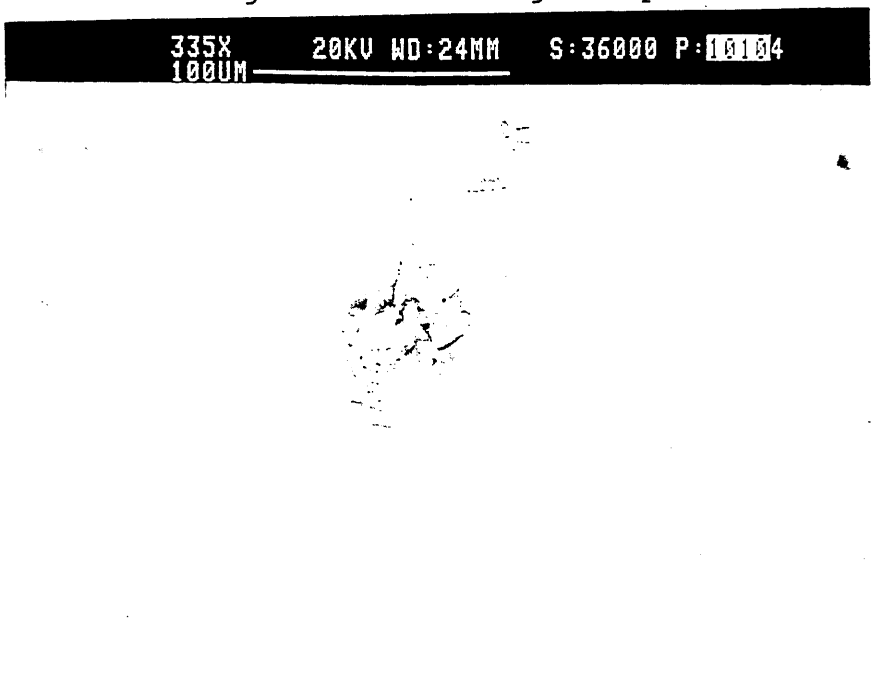
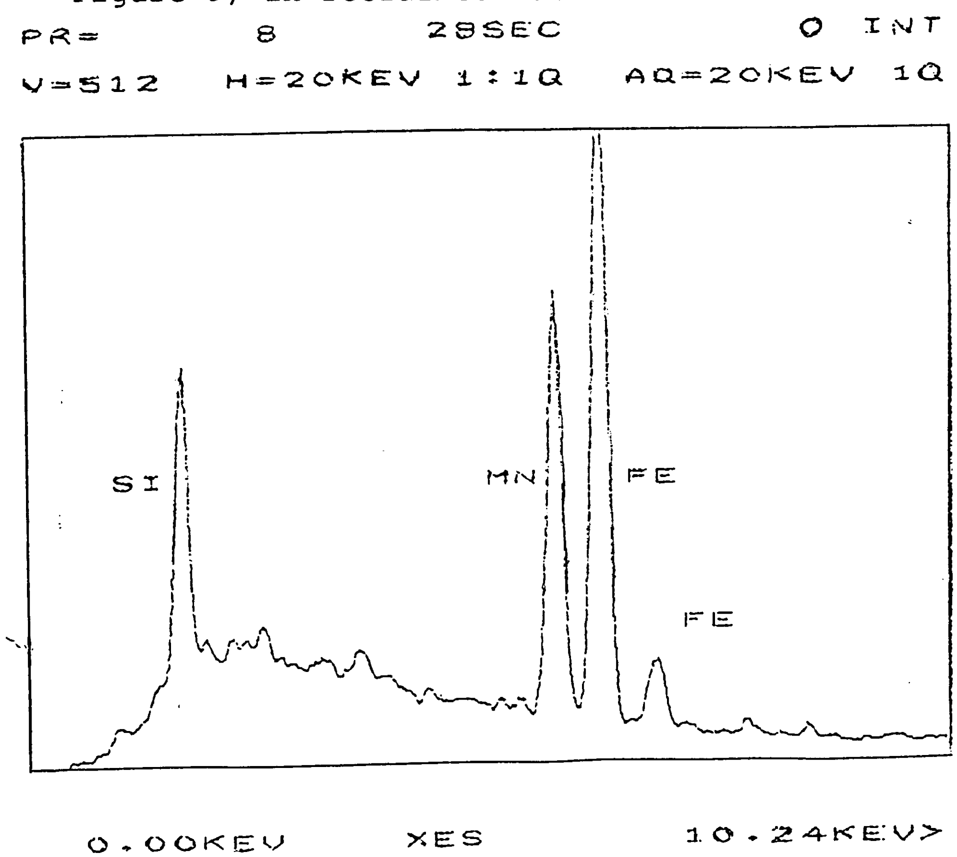


Figure 10. Energy dispersive X-ray analysis of particle (see Figure 9) in reclaimed wastewater



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