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DISCLAIMER STATEMENT

ABSTRACT

Organic and microbial contaminants that are currently or are planned to be regulated under the 1986 amendments to the Safe Drinking Water Act (SDWA) were investigated in the following water supplies of the Urban Water Consortium established by The Water Resources Research Institute of the University of North Carolina: Burlington, Orange Water and Sewer Authority (OWASA), Durham, High Point, Raleigh and Winston-Salem. A review of the NPDES permits in each of these water supply sources confirmed that only the water supplies for Raleigh and Winston-Salem are vulnerable to industrial waste from direct discharges (six and seven sources, respectively). Those listed for Raleigh, however, are classified as minor industrial dischargers by an EPA rating system. At High Point, vulnerability is not so much from industrial discharges as from the potential for accidental contamination due to leakage from several oil storage depots. Very few contaminants that are or will be regulated by the SDWA were uncovered in these NPDES permits

Monitoring data on finished water supplies required by the NC Division of Health Services (Department of Human Resources) showed only one instance from two quarters of sampling (fourth of 1987 and first of 1988) in which a currently unregulated synthetic organic chemical (SOC) (chlorobenzene at 0.8 ppb) was found above detectability (>0.5 ppb); this occurred in the Durham supply. Each city's finished water was sampled once in summer of 1988. Sampling and analysis showed that all volatile organic chemicals (VOCs) and SOCs, with exception of the trihalomethanes (THMs) and chloropicrin (another disinfection by-product), were below the detection limit (0.5 ppb for most analyses). Regulatory data for THMs showed that while all utilities are in compliance with the current maximum contaminant levels (MCLs), all need to be concerned if the MCL is lowered to 50 ug/L.

Giardia lamblia and Cryptosporidium parvum were found in the raw water supplies of OWASA, Durham and Winston-Salem on two sampling occasions. These cysts or oocysts were not significantly associated with levels of fecal coliforms or enterococci in the raw water. All of the biological contaminants were undetectable in samples taken after water treatment, which shows the effectiveness of conventional processes including coagulation, sedimentation, filtration and chlorine disinfection.

Investigation of agricultural chemical usage was limited to the Winston-Salem watershed. At least 15 agricultural chemicals (insecticides, fumigants, nematicides and herbicides) on the SDWA lists may be in use. The annual application rate exceeds two million pounds. The amount of these chemicals entering the water supply is unknown. Sediments rather than water is the logical sink.

It appears that the SDWA amendments' requirement for removal of disinfection by-products will have a much greater impact on the six cities studied than will the regulations regarding SOCs and VOCs.

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SUMMARY AND CONCLUSIONS

A compilation was made of the contaminants in drinking water to be regulated in the foreseeable future, including those 83 mentioned in the 1986 SDWA amendments and those on the initial Drinking Water Priority List (DWPL), the latter being of less regulatory concern for the present. The chemicals on both of these lists were compared to those on U.S. EPA Priority Pollutant list used by states in issuing National Pollution Discharge Elimination (NPDES) permits to implement the Clean Water Act (CWA). While many contaminants are cross-listed as a result of both the SDWA and CWA, more appear on the SDWA list; these include include agricultural chemicals and disinfection by-products.

The research focused on determining whether organic contaminants originating from the SDWA are present in the following water supplies of the Urban Water Consortium established by the Water Resources Research Institute of the University of North Carolina: Burlington, Orange Water and Sewer Authority (OWASA), Durham, High Point, Raleigh and Winston-Salem. Existing data on NPDES permits and on monitoring of volatile organic chemicals (VOCs) and synthetic organic chemicals (SOCs) were collected from state regulatory agencies. In addition, new data were collected for VOCs and SOCs (including pesticides) and four microbial contaminants: fecal coliforms, enterococci, Giardia lamblia cysts and Cryptosporidium parvum oocysts. G. lamblia is regulated under the Surface Water Treatment Rule and Cryptosporidium is anticipated for regulation in the near future.

A review of the NPDES permits in each of the watersheds confirmed that the water supplies of OWASA and Burlington are free of industrial wastes and that only two minor industrial discharges enter the Durham water supply. The water supplies for Raleigh and Winston-Salem are somewhat more vulnerable to industrial waste from direct discharge (six and seven sources, respectively). Those listed for Raleigh, however, are classified as minor discharges by an EPA rating system. At High Point, vulnerability is not so much from industrial discharges as from the potential for accidental contamination due to leakage from several oil storage depots. In addition, both Raleigh and Winston-Salem must contend with indirect industrial discharges resulting from publicly owned wastewater treatment works (POTWs). Very few priority pollutants of concern from the point of view of the SDWA were uncovered in these NPDES permits. The most commonly noted SOCs were phenols, including trichloro- and pentachlorophenol; those inorganic chemicals (IOCs) were chromium, copper, nickel, silver and zinc. It is impossible to determine without a great deal more research the amount of these contaminants being discharged. In addition, the NPDES data base is incomplete with regard to its listings of organic contaminants and cannot be relied upon to judge the integrity of the receiving water when used for water supply.

Monitoring data on finished water supplies, as required by the NC Division of Health Services (Department of Human Resources), showed only one instance from two quarters of sampling (fourth of 1987 and first of 1988) in which an unregulated SOC (chlorobenzene at 0.9 ppb) was found above detectability (>0.5 ppb). This occurred in the Durham supply and is suspected to have resulted from chlorination of a liquid polymer being used as a filter aid and sludge conditioner. Regulated pesticides (six) were never found above detection limit in any of the six finished waters. A more extensive data base for total trihalomethanes (TTHMs) exists due to the regulatory requirements for monitoring. A separate study by Haws (1988) showed that the average TTHM concentrations for the last two years in all six cities studied were less than the current maximum contaminant level (MCL) of 100 ppb but greater than 50 ppb, a value being suggested by some as a future MCL. Thus, control of TTHMs by altering treatment and disinfection strategies emerges from the existing data base as most important when examining the entire array of chemical contaminants slated for regulation by the SDWA.

The results of sampling each finished water once in summer of 1988 showed that all VOCs and SOCs, with exception of the THMs and chloropicrin (a disinfection by-product) were below the detection limit (0.5 ppb for most analyses). This included all but five organic contaminants on the current list to be regulated by the SDWA and all but ten on the DWPL (these ten being agricultural chemicals and some disinfection by-products). The appearance of chloropicrin (DWPL) in concentrations of about 1 ppb in two samples may have been due to extended reaction time with chlorine because these samples were not dechlorinated when taken.

The samples analyzed from the six water supplies in summer of 1988 were taken in the middle of a severe drought. This minimized dilution of industrial and municipal wastewater thereby maximizing the concentration of contaminants. Yet, no chemical contamination could be measured in the finished water. This is not to say that contaminants were absent in the raw water supplies. Budget considerations for this project made it possible to sample only the finished water. Another factor which could not be included was the impact of stormwater runoff -- either agricultural or urban -- owing to the drought conditions.

The in-house analysis of Giardia lamblia and Cryptosporidium parvum revealed their presence in the raw water supplies of OWASA, Durham and Winston-Salem on two sampling occasions. These cysts or oocysts were not significantly associated with levels of fecal coliforms or enterococci in the raw water. All of the biological contaminants were undetectable in samples taken after water treatment, which shows the effectiveness of conventional processes including coagulation, sedimentation, filtration and chlorine disinfection.

Many agricultural chemicals appear on the SDWA lists of contaminants to be regulated now or in the future. Given the importance of agriculture in North Carolina, it was deemed necessary

to account for the current usage of these agricultural chemicals. This aspect of research, however, was limited in scope to the Winston-Salem watershed. With about 94,000 acres of various crops, it was estimated that at least 15 agricultural chemicals (insecticides, fumigants, nematicides and herbicides) on the SDWA lists may be in use. The annual pounds applied were calculated based on typical recommended use rates. Taking all 15 chemicals together, the annual application rate exceeds two million pounds. The amount of these chemicals entering the water supply is open to debate. The mechanisms include storm-water runoff and associated soil erosion but not much is known about the associated transport and fate processes. Nevertheless, the molecular structure of agricultural chemicals suggests a very high affinity for soil particles, thereby making sediments rather than water the logical sink.

All data gathered for this research point toward the major impact of the SDWA amendments of 1986 being on removal of disinfection by-products rather than removal of SOCs and VOCs at these six water supplies. The NPDES permits, historical monitoring data, and new data gathered in this project did not show the presence of any organic contaminants of regulatory concern in any significant concentration. This study, however, did not examine the IOCs or radionuclides which are to be regulated.

RECOMMENDATIONS

The course of action mandated by the SDWA is very clear: more contaminants will be monitored and regulated each year and the MCLs will be very low - on the order of ppb and lower. Utilities have been responding to the challenge of knowing what their water supplies might contain. However, the following are recommendations for expanding the effort:

- special diligence is needed for those unprotected supplies like Winston-Salem and Raleigh
- current monitoring focuses on finished water quality, but attention should be given to monitoring of raw water quality and to sediments and to the effects of urban runoff
- knowledge of industrial chemicals, both type and quantity, that are discharged either directly or indirectly needs to be improved because the NPDES permit system is inadequate for this purpose
- agricultural chemicals can impact all water supplies -- protected and unprotected -- and thus, there is a need for inventorying chemical usage and for determining environmental fate
- although NPDES permits do provide a good starting point for assessing vulnerability to contamination, the potential for accidental spills from chemical storage areas and from rail and road accidents needs to be assessed
- while microbial contamination by Giardia lamblia and Cryptosporidium parvum was not found serious, prudence suggests a seasonal survey in source waters

In addition to the above, it is recommended that a new data base be developed that lists all NPDES permittees affecting each surface water supply in North Carolina. This would be an efficient beginning point for updating NPDES permit information and assessing its usefulness for determining the vulnerability of water supplies to chemical contamination.

INTRODUCTION

The 1974 Safe Drinking Water Act (SDWA) requires that the U.S. Environmental Protection Agency is to issue its Maximum Contaminant Levels (MCLs) and revise them periodically. These MCLs are enforceable and are set as close to the maximum contaminant level goal (MCLG) as possible. By policy, EPA sets MCLGs at zero for all known or probable carcinogens. The 1974 SDWA resulted in the setting of 21 MCLS. The 1986 amendments to the SDWA stated that MCLs must be established for an additional 83 specific contaminants. The original timetable requires that at least nine were to be established by June 19, 1987; an additional 40, by June 19, 1988; and the remainder, by June 20, 1989. For convenience, these contaminants have been grouped into the following categories:

- Volatile organic chemicals (VOCs)
- Synthetic organic chemicals (SOCs)
- Inorganic chemicals (IOCs)
- Microbiological contaminants
- Radionuclide contaminants
- Disinfection by-product contaminants

Although behind the original timetable, EPA added nine MCLs (eight VOCs and fluoride, an IOC) to the original list of 21 (i.e., prior to the 1986 SDWA amendments). In May 1989, EPA proposed in the Federal Register MCLs (or treatment requirements) for 30 SOCs and 8 IOCs. Final regulations are expected in December 1990. MCLs for the remaining SOCs and IOCs plus radionuclides and disinfection by-products will follow in 1991.

The Drinking Water Priority List (DWPL) contains additional contaminants which may require regulation in the future. These include those already identified by the Superfund Amendments and Reauthorization Act (SARA) and the National Pesticide Survey. According to the 1986 SDWA amendments, future MCLs and MCLGs can be anticipated at a rate of 25 every three years.

The objective of this research was to determine if any of the contaminants to be regulated in the foreseeable future (including those 83 mentioned in the 1986 SDWA amendments and those on the initial DWPL) will affect treatment provided by the following Urban Water Consortium cities: Burlington; Orange Water and Sewer Authority (OWASA) which serves Chapel Hill/Carrboro; Durham; High Point; Raleigh; and Winston-Salem. The approach consisted of a survey of existing data on chemical contaminants as well as the collection of new data, specifically for VOCs and SOCs (including pesticides) and four microbial contaminants: fecal coliforms, enterococci, Giardia lamblia cysts and Cryptosporidium parvum oocysts. G. lamblia is now regulated under the new Surface Water Treatment Rule, and Cryptosporidium is expected to be regulated in the near future.

METHODOLOGY

Survey of Existing Data

The Division of Environmental Management (DEM) in the N.C. Department of Natural Resources and Community Development was consulted to determine the point dischargers of industrial wastewater in each watershed and to discover which contaminants are listed on their respective National Pollutant Discharge Elimination (NPDES) permits. However, NPDES permits include only those 126 specific chemicals on the EPA Priority Pollutant list (Keith and Teillard 1979), and many of the contaminants found on the SDWA lists are not these "priority pollutants." An additional problem in using the NPDES permit data base is that it may not be an accurate listing of chemical contaminants due to changes in operations since the permit was issued and to the possibility that the information reported is not complete. Thus, this data base is not sufficient to determine if contaminants to be regulated under the SDWA are actually present in each watershed.

Another data base was obtained from the Division of Health Services (DHS) in the NC Department of Human Resources (DHR). This data base consists of monitoring data provided to DHS by the six water suppliers on certain unregulated VOCs and SOCs and the regulated total trihalomethanes (TTHMs) and six pesticides. When this research was being done, the unregulated contaminants had been measured quarterly for a year to determine if any are of concern. The TTHM's have been measured quarterly since inception of the regulation in 1979. Another recent study (Haws 1988) has summarized all the TTHM monitoring data in North Carolina. This study was used to obtain further insight into the impact of lower MCLs for TTHMs as part of the regulations planned for disinfectants and their by-products in 1991.

Pesticides are included in the list of 83 chemical to be regulated. The Soil Science Department of North Carolina State University is developing a pesticide/herbicide-use data base for the state by county. Because this data base was not yet available, County Agricultural Extension Agents were contacted to obtain information on the acreage of each crop type and the pesticide type and quantity normally applied. The scope of this project did not permit that such an analysis be conducted for all six water supplies. Rather, the Winston-Salem water supply was selected because its watershed has the most extensive agricultural use.

Acquisition of New Data

As part of this research, additional data for VOCs and SOCs, either already regulated or being considered for regulation, as well as data for *Giardia lamblia* cysts and *Cryptosporidium parvum* oocyst (two new microbial contaminants anticipated for regulation), fecal coliforms and enterococci were collected at the six water supplies. Not included were IOCs, radionuclide

contaminants and certain of the disinfection by-product contaminants listed by EPA. Because of the number of different analytical procedures needed for the VOCs and SOCs slated for regulation by the SDWA and the concomitant sophistication of quality assurance and quality control programs, it was necessary to use a commercial laboratory rather than make these measurements in-house. The cost of commercial laboratory analyses (on the order of $800 per round of chemical analyses for VOCs and SOCs) restricted sampling to once at each of the six water supplies. The microbiological testing for Giardia lamblia cysts and Cryptosporidium parvum oocyst was conducted in the laboratories of the Department of Environmental Sciences and Engineering at The University of North Carolina.

The finished water at each water treatment plant was sampled once in July - August 1988. The summer of 1988 was very dry. This minimized instream dilution of industrial and municipal wastewater, thereby maximizing the concentration of contaminants. However, it also meant that stormwater runoff -either agricultural or urban- did not affect water quality during this sampling.

Microbial Analyses of Raw and Finished Waters

Sampling. Two samples of raw and finished water were taken at each of the six Urban Water Consortium water treatment plants (WTPs) to determine concentrations of G. lamblia cysts, C. parvum oocysts, fecal coliforms and enterococci. Raw waters were sampled to determine cyst and oocyst presence. Finished waters were sampled to determine whether or not the treatment used by WTPs having cysts or oocysts in their raw waters was sufficient to reduce cyst or oocyst levels to below detection limits. Samples of raw water were also analyzed for fecal indicator bacteria, fecal coliforms and enterococci, to determine if there was a statistically significant positive association between the presence of either protozoan and the concentrations of these bacterial indicators. If a strong, consistent, positive association was found, then the bacterial indicator could be used as a predictor of protozoan presence. Samples of finished water were analyzed for the above bacterial indicators and protozoans to determine if these microbes persisted through treatment and if the fecal bacteria indicators are adequate predictors of the presence of cysts or oocysts.

Sample Processing. Detection of G. lamblia cysts and C. parvum oocysts from environmental samples involves six steps: concentration, extraction, purification, detection, identification and quantitation (Jakubowski 1988). Methods for G. lamblia have been available for ten years and for C. parvum for three years. There is no "standard method" for either protozoan. The 15th edition of Standard Methods for the Examination of Water and Wastewater contained a tentative method for G. lamblia; the 16th edition contains a consensus method for G. lamblia and the 17th edition will have revisions of the consensus method for G. lamblia and will introduce a consensus method for C. parvum (Jakubowski 1988).

Analyses for G. lamblia cysts and for C. parvum oocysts were performed simultaneously because of time and budgetary constraints. Initially, a method from the University of Arizona was used (Musial et al. 1987). However, cyst and oocyst recoveries were low due to concentration and purification problems caused by high concentrations of particles in the waters, especially diatoms and other algae. The selected method was developed by Sauch (1985) and Tom Trok of the Western Pennsylvania Water Company (personal communication, 1988). This method was effective for the waters in North Carolina, as confirmed by recovery studies using spiked samples (see Methods to Evaluate Cyst and Oocyst Recovery).

Cysts and oocysts were concentrated by filtering a volume of water through a 10 inch, polypropylene cartridge filter (Microwynd II, nominal pore size 1.0 um, AMF/CUNO Division, Meriden, CT). Approximately 100 gallons of water, as suggested by the EPA (Craun and Jakubowski 1987), at 5-11 gpm, and 500 gallons of finished water, at 10-20 gpm, were filtered each time. Because of the risk of cyst and oocyst contamination, separate filter housings and hoses were used for raw and finished waters. After each sample was collected, the filter was removed from the housing, put into a one gallon "Zip-lock" style bag, labeled and placed on ice in an insulated container for transport back to the laboratory. There the filters were stored at 4°C until extracted, which was done within seven days. All sampling equipment, except the pump and hoses, was disinfected with a 10-15 mg/L solution of chlorine (NaOCl) for 30 min., thoroughly scrubbed and rinsed successively in tap and deionized (DI) water. The pump and hoses were flushed with at least 100 gal of tap water (Rose et al. 1986).

Particulates from each filter were extracted by back-flushing with 2700 ml of 0.1% Tween 80 solution (Figure 1). The recovered eluate was then used as a wash solution for the filter to recover additional cysts and oocysts. The filter was cut off its tubular support, torn in half, thoroughly teased apart, and each half was washed in 1/2 of the eluate in a 4L flask on a shaker for 10 minutes. The eluate was wrung out of the filter media by hand then centrifuged at 1800 x g for 15 minutes (Rose, personal communication 1988). The supernatant was removed by aspiration and discarded, and the pellet plus a small amount of residual supernatant was brought to 50 ml with deionized (DI) water and processed further or supplemented with 5 ml 10% formalin and stored 4°C for further processing (Trok and Burns 1987).

Samples stored in formalin were washed in DI water by centrifugation prior to further processing (Figure 2). A 20% (10 ml) subsample was further processed, and the rest of the sample was preserved with 5 ml of 10% formalin and stored at 4°C. The subsample was purified by flotation and cleaned by washing with DI water (Figures 3 and 4) using methods adapted from those previously described (Sauch 1985; Trok and Burns 1987). Processed samples were stored in 2 ml 10% formalin at 4°C until microscopic examination and enumeration by immunofluorescence.

Figure 1. Flow Diagram of Procedures for Extracting Cysts and Oocysts from Filters.

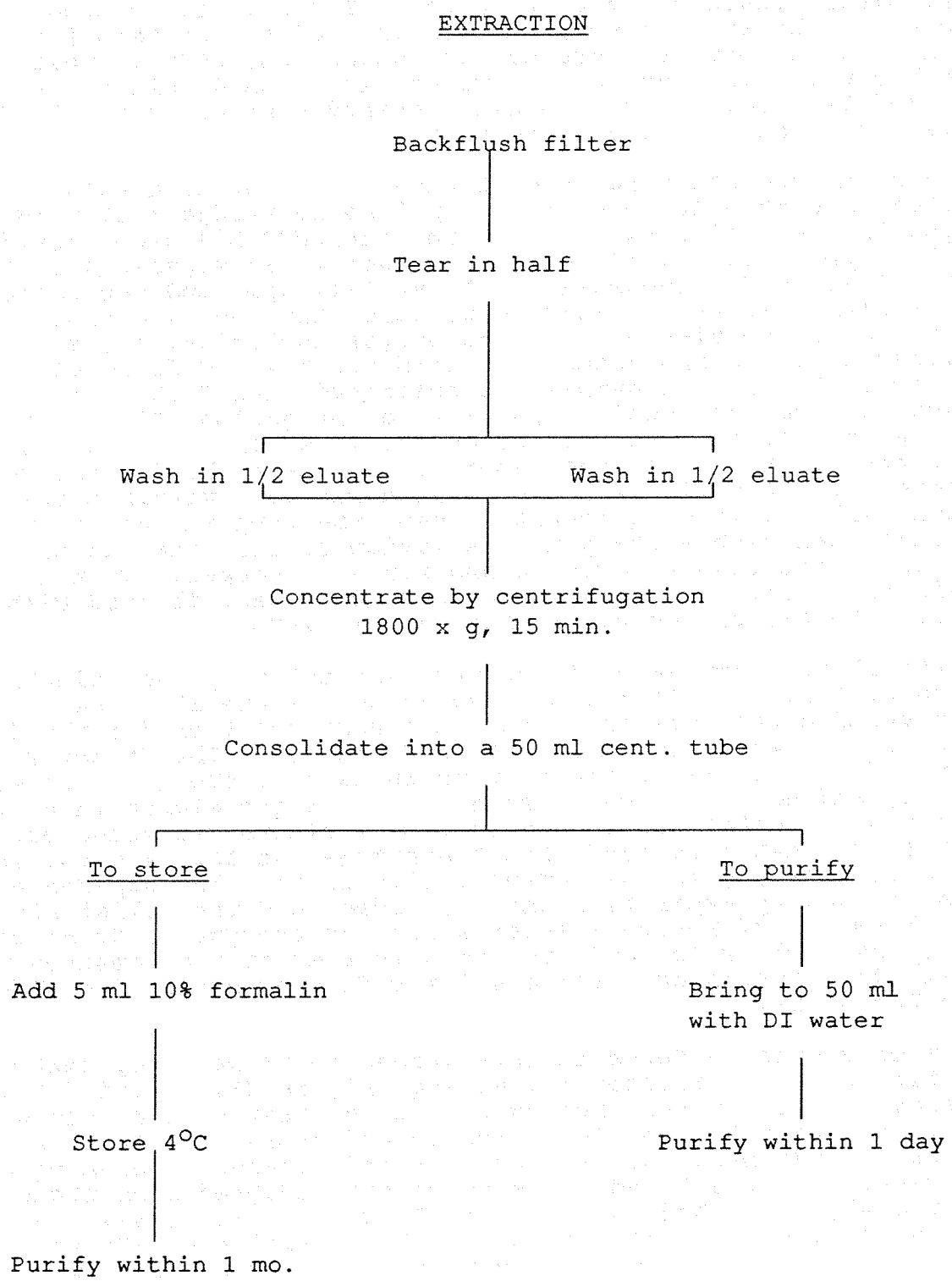


Figure 2. Flow Diagram of Procedures for Washing Cysts and Oocysts Extracted from Filters.

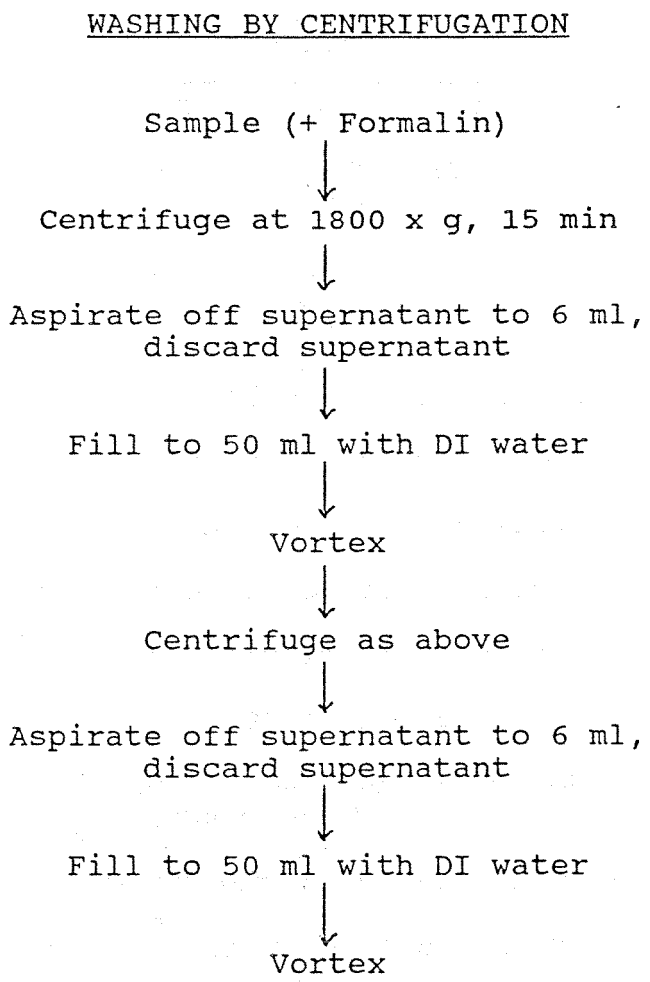


Figure 3. Flow Diagram of Procedures for Purifying Cysts and Oocysts from Raw and Finished Water Samples.

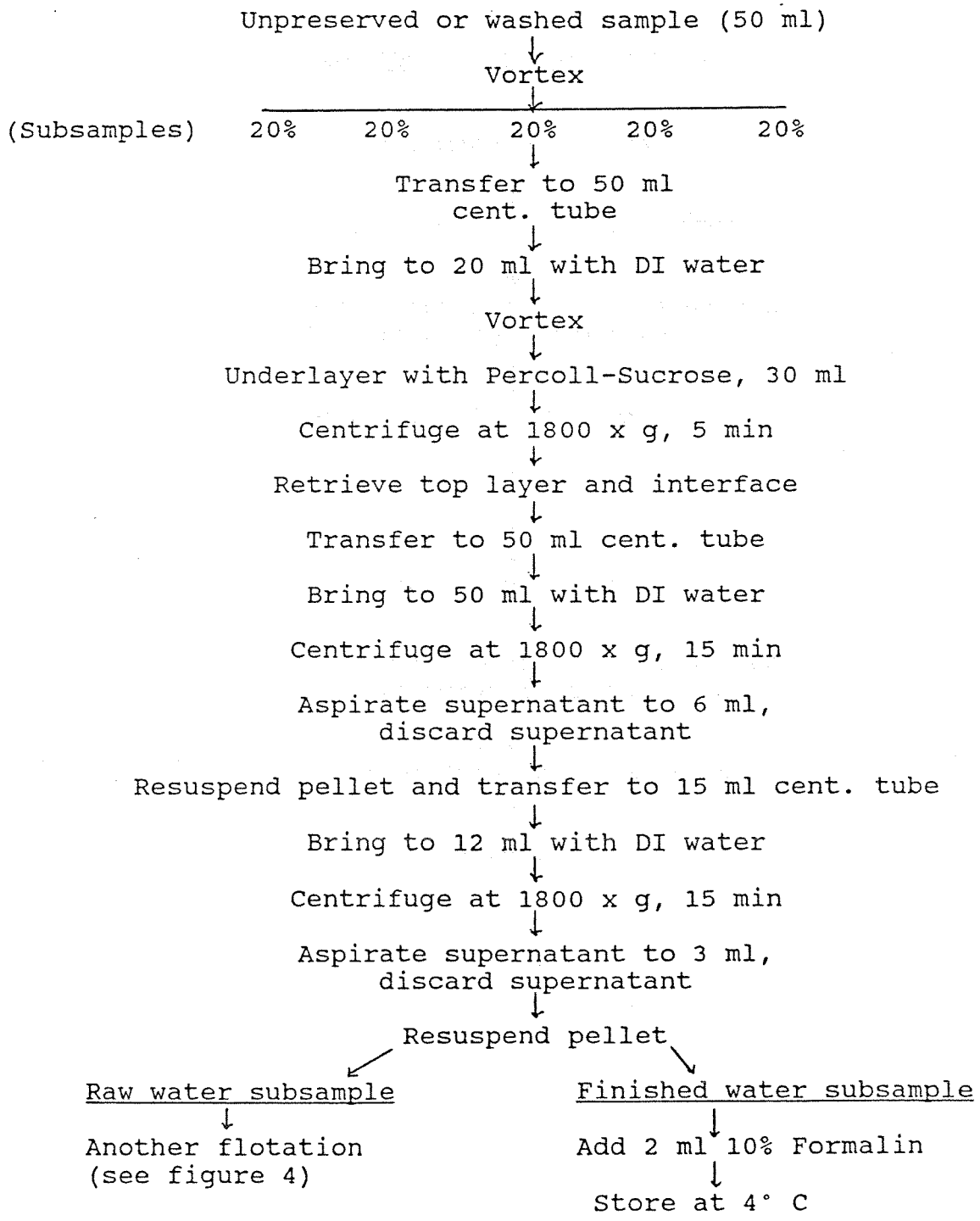
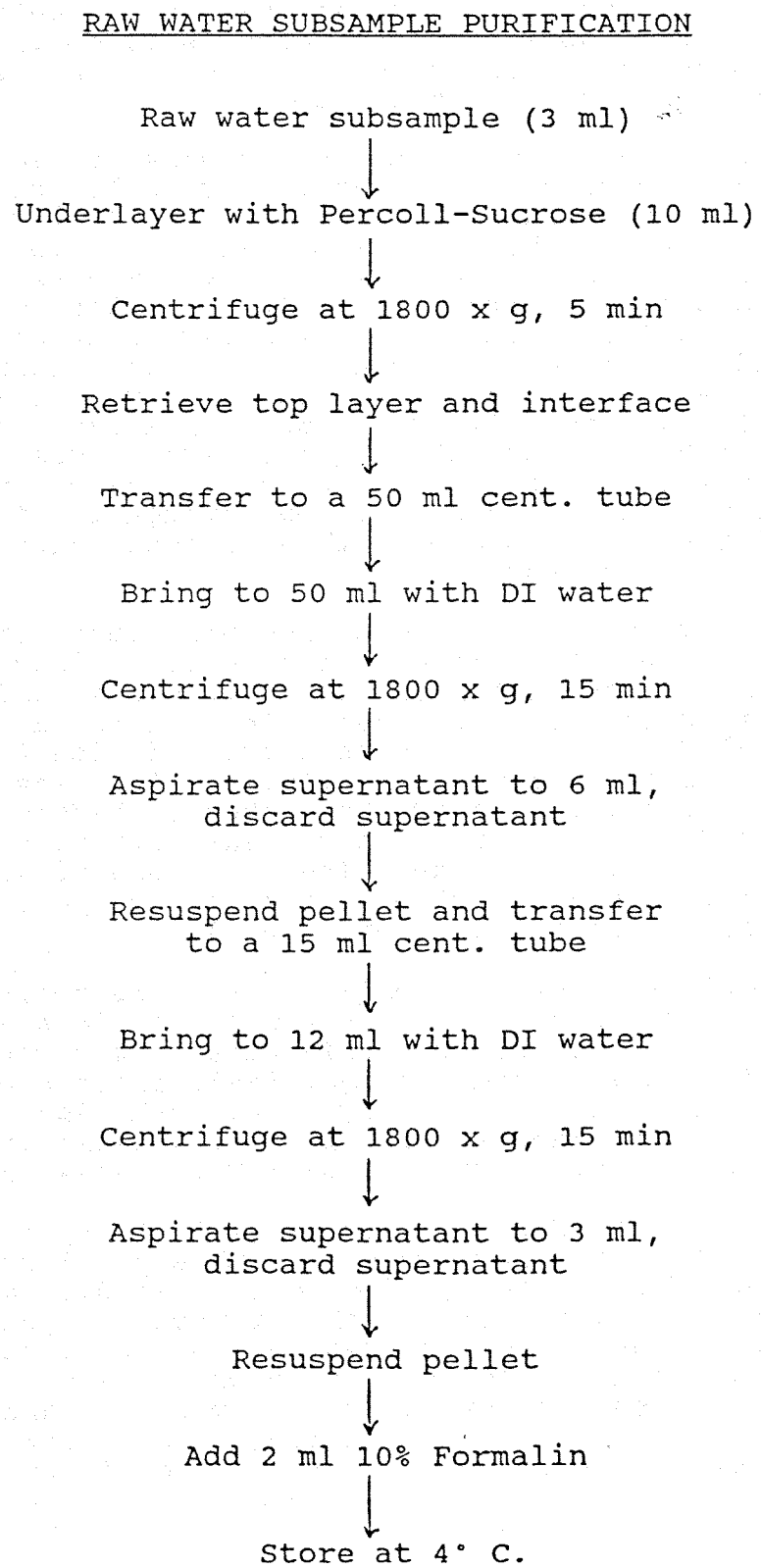


Figure 4. Flow Diagram of Additional Processing Steps for Purifying Cysts and Oocysts from Raw Water Samples.



Counting. G. lamblia cysts and C. parvum oocysts were counted microscopically after labeling by the Merifluor(tm) indirect immunofluorescent procedure using commercially available reagents (Figure 5). Monoclonal antibodies against G. lamblia and C. parvum were added to the samples to bind to cyst and oocyst walls. Cysts and oocysts with bound antibodies were then reacted with fluorescein-conjugated anti-species antibodies. Fluorescing cysts and oocysts were then viewed and counted under a fluorescent microscope.

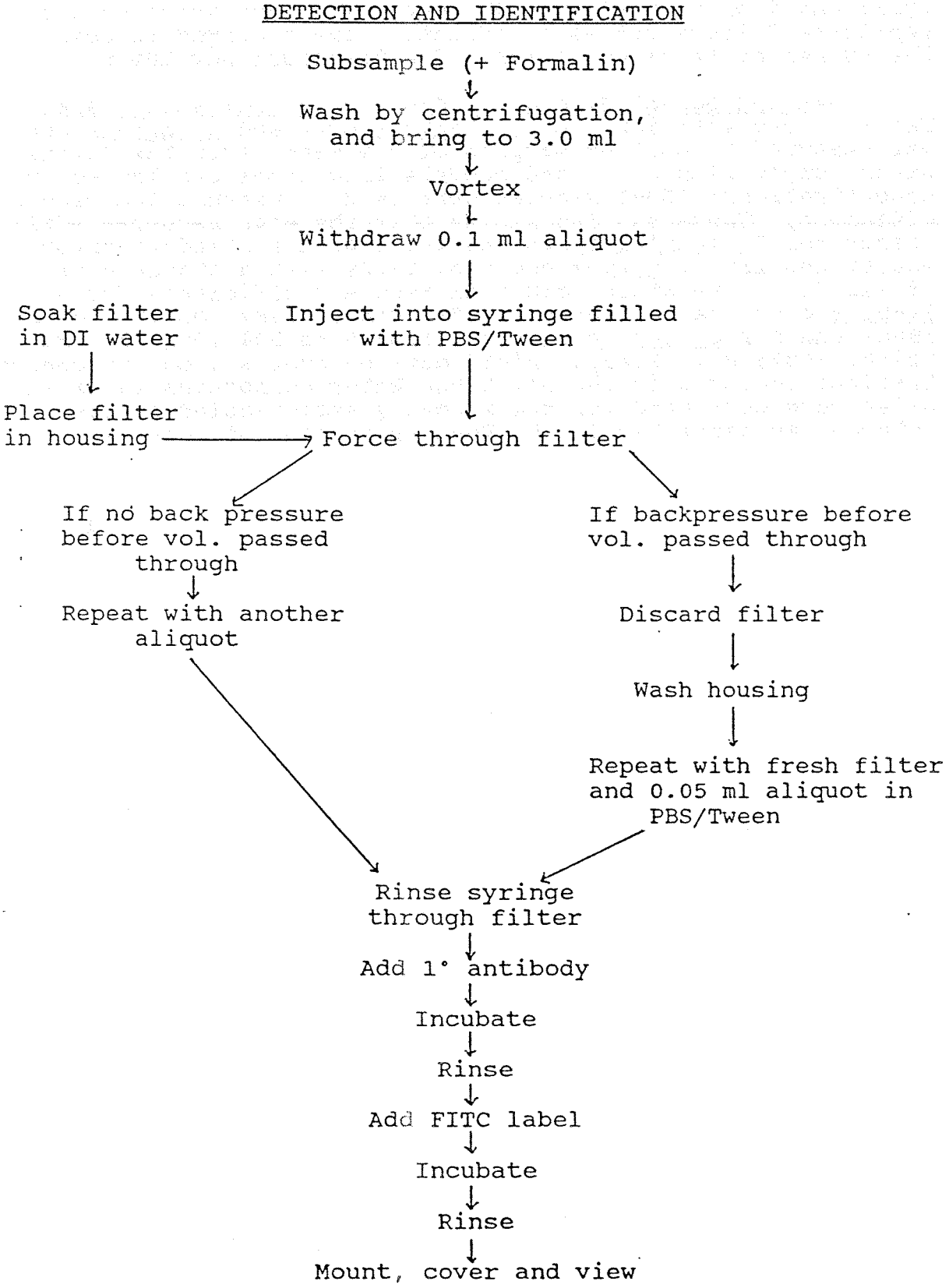
The filters upon which cysts and oocyst were collected for labelling and microscopic examination were polycarbonate, 13 mm diameter, 2.0 um porosity and black (Nuclepore, Inc.). Filters were briefly soaked in DI water and then placed in in-line stainless steel filter holders (Millipore, Swinnex, 13 mm diameter). Subsamples were washed with DI water by centrifugation at 1800 x g for 5 minutes. The supernatant was aspirated to 3.0 ml and the pellet resuspended by vortex mixing (Trok and Burns 1987). A 3.0 ml syringe was loaded with 1.0 ml 0.05% Tween 80 in PBS and then 0.1 ml of subsample was injected into the syringe with a micropipette. This mixture was forced through the filter. The syringe was rinsed with 3 ml of 0.05% Tween in PBS and this wash was forced through the filter. These procedures were repeated with additional subsample volumes until backpressure occurred.

Primary antibody (Meridian Diagnostics Merifluor kit) was diluted 1:10 with PBS, 0.15 ml of the diluted antibody was added to the filter and the filter assembly was sealed and incubated at room temperature for 30 minutes. The filter was washed with 10 ml of 0.05% Tween in PBS and then treated with 0.15 ml of FITC-antispecies antiserum, also diluted 1:10. The filter assembly was sealed, incubated and washed as before. The filter was removed, mounted on a glass slide with mounting medium and covered with another slide. The slide was viewed at 400 X by epifluorescence using a fluorescent microscope equipped with filters for fluorescein (Leitz Ortholux II).

Presumptive criteria for G. lamblia cysts were definite bright apple-green fluorescence of the cyst wall, ovoid shape, and 8-12 um length. Confirmatory criteria were: 2-4 nuclei and a well- defined cyst wall under bright field microscopy (Trok and Burns 1987). Criteria for C. parvum were spherical to slightly ovoid shape, 4-6 um diameter, suture line visible and definite oocyst walls fluorescing bright apple-green (Rose 1988).

Bacterial analysis of fecal coliforms (APHA 1985) and enterococci (US EPA 1985) was performed by membrane filtration using 100-ml volumes of raw waters, diluted 1:10 in 0.1% peptone water, and 100-ml volumes of finished waters. Eight 100-ml aliquots of each sample were passed through separate 47 mm, 0.45 um porosity filters (Gelman) by vacuum. Four replicate filters from each sample were placed on mFC agar and incubated at 37°C for 24 hrs. Shiny, blue colonies were scored as positive colony forming units (CFUs) for fecal coliforms. Four replicate filters from each sample were placed on mE agar and incubated at 41.5°C for 48 hrs. Filters with shiny, dark red

Figure 5. Flow Diagram of Procedures for Detecting and Identifying Cysts and Oocysts by Membrane Filtration, Fluorescent Antibody Labelling and Fluorescence Microscopy.



colonies were considered presumptive positives for enterococci, placed on plates of esculin iron agar substrate (EIA) and incubated at the same temperature for 1 hr. Confirmation as enterococcus was a black ring around the colony from esculin hydrolysis and iron reduction. CFU counts for each group of four replicate filters for each indicator were averaged to compute the number of fecal coliforms and enterococci per 100 ml.

Cyst and Oocyst Recovery Efficiencies from Spiked Samples. The recovery efficiency of G. lamblia cyst and C. parvum oocyst was measured by spiking samples of raw water from the Durham water supply with cysts and oocysts from stool samples at known concentrations; 150-l samples were used to measure the recovery efficiency. These studies showed that the mean recovery efficiency for G. lamblia cysts was 46.4% with a standard error of +26.6% and for C. parvum oocysts, 37.6% with a standard error of +13.6%. Literature values of recovery efficiency for G. lamblia cysts range from 5 to 85% (Hibler 1987; Ongerth et al. 1988) and for C. parvum oocysts, from 5 to 59% (Ongerth and Stibbs 1987; Rose 1988). Field data on cyst and oocyst concentrations measured in the six Urban Water Consortium water supplies were corrected for the recovery efficiencies of the methods, as described in the Results section of this report.

RESULTS

Description of Watersheds and Water Treatment Plant Processes

Several of the cities included have more than one water treatment plant (WTP) and in some instances, more than one water supply. Not all of these were included in this research. The VOCs and SOCs were measured in the finished waters from the WTPs listed in Table 1 and *Giardia lamblia* cysts and *Cryptosporidium parvum* oocysts were measured in both the raw and finished waters. These raw waters vary from highly protected (University Lake for OWASA, Stoney Creek [Burlington Lake] for Burlington and Lake Michie for Durham) to highly unprotected (e.g., Yadkin River for Winston-Salem). All six water treatment plants use conventional water treatment consisting of alum coagulation, sedimentation and dual media filtration (anthracite and sand) with chlorination above the filters and ahead of the clear well.

Table 1. Water Treatment Plants (WTP) and Source Water Included in This Study

WTP	City Served	Source Water
OWASA	Chapel Hill-Carrboro	University Lake
Neilsen	Winston-Salem	Yadkin River/Salem Lake
Johnson	Raleigh	Neuse River
Williams	Durham	Lake Michie
High Point	High Point	Deep River
Ed Thomas	Burlington	Stony Creek

The sources of industrial waste discharge that may impact each water supply were located with the help of sub-basin maps that the NC DEM has developed for plotting the location of NPDES permittees. Sub-basin maps are available for each major river basin. Those that contain the watershed of the water supplies listed in Table 1 are included in this report as:

Figure No.	Water Supply
6	OWASA
7a-e	Winston-Salem
8	Durham and Raleigh
9	High Point
10a,b	Burlington

Each sub-basin map is identified by NC DEM with the code number that appears above the map scale. The open circles with enclosed numbers designate NPDES permitted dischargers (both industrial and municipal). The drainage area covered by each sub-basin map is greater than that of the water supplies being investigated. Thus, the number of dischargers shown in any sub- basin map is not an indicator of the severity of impact.

Instead, it is necessary first to locate the water supply on the sub-basin map and then to locate the dischargers that are upstream.

Information for all the dischargers located on each of the maps was obtained from the NC DEM. This includes the name of the discharger, the NPDES permit number, classification as major or minor discharge, the receiving stream and the exact location (latitude and longitude) of the discharge. These dischargers were screened, first to determine which were upstream of each water supply, and then to isolate the industrial sources of wastewater for further investigation. Many of the domestic wastewater dischargers are small volumes from schools, sub-divisions, etc. and not believed to be potential sources of VOCs and SOCs. However, some publicly owned treatment works (POTWs) include industrial wastes and are located upstream of the water supplies for both Raleigh and Winston-Salem. These may discharge VOCs and SOCs of concern but were not investigated in this research.

The location of University Lake, the sole water supply for OWASA before construction of the Cane Creek Reservoir, is shown by the solid circle in Figure 6. No dischargers are located upstream of this supply. While not shown, there are also no dischargers upstream of the Cane Creek Reservoir.

Winston-Salem uses both the Yadkin River and Salem Lake. The two sub-basins affecting the Yadkin River supply are Section 03 07 01 (Figure 7a) and Section 03 07 02 (Figure 7b and 7c).The location of the supply is shown by the solid circle in Figures 7b and 7c. Section 03 07 02 is repeated in order to show all the dischargers in a more readable form. The sub-basin map for the Salem Lake supply (solid circle) is Section 03 07 04 (Figures 7d and e). Again, this section is repeated in Figure 7e to plot the dischargers conveniently. This study focused on the Neilsen WTP which takes its raw water from both the Yadkin River and Salem Lake.

The Durham (half-filled circle) and Raleigh (solid circle) water supplies both appear in sub-basin Section 03 04 01 (Figure 8). Durham has only two dischargers upstream whereas Raleigh has many more, of which seven are direct industrial dischargers and one is a POTW (Durham North Side) that includes industrial wastes.

The High Point water supply (solid circle) is shown in sub-basin Section 03 06 8 (Figure 9). Only one industrial discharger is upstream.

Burlington uses Alamance Creek and Stony Creek for water supply. Thus, two sub-basin maps, Section 03 06 03 (Figure 10a) and Section 03 06 02 (Figure 10b) were needed. The chemical and microbiological data in this study was focused on Stony Creek, which has no dischargers upstream.

Figure 6. Sub-basin 03 06 06 that Includes OWASA Water Supply (solid circle) and Shows Location of NPDES Discharge Permits (open circles).

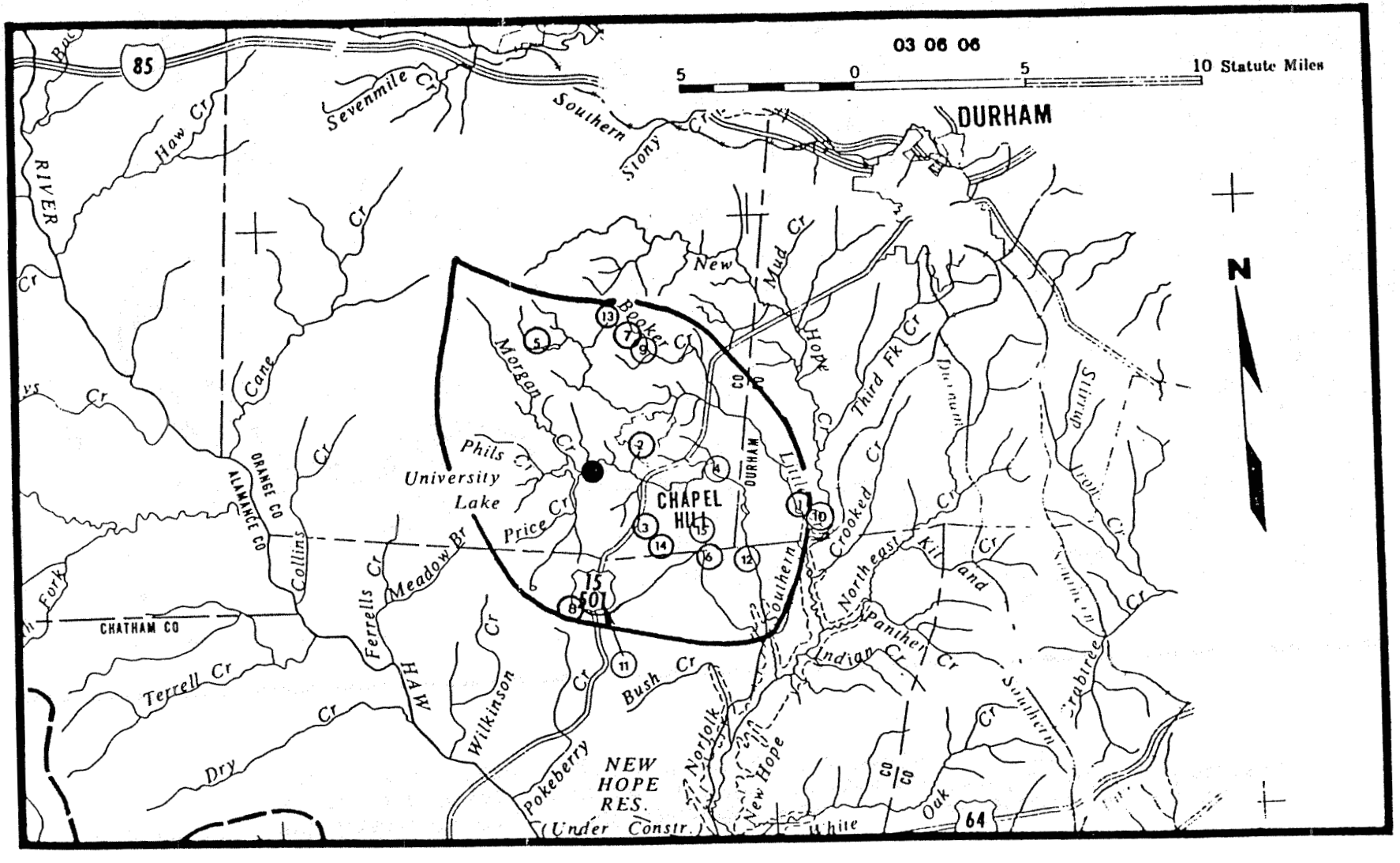


Figure 7a. Sub-basin 03 07 01 that Includes Winston-Salem Supply on Yadkin River and Shows Location of NPDES Discharge Permits (open circles); location of water supply shown in Sub-basin 03 07 02.

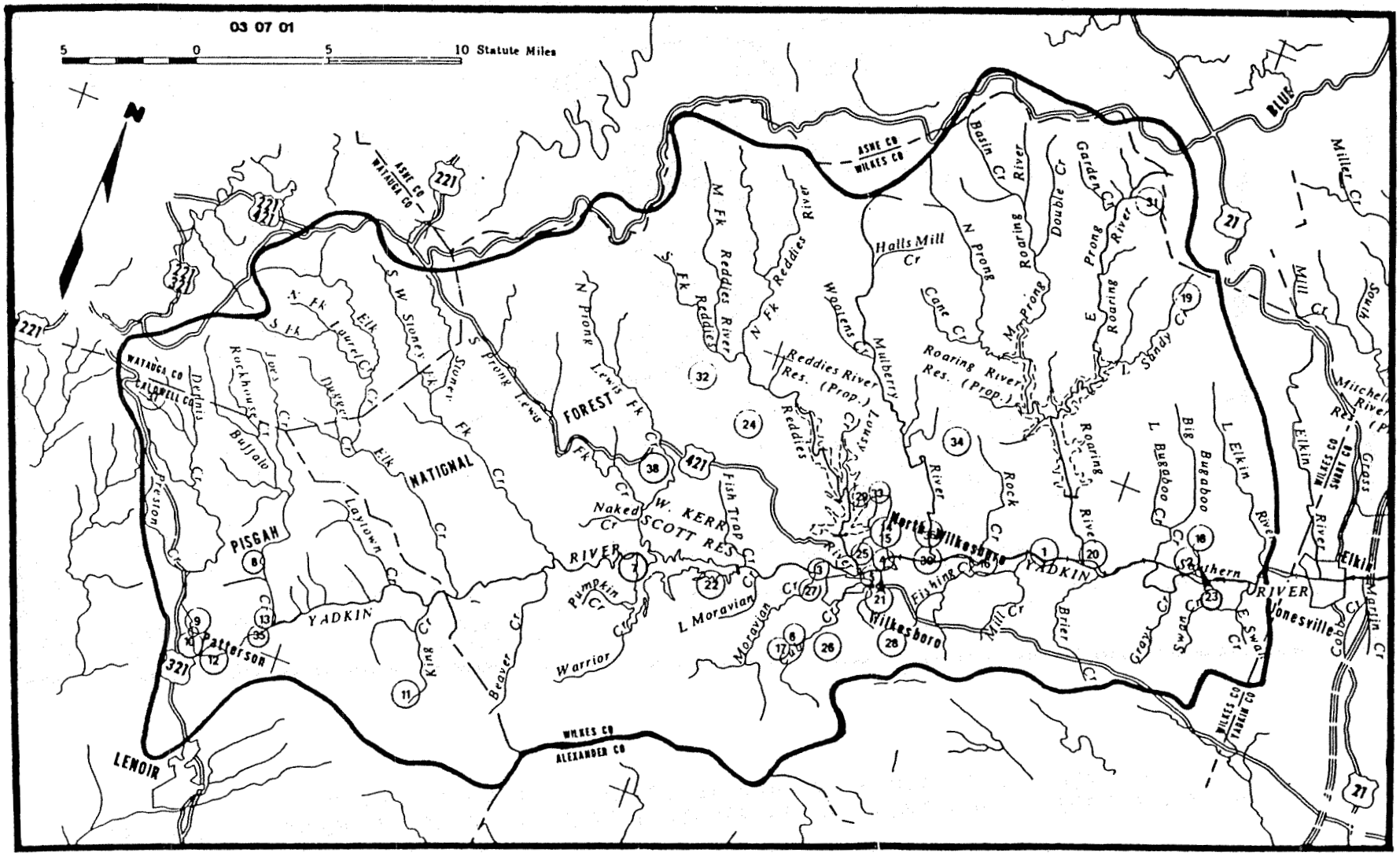


Figure 7b. Sub-basin 03 07 02 That Includes Winston-Salem Water Supply on Yadkin River (solid circle) and Shows Location of NPDES Discharge Permits nos 1-69 (open circles).

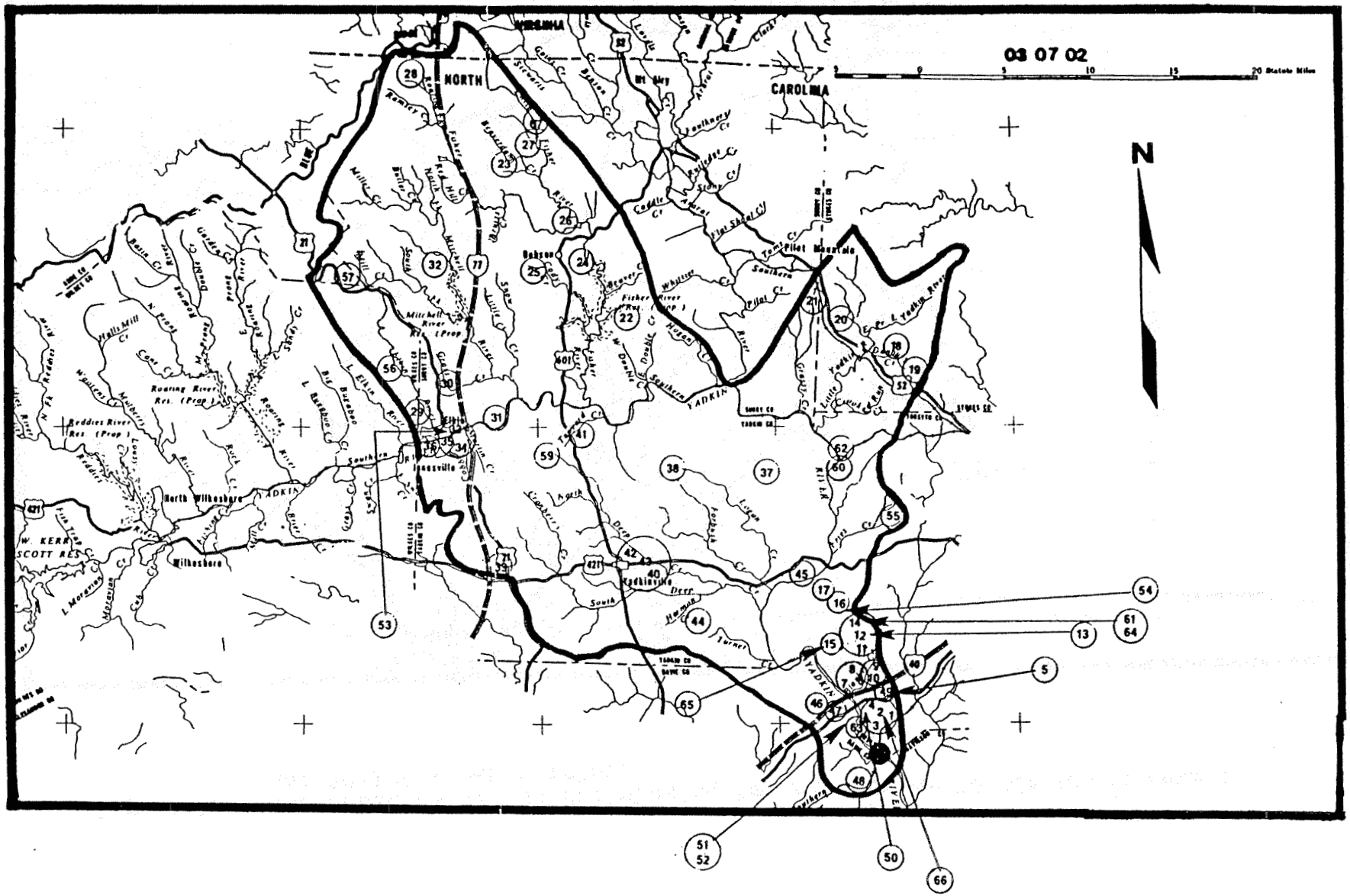


Figure 7c. Sub-basin 03 07 02 But Showing Location of NPDES Discharge Permit nos 70-100 (open circles).

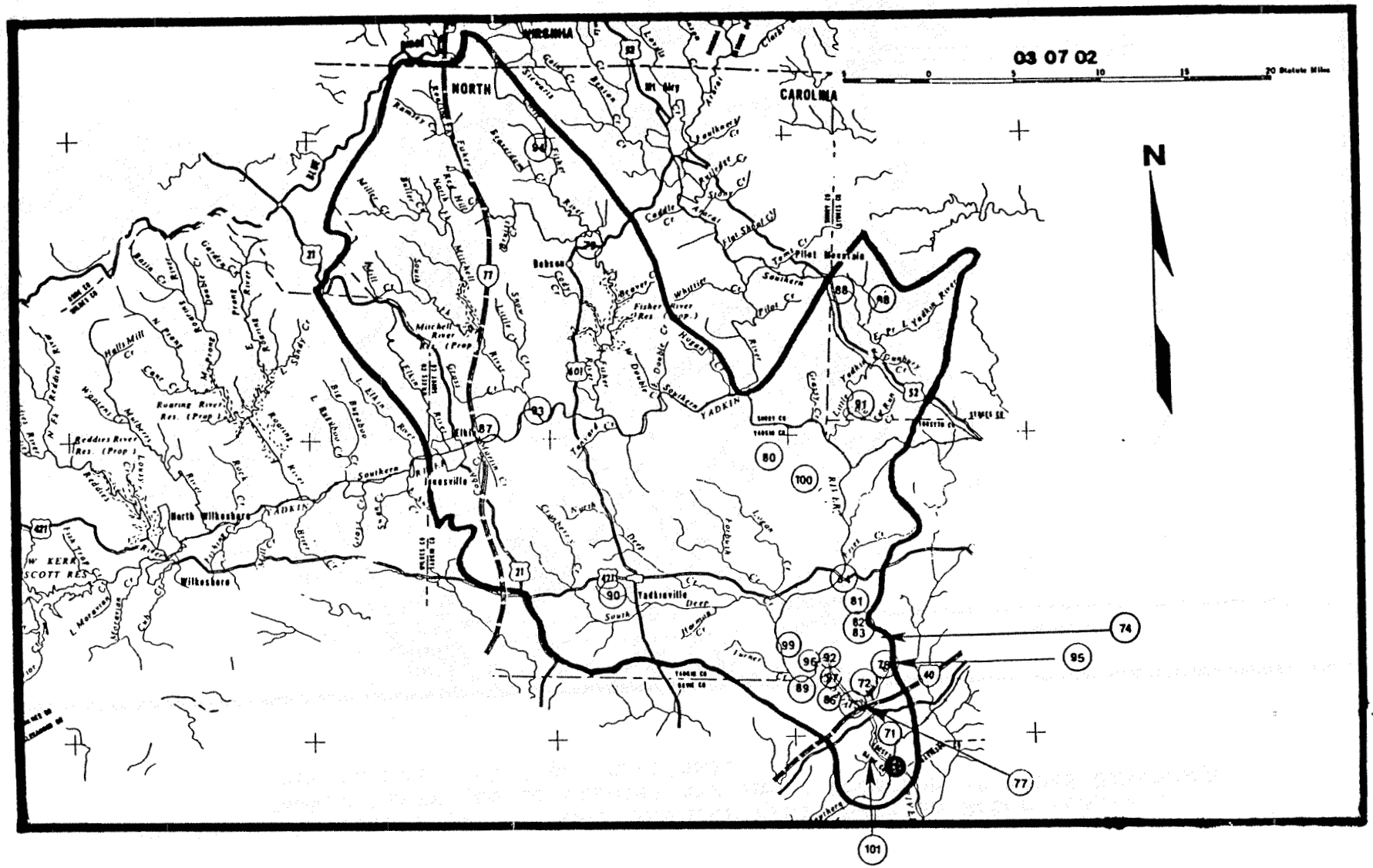


Figure 7d. Sub-basin 03 07 04 That Includes Winston-Salem Water Supply on Salem Lake (solid circle) and Shows Location of NPDES Discharge Permits 1-100. (open circles).

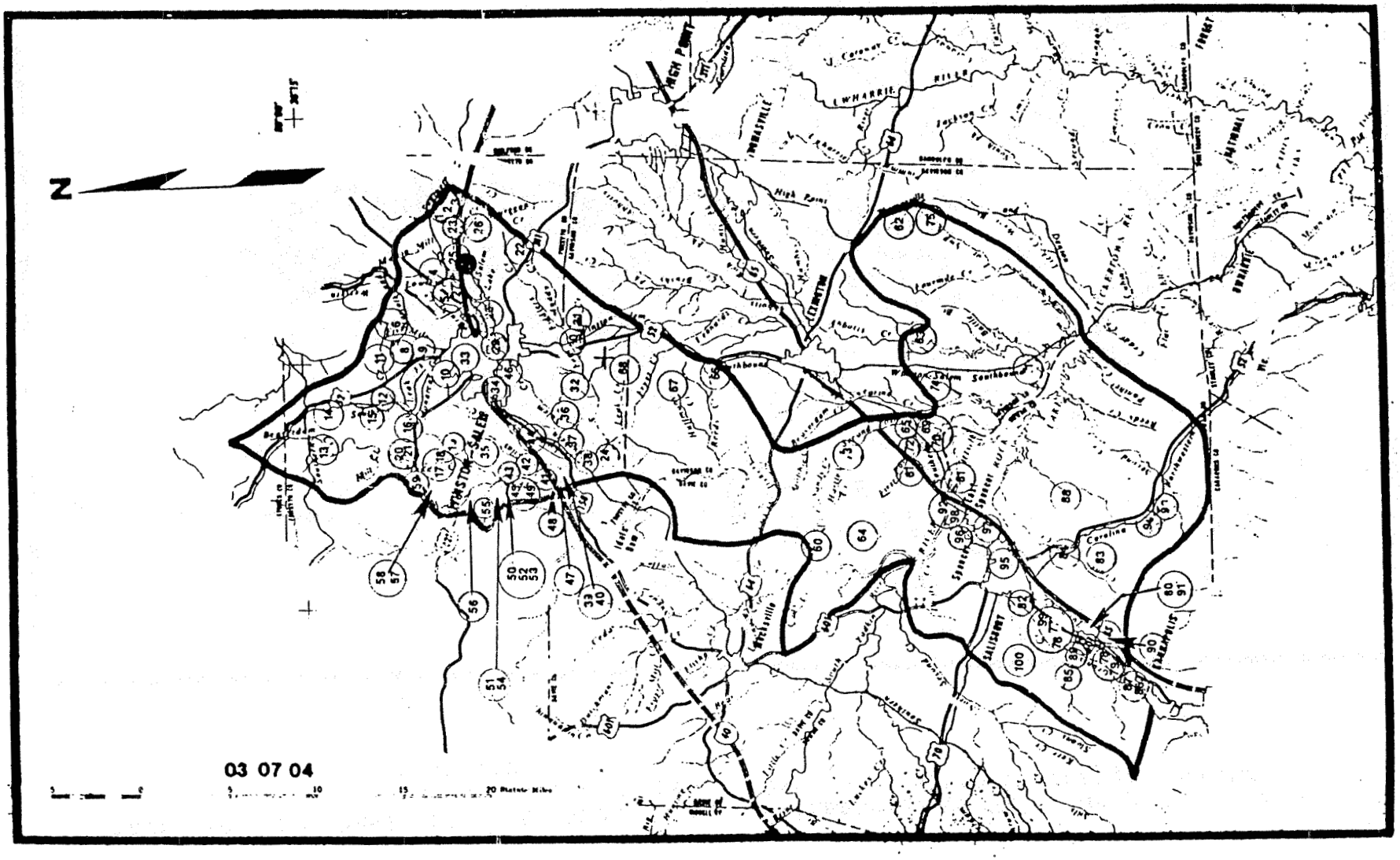


Figure 7e. Sub-basin 03 07 04 That Includes Winston-Salem Water Supply on Salem Lake (solid circle) and Shows Location of NPDES Discharge Permits 101- . (open circles).

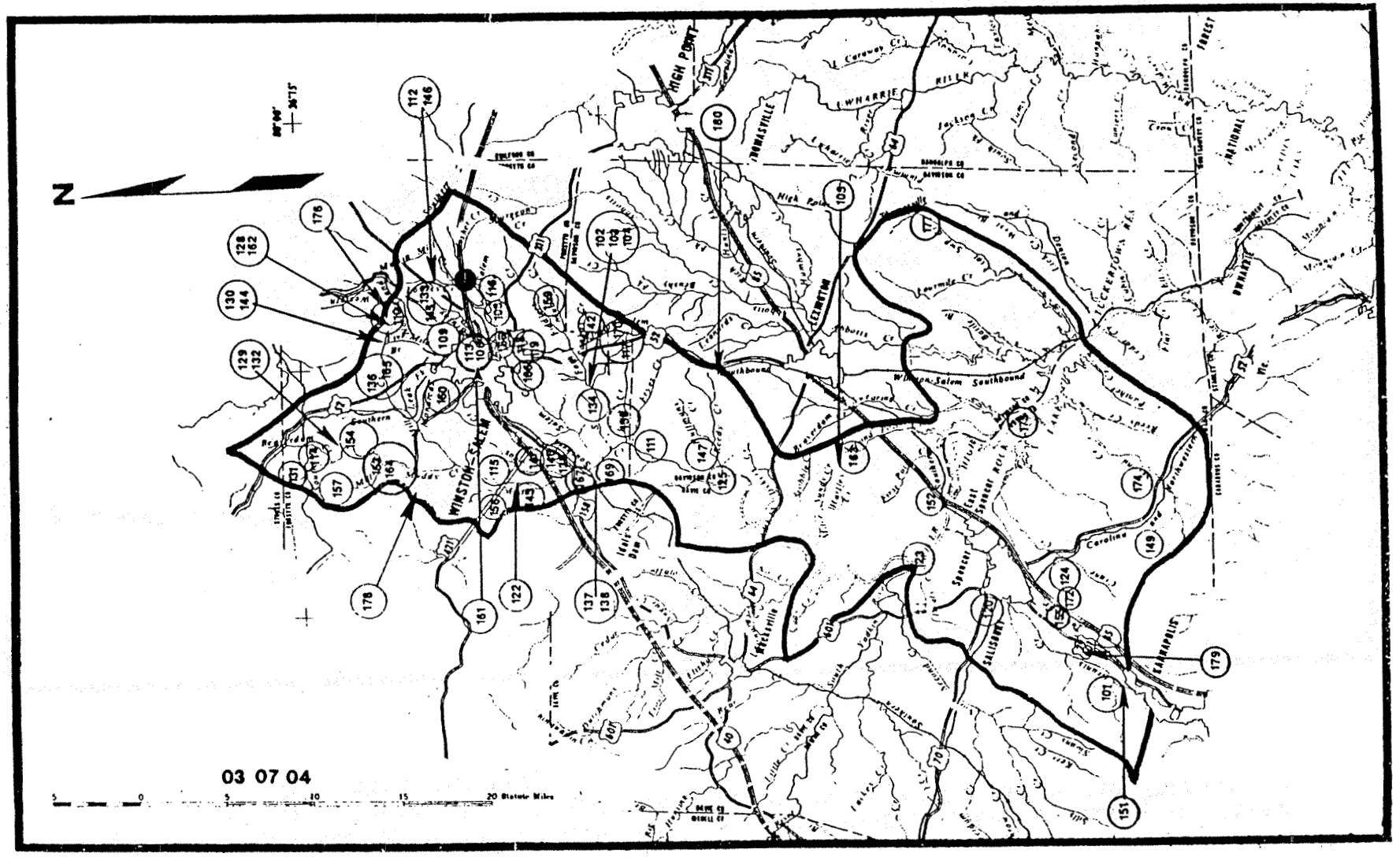


Figure 8. Sub-basin 03 04 01 That Includes Durham (half-filled circle) and Raleigh (solid circle) Water Supplies and Shows Location of NPDES Discharge Permits (open circles).

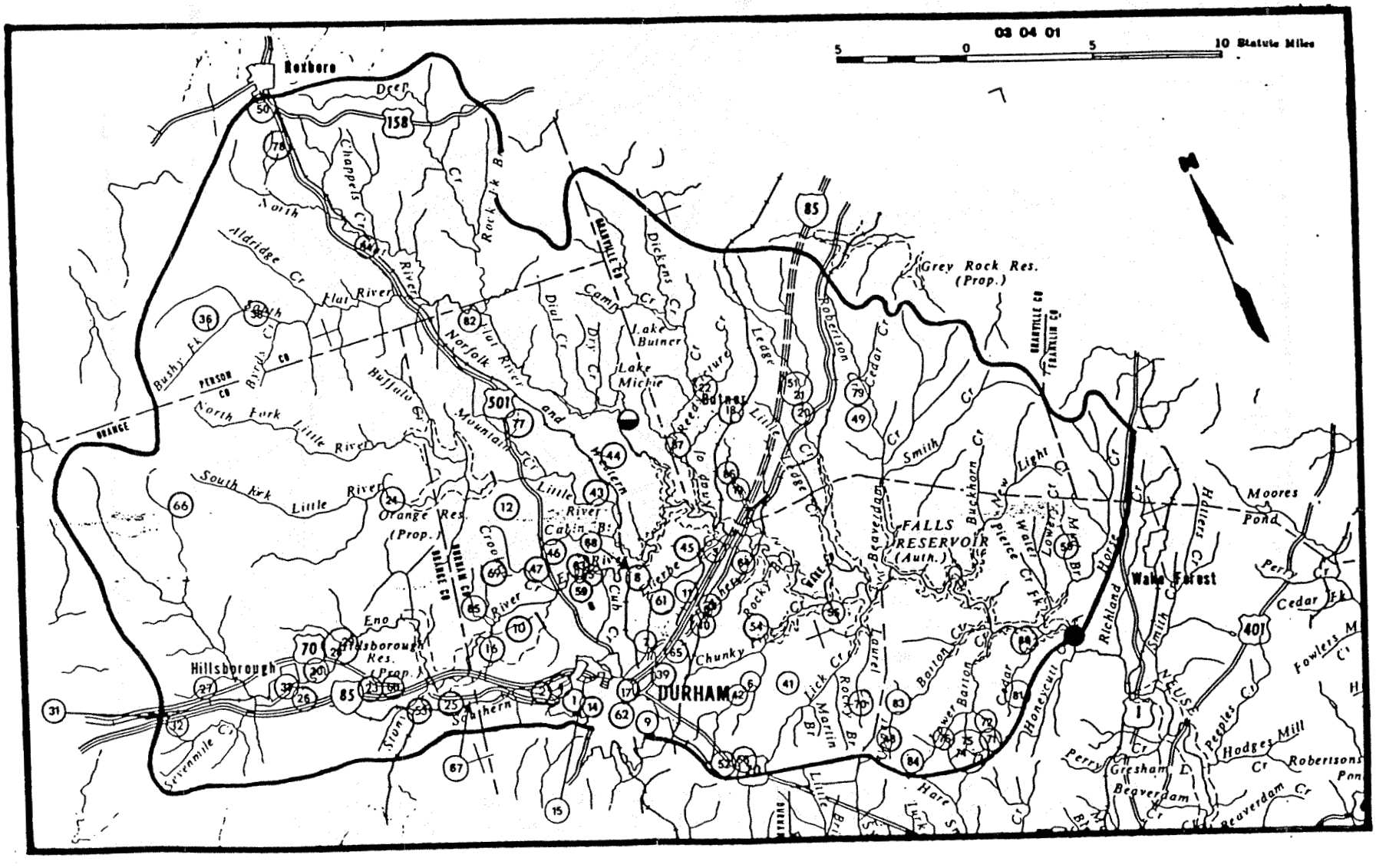


Figure 9. Sub-basin 03 06 08 That Includes High Point Water Supply (solid circle) and Shows Location of NPDES Discharge Permits (open circles).

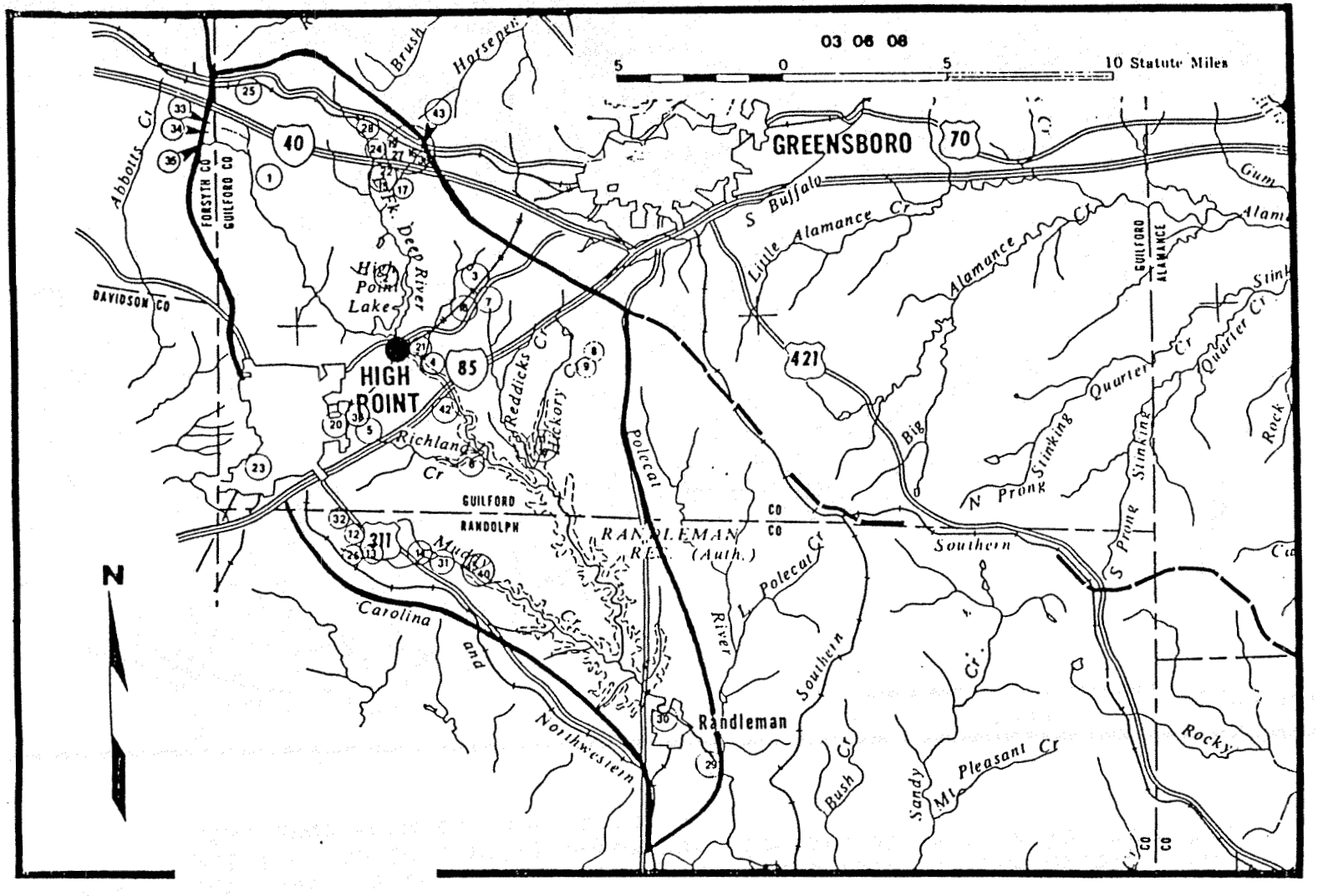


Figure 10a. Sub-basin 03 06 03 That Includes Burlington Water Supply on Alamance Creek (solid circle) and Shows Location of NPDES Discharge Permits (open circles).

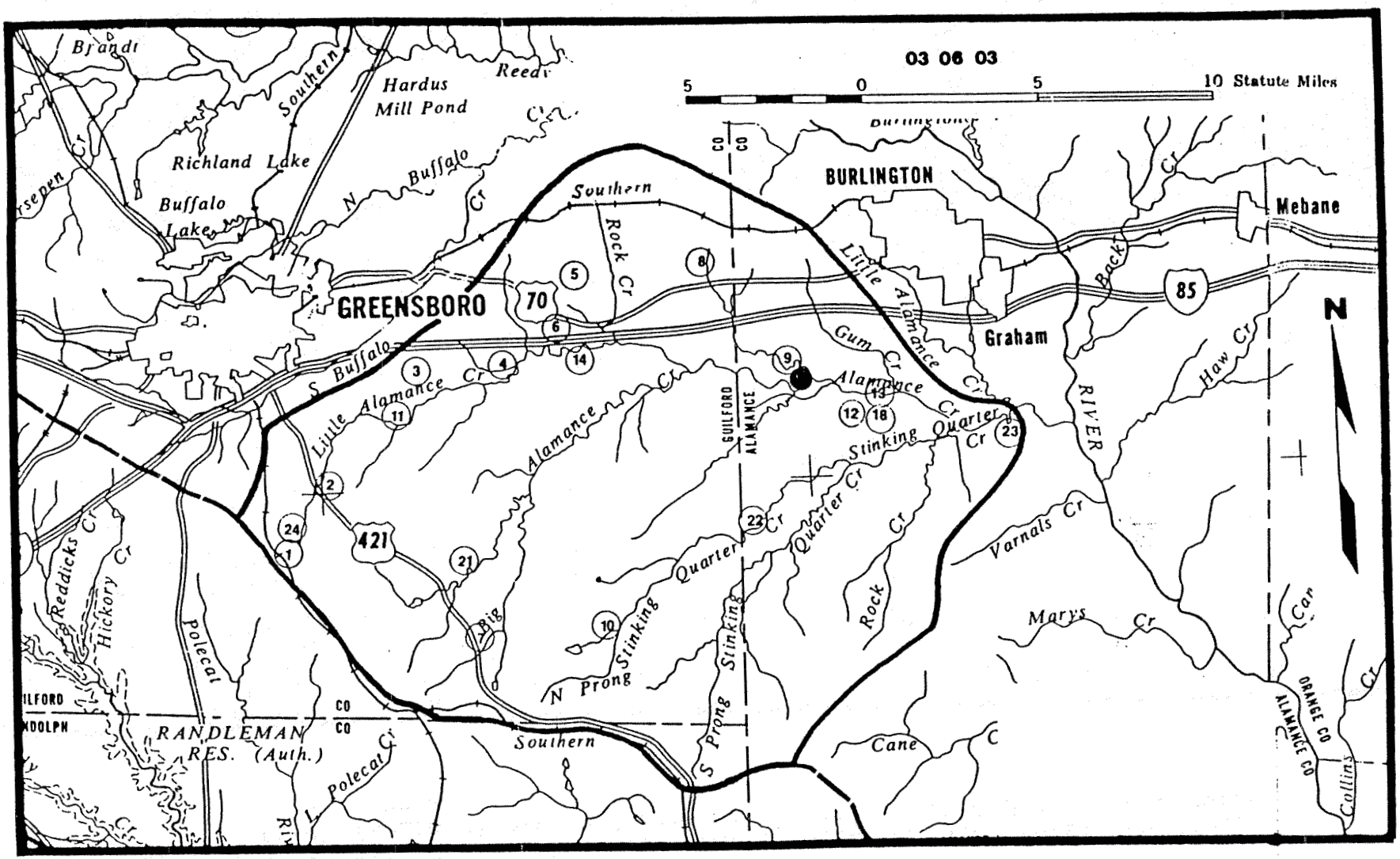
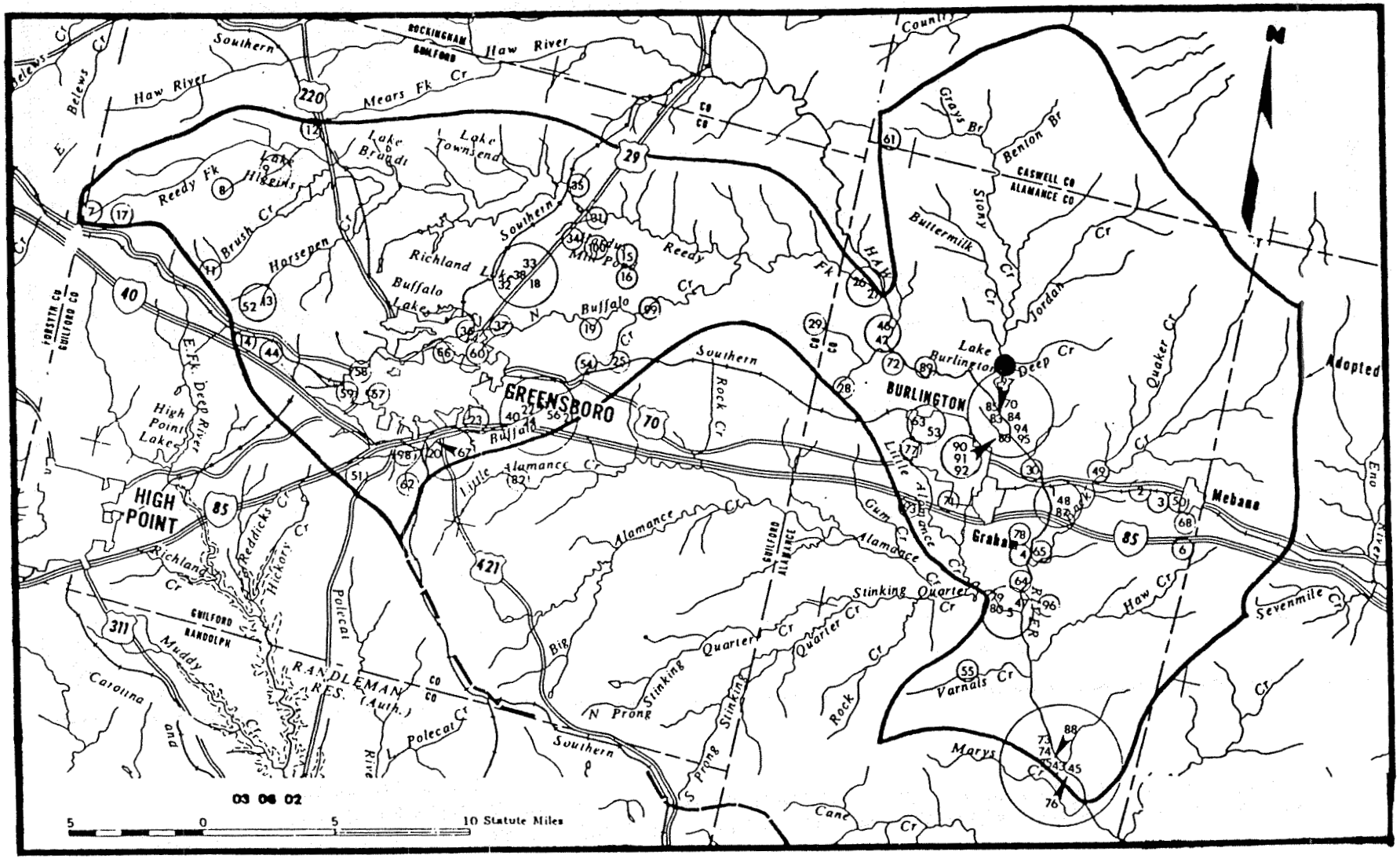


Figure 10b. Sub-basin 03 06 02 That Includes Burlington Water Supply on Stony Creek (solid circle) and Shows Location of NPDES Discharge Permits (open circles).



Potential Chemical Contaminants Discharged by Industries

A summary of information available from the NC DEM for all industrial dischargers upstream of each water supply is presented in Table 2. This includes the NC NPDES permit number, the Standard Industrial Characterization (SIC) code (where available), classification as major or minor discharger, the type of products produced, the contaminants listed in the NPDES permit; and the receiving stream. No dischargers of industrial wastewaters were found upstream of the water supplies for OWASA, Burlington and the Salem Lake supply of Winston-Salem. All but one of the industrial dischargers above the other water supplies is ranked as "minor" by the NC DEM.

The contaminants shown in Table 2 are those organic and inorganic chemicals on the Priority Pollutant list of the NPDES permit system that are also on either the SDWA list of 83 contaminants scheduled for regulation or the DWPL of contaminants that may be considered for regulation in the future. The IOCs listed are chromium, copper, nickel, silver and zinc. The most commonly listed SOCs are phenols, including trichloro- and pentachlorophenol. Oils and grease have also been included because these may, in fact, contain organic contaminants of concern even though no specific chemical composition information is given in the NPDES permit. Review of NPDES permits is of very limited value for qualitative and quantitative estimates of chemical contaminants being discharged. It would be very difficult without further information to estimate the in-stream waste concentrations of the specific chemicals listed in the permits.

To summarize the results of Table 2, the water supplies for OWASA and Burlington have no dischargers of industrial wastewater upstream; those for Durham and High Point have only two and one, respectively. However, High Point has a number of oil storage depots on the East Fork of the Deep River. In the event of a catastrophic accident, these could be significant sources of a wide range of petroleum chemicals, some of which are likely to be regulated by the SDWA. Winston-Salem (Yadkin supply) and Raleigh have seven (excluding industries discharging only domestic wastes, truck washing and service stations with NPDES permits) and six sources of direct industrial discharge, respectively. Those upstream of Raleigh's water supply have all been categorized as "minor", i.e., defined by North Carolina and EPA as an industrial discharger receiving less than 80 points under the NPDES Industrial Permit Rating System (Turner, DiGiano and DeRosa 1984).

Table 2 does not include POTWs upstream of the water intakes of Winston-Salem and Raleigh. Some of these are subject to pretreatment regulations for indirect industrial dischargers.

Review of Monitoring Data for Water Supplies

Unregulated Contaminants. The water supply monitoring data for the unregulated contaminants (prior to regulations for the eight VOCs) were reviewed for the fourth quarter of 1987

Table 2. Summary of NCDEM Information on Industrial Waste Dischargers Upstream of Each Water Supply

Dischargers Upstream of Winston-Salem Water Supply (Yadkin River)

Source Map	Map ID No.	Name NPDES Permit No. Minor or Major Classification	SIC Code No.	Products	Contaminants NPDES Permit and Potentially Discharged*	Receiving Stream
03-07-01	1	Abitibs NC 0005266 Minor	2499	wood products	phenols, Ni, Cr, Zn pentachlorophenol* phenol*, Cu* As*	Yadkin
	9	Sealed Air Corp Patterson Plant NC 0006254 Minor	2649 2679 (1987)	Pulp & paper Converted paper products	Trichlorophenol, Pentachlorophenol Chloroform*	Yadkin
	12	Nitso, Inc. NC 0035947 Minor	2369	Children's outerwear	Domestic waste only	Yadkin
	14	Carolina Mirror Co. of Eastern Band of Cherokees of N.C. NC 0006696 Minor	3231	Mirrors Glass products, made of purchased glass	Cu** Ag**	UT to Mulberry to Yadkin
	15	Gardner Mirror NC 0005096 Minor	8231 3231	Mirrors	Cu** Ag**	UT to Mulberry to Yadkin
	30	Lowe's Companies, Inc. NC 0057461 Minor		Truck wash		Yadkin
03-07-02	1	Gravely Tractor NC 0021776 Minor		Metal finishing	Cu, Zn, Pb* oil/grease	Johnson Creek to Yadkin
	24	Wayne Poultry NC 0006548 Minor		Meat processing and rendering		Chapman Creek to Yadkin
	27	Brantle's 89 Truck Stop Smith & Richard Truck Stop NC 0044211 Minor	5541	Service station	Oil/grease	Little Fisher River to Yadkin

* Priority pollutants potentially discharged from stated industrial category as compiled by EPA (DEM, 1982)
** Print out self-monitoring data
UT = Unnamed tributary

Table 2. Continued

Dischargers Upstream of Durham Water Supply

Source Map	Map ID No.	Name NPDES Permit No. Minor or Major Classification	SIC Code No.	Products	Contaminants NPDES Permit and Potentially Discharged*	Receiving Stream
	53	Chatham Manufacturing NC 0005312 Major		WWTP, Textile, fabric coating	Phenol, Cr Oil/grease	Yadkin
	100	John S. Clark Company NC 0064726 Minor		Domestic waste	Oil/grease	UT to Yadkin
03-04-01	50	Aluminum Coil NC 000336 Minor	3341	Smelting Refining Non-ferrous	Cr, Zn, Oig & Grease	UT to N. Flat River
	78	Eaton Corp NC 0003379 Minor	9999		Cooling water blowdown Cr, Cu, Zn Oil/grease	UT to N. Flat River

* Priority pollutants potentially discharged from stated industrial category as compiled by EPA (DEM, 1982)

** Print out self-monitoring data

UT = Unnamed tributary

Table 2. Continued

Dischargers Upstream of Raleigh Water Supply

Source Map	Map ID No.	Name NPDES Permit No. Minor or Major Classification	SIC Code No.	Products	Contaminants NPDES Permit and Potentially Discharged*	Receiving Stream
03-04-01	9	Unity Oil Company NC 0026981 Minor	5171	Petroleum bulk Station and terminals	Phenols Oil/grease	UT Little Lick Creek
	10	Garrard Sausage NC 0002437 Minor	9999		Oil/grease	
	14	Liggett & Myers Tobacco NC 0003248 Minor	2141	Tobacco stemming and redrying	Cr**, Zn**	UT Ellerbee Creek
	18	Athol Manufacturing Co. NC 0036846 Minor	2295	Coated fabrics not rubberized	Effluent Toxicity** Zn**	UT Picture Creek
	50	Aluminum Coil NC 0003336 Minor	3341	Aluminum Manufacturing 2° Smelting and refining Non-ferrous	Cr Zn Oil/grease	UT North Flat River
	87	John Umstead Hospital NC 0026824 Major	4952	Sewerage system	Effluent Toxicity**	
	78	Eaton Corp. NC 0003379 Minor	9999		Cr, Cu, Zn Oil/grease	UT North Flat River

* Priority pollutants potentially discharged from stated industrial category as compiled by EPA (DEM, 1982)

** Print out self-monitoring data

UT = Unnamed tributary

Table 2. Continued

Dischargers Upstream of High Point Water Supply

Source Map	Map ID No.	Name NPDES Permit No. Minor or Major Classification	SIC Code No.	Products	Contaminants NPDES Permit and Potentially Discharged*	Receiving Stream
03-06-08	16	Richardson-Vicks Manufacturing NC 0027928 Minor		Toiletry products	Cooling tower and boiler blowdown	UT South Buffalo (Guilford)
	19	Union Oil NC 0026247 Minor	5171	Oil terminal storage	Phenols, Oil/grease	UT East Fork Deep River (Guilford)
	22	Colonial Pipeline NC 0031046 Minor	4613 5171	Oil terminal storage	Phenols, Oil/grease	UT East Fork Deep River (Guilford)
	24	Exxon NC 0000795 Minor	5171	Oil terminal storage	Phenols, Oil/grease	UT East Fork Deep River (Guilford)
	28	Phillips Pipeline NC 0032883 - 001 002 003 Minor	5171	Oil terminal storage	Phenols, Oil/grease	UT East Fork Deep River Ditches to pond to UT to Horspen Creek
	36	Texaco Refining and Marketing NC 0022209 Minor	5171	Oil terminal storage	Phenols, Oil/grease	UT to Long Branch (Guilford)
	43	Plantation Pipeline NC 0051161 Minor	4613	Oil terminal storage	Phenols, Oil/grease	UT East Fork Deep River (Guilford)

* Priority pollutants potentially discharged from stated industrial category as compiled by EPA (DEM, 1982)

** Print out self-monitoring data

UT = Unnamed tributary

and first quarter of 1988. The list of measured VOCs and SOCs is given in Table 3. Only one instance in which an unregulated contaminant has appeared above the limit of detectability (0.5 ppb) was noted. This was 0.8 ppb of chlorobenzene measured at the Durham WTP. The source was tracked by Durham Water Treatment personnel to a chlorination reaction with the liquid polymer used as a filter aid and sludge conditioner. This polymer has been replaced.

Regulated Pesticides. The six regulated pesticides are: Endrin, Lindane, Methoxylchlor (Marlate) Toxaphene, 2,4 D and 2,4,5 TP (Silvex). Listed below are the sampling dates at each water supply that were provided by the NC DHS during which these pesticides were analyzed:

Water Supply	Sampling Dates
OWASA	3/15/83; 2/21/84; 8/28/84; 4/1/85; 9/4/85; 5/20/86; 9/12/86; 6/12/87; 11/3/87
Winston-Salem	5/16/79; 8/18/82; 5/24/85
Raleigh	1/19/81; 5/25/83; 5/28/86; 5/18/87; 7/17/87
Durham	3/5/80; 10/22/80; 5/4/82; 11/1/82; 9/7/83 10/25/84; 6/18/85; 8/22/86
High Point	10/15/79; 3/8/82; 3/26/84; 3/10/87
Burlington	10/16/79; 12/14/83; 12/29/86

None of these analyses revealed pesticides in excess of the MCL's. However, not all sampling was done during a time of the year when pesticides are being applied and the data need to be further checked to determine if runoff events were likely.

TTHMs. The TTHM data for each consortium city were reviewed recently by Haws (1988). Two years of quarterly reporting were averaged to provide the results shown in Table 4.

Differences in average values of TTHM could be due to many factors among these being: time for chlorine to react in the distribution system; concentration of chlorine used; and concentration of natural organic matter. While all six water supplies are now in reasonable compliance with the current MCL of 100 ppb, there is concern about a future lowering of this MCL. Some believe it will be as low as 50 ppb. If this were to be true, the available TTHM data suggest that all the consortium cities will be out of compliance most of the year.

Table 3. List of VOCs and SOCs Monitored for Each Water Supply

Chemical Name

Volatile Organics
- Trichloroethylene
- Carbon tetrachloride
- Vinyl chloride
- 1,2-Dichloroethane
- Benzene
- para-Dichlorobenzene
- 1,1-Dichloroethylene
- 1,1,1-Trichloroethane

Synthetic Organics
- Bromobenzene
- Bromodichloromethane
- Bromoform
- Bromomethane
- Chlorobenzene
- Chlorodibromomethane
- Chloroethane
- Chloroform
- Chloromethane
- o-Chlorotoluene
- p-Chlorotoluene
- Dibromomethane
- m-Dichlorobenzene
- o-Dichlorobenzene
- trans-1,2-Dichloroethylene
- cis-1,2-Dichloroethylene
- Dichloromethane
- 1,1-Dichloroethane
- 1,1,-Dichloropropene
- 1,3-Dichloropropene
- 1,2-Dichloropropane
- 1,3-Dichloropropane
- 2,2-Dichloropropane
- Ethylbenzene
- Styrene
- 1,1,2-Trichloroethane
- 1,1,1,2-Tetrachloroethane
- 1,1,2,2-Tetrachloroethane
- Tetrachloroethylene
- 1,2,3-Trichloropropane
- Toluene
- p-Xylene
- o-Xylene
- m-Xylene

For Vulnerable Systems
- Ethylene dibromide (EDB)
- 1,2-Dibromo-3-Chloropropane (DBCP)
- Total THMs
- PCBs

Table 4. Two-Year Average of Finished Water TTHMs at the Six WRRI Consortium Cities (Haws 1988)

Water Supply	TTHM (ppb)
OWASA	77
Winston-Salem	67
Raleigh	94
Durham	78
High Point	70
Burlington	62

Acquired Data for VOCs and SOCs in Finished Waters

The VOCs, IOCs and SOCs to be regulated by the 1986 SDWA amendments (including those substitutions made in 1988) are listed in Table 5 (US EPA 1988). The specific chemicals analyzed by Oxford Laboratories, Inc. of Wilmington, North Carolina, for this study are shown in column two. The appearance of these contaminants on the EPA Priority Pollutant List (used in issuing NPDES permits) has been noted in column three. While the majority of contaminants appear on both lists, there are also important exceptions, many of these being insecticides (I), nematicides (N), fumigants (F) or herbicides (H). Those SDWA contaminants currently reported by the NC DHS as either monitored but unregulated (MU) or monitored and regulated (MR) in finished water supplies are shown in column three. This shows that most organic contaminants on the SDWA are already included in monitoring. The last column indicates those chemicals reported to DEM by NPDES permittees discharging above the six water supplies of concern.

Oxford Laboratories, Inc. is certified by the state of North Carolina and uses EPA methods of analysis. These include EPA Method 501.2 (liquid/liquid extraction with GC/ECD) for THMs; EPA Method 502.1 (purge and trap/GC modified to allow detection by photoionization and Hall electrolytic conductivity detection) for regulated VOCs and some additional required by NC as of January 1, 1988; EPA Method 504 (liquid/liquid extraction with GC/ECD) for ethylene dibromide and dibromopropane; EPA Method 503.1 for additional VOCs monitored at the discretion of NC; EPA Method 610 (solvent extraction followed by HPLC/UV and fluorescence) for PAHs.

All but the following six of the organic contaminants listed by SDWA were included for analysis: pthalates, diquat, endothall, dioxin, acrylamide and adipates. These exceptions were chemicals that would have either required analysis by procedures not currently available or by procedures that were deemed too costly for the study.

Table 5. Sources of Data for Contaminants Listed in the Safe Drinking Water Act (1986) and EPA 1988 Substitutions (U.S. EPA 1988)

	Analyzed by Oxford Lab	Listed by EPA As Priority Pollutants	Reported by NC DHS	Reported in NPDES Permits
SDWA CONTAMINANTS				
Volatile Organic Chemicals				
1,4-Dichlorobenzene, (para-)	Yes	Yes	MR	
1,2-Dichloroethane	Yes	Yes	MR	
1,1,1-Trichloroethane	Yes	Yes		
1,1-Dichloroethylene	Yes	Yes	MR	
cis-1,2-Dichloroethylene	Yes		MU	
trans-1,2-Dichloroethylene	Yes		MU	
Benzene	Yes	Yes	MR	
Carbon Tetrachloride	Yes	Yes	MR	
Chlorobenzene	Yes	Yes	MU	
Ethylbenzene*	Yes	Yes	MU	
Methylene chloride	Yes	Yes		
Trichlorobenzene	Yes	Yes		
Trichloroethylene	Yes	Yes	MR	
Tetrachloroethylene	Yes	Yes	MU	
Vinyl Chloride	Yes	Yes	MR	
Inorganics				
Antimony		Yes		
Arsenic		Yes		
Asbestos		Yes		
Barium				
Beryllim		Yes		
Cadmium		Yes		
Chromium		Yes		Yes
Copper		Yes		Yes
Cyanide		Yes		
Flouride				
Lead		Yes		
Mercury		Yes		
Nickel		Yes		
Nitrate				
Nitrite*				
Selenium		Yes		
Sulfate				
Thallium		Yes		
Synthetic Organic Chemicals				
Endrin (I)	Yes	Yes	MR	
Lindane (I)	Yes	Yes	MR	
Methoxychlor (Marlate) (I)	Yes		MR	
Toxaphene (I)	Yes	Yes	MR	
2,4-D (H)	Yes		MR	

Table 5. Continued

	Analyzed by Oxford Lab	Listed by EPA As Priority Pollutants	Reported by NC DHS	Reported in NPDES Permits
2,4,5-TP (Silvex) (H)	Yes		MR	
Alachlor (Lasso) (H)	Yes			
Aldicarb (Temik) (N,I)	Yes			
Aldicarb sulfone	Yes			
Alidcarb sulfoxide	Yes			
Atrazine (H)	Yes			
Carbofuran (Furadan) (N,I)	Yes			
Chlordane (I)	Yes	Yes		
Dalapon (H)	Yes			
Dibromochloropropane (DBCP) (F)	Yes		MU	
Dinoseb (Premerge) (H)	Yes			
Diquat (H)				
Endothall (H)				
Ethylene dibromide (EDB) (I,F)	Yes		MU	
Glyphosate (Roundup) (H)				
Heptachlor (I) *	Yes	Yes		
Heptachlor epoxide *	Yes	Yes		
Pentachlorophenol (PCP) (H)	Yes	Yes		Yes
Pichloram (Tordon) (H)	Yes			
Simazine (Princep) (H)	Yes			
Vydate (Uxamyl) (I)	Yes			
1,2-Dichlorobenzene	Yes	Yes		
1,2-Dichloropropane	Yes	Yes	MU	
1,1,2-Trichloroethane	Yes	Yes	MU	
2,3,7,8-TCOD (Dioxin)				
Acrylamide				
Adipates				
Epichlorohydrin	Yes			
Hexachlorocyclopentadiene	Yes	Yes		
PAHs	Yes			
PCBs	Yes	Yes		
Styrene*	Yes		MU	
Toluene	Yes	Yes	MU	
Xylene	Yes		MU	
TTHMS	Yes		MU	

* = Substituted into the original SDWA list by the EPA, January 1988
MR = Monitored and regulated by NC DHS
MU = Monitored and unregulated by NC DHS
F = Fumigant, H = Herbicide, I = Insecticide, N = Nematicide

Samples of finished water to be analyzed for VOCs and some of the SOCs (exclusive of the pesticides, herbicides, PAHs, PCBs and chlorinated hydrocarbons) were taken on July 18, 1988, at the Winston-Salem and High Point facilities and on July 27, 1988, in Durham, and July 28, 1988, in Raleigh. Those collected on July 18, 1988 were received by Oxford Laboratories on July 20; those collected on July 27 and 28 were received on August 5. A later sampling was made for the remaining SOCs. All the analyses were completed by September 13, 1988. Because the OWASA and Burlington water supplies did not receive wastewater discharges (either industrial or domestic), it was decided to analyze only for the pesticides and herbicides. Unfortunately, this plan excluded TTHM analyses at these two facilities.

The Drinking Water Priority List (January 1988) is given in Table 6 (US EPA 1988) and cross-referenced with the Priority Pollutant List (for NPDES permits) and DHS monitoring in the same format issued in Table 5. The organic contaminants analyzed by Oxford Laboratories, Inc. for this research are also shown. Many of the contaminants on the DWPL are disinfectants or disinfectant by-products.

The results from Oxford Laboratories, Inc. indicated that all organic contaminants listed in Table 5, except for the THMs were below the detection limits. The results for THMs at the four water supplies sampled are presented in Table 7. These show that TTHMs approached or exceeded the current limit of 100 ppb, as may be expected for samples taken during the middle of the summer.

For all six of the water supplies sampled, Oxford Laboratories found the contaminants listed in Table 6 for which analyses were conducted to be below the detection limits, with the exception of chloropicrin and the individual THMs listed separately in Table 7. Chloropicrin was found in the finished waters of the Durham (0.61 ppb) and Raleigh (0.91 ppb) facilities and is most likely a by-product of chlorination. These two samples were not dechlorinated at the time of collection as was done for samples taken at High Point and Winston-Salem; chloropicrin was not detected at these latter two facilities. This suggests formation after long periods of contact with chlorine. Also, TTHMs may be somewhat higher than usual for the same reason.

G. lamblia, C. parvum and Indicator Bacteria

Raw Waters. G. lamblia cysts and/or C. parvum oocysts were detected in raw water samples from 3 WTPs: OWASA, Durham and Winston-Salem (Table 8). No cysts or oocysts were detected in raw water samples from Raleigh, Burlington or High Point. Turbidity ranged from 1.0 to 45 NTU (nephelometric turbidity unit) with one value of questionable validity from Raleigh on 7/28/88. This sample gave the most turbid pellet after purification processing for cysts and oocysts, yet it had a turbidity reading of only 1.0 NTU.

Table 6. Sources of Data for Contaminants Listed on the EPA Drinking Water Priority List, January 1988 (US EPA, 1988)

DWPL CONTAMINANTS	Analyzed by Oxford Lab	Listed by EPA As Priority Pollutants	Reported by NC DHS	Reported in NPDES Permits
1,1,1,2-Tetrachloroethane	Yes		MU	
1,1,2,2-Tetrachloroethane	Yes	Yes	MU	
1,1-Dichloroethane	Yes	Yes	MU	
1,1-Dichloropropene	Yes		MU	
1,2,3-Trichloropropane	Yes		MU	
1,3-Dichloropropane	Yes		MU	
1,3-Dichloropropene	Yes		MU	
2,2-Dichloropropene	Yes		MU	
2,4,5-T (H)	Yes			
2,4-Dinitrotoluene	Yes	Yes		
Aluminum *				
Ammonia				
Boron				
Bromobenzene	Yes		MU	
Bromochloroacetonitrile				
Bromodichloromethane	Yes	Yes	MU	
Bromoform	Yes	Yes	MU	
Bromomethane	Yes	Yes	MU	
Chloramines				
Chlorate				
Chlorine				
Chlorine dioxide				
Chlorite				
Chloroethane	Yes	Yes	MU	
Chloroform	Yes	Yes	MU	
Chloromethane	Yes	Yes	MU	
Chloropicrin (F)	Yes			
Cryptosporidium				
Cyanazine (H) (Bladex)				
Cyanogen chloride				
Dibromoacetonitrile				
Dibromochloromethane		Yes	MU	
Dibromomethane *	Yes		MU	
Dicamba (H) (Dicamba)	Yes			
Dichloroacetonitrile				
ETU (ethylene thiourea)				
Hypochlorite ion				
Isophorone	Yes	Yes		
Methyl tert-butyl ether	Yes			
Metolachlor (H) (Dual)				
Metribuzin (H) (Sencor, Lexone)				
Molybdenum *				
Ozone byproducts				
Silver *		Yes		Yes

Table 6. Continued

	Analyzed by Oxford Lab	Listed by EPA As Priority Pollutants	Reported by NC DHS	Reported in NPDES Permits
Sodium *				
Strontium				
Trichloroacetonitrile				
Trifuralin (H) (Trefland)				
Vanadium *				
Zinc *		Yes		Yes
o-chlorotoluene	Yes		MU	
p-chlorotoluene	Yes		MU	
Halogenated acids, alcohols aldehydes, ketones and other nitriles:	Yes			

* = Chemicals removed from the SDWA 1988
F = Fumigant
H = Herbicide
MU = Monitored unregulated by NC DHS
(name) = Commercial name

Table 7. THMs (in ppb) Measured at the Six Urban Water Consortium Cities

	Winston-Salem	Raleigh*	Durham*	High Point
chloroform	76	68	60	95
Bromoform	9	14	10	17
chlorodibromomethane	1	2	1	2
bromoform	<0.5	<0.5	<0.5	<0.5
TTHMs	86	84	71	114
Date of Analysis	7/18/88	7/28/88	7/27/88	7/18/88
Time before Analysis (d)	3	8	9	3

* Samples were not dechlorinated; time between sampling and analysis (last row) allowed for further reaction of residual chlorine in sample to produce THMs.

All WTPs had raw water fecal coliform and enterococci concentrations of >1/100 ml in at least one sample. One sample each from Raleigh (3/18) and OWASA (3/23) had fecal coliforms and enterococci concentrations of <1/100 ml (Table 8). Fecal coliforms ranged from 0.25-97/100 ml, and enterococci ranged from 0-79/100 ml. One sample (OWASA 1/11/88) gave bacterial colony counts that were too-numerous-to-count (TNTC) in the undiluted sample and much too low in the 1:10 dilution. Using a technique derived by Haas and Heller (1987), approximate values for fecal coliforms and enterococci concentrations were determined (Table 8).

Because recovery efficiencies for both protozoans were less than 100%, adjustments in measured concentrations were made to correctly interpret their concentrations in raw water samples (Table 9). Concentrations determined by counting cysts and oocysts were divided by the appropriate mean recovery efficiency to correct for expected losses during processing. Corrected Giardia concentrations ranged from 0-1.36 cysts/L (0-5.2 cysts/gal) and corrected Cryptosporidium concentrations ranged from 0-0.70 oocysts/L (0-2.6 oocysts/gal). This compares to results of previous studies giving 0-15 cysts/L (Monzingo et al. 1986; Ongerth et al. 1988; Rose et al. 1988; Sykora et al. 1987) and 0-240 oocysts/L (Ongerth and Stibbs 1987; Rose 1988; Rose et al. 1988).

Raw water samples in which no cysts or oocysts were detected should not be considered free of protozoans. A more accurate interpretation of the results would be that about 46% and 38% of the time, cysts and oocysts, respectively, would be found if present. Limits of detection were calculated for each sample in which no protozoans were detected (Table 9); these range from <0.03 - <1.76 cysts or oocysts/L in raw water samples.

Table 8. Concentrations of Protozoans, Bacteria and Turbidity in Raw Waters

		Analyte and Concentration*				
Sample	Date	G.l. Cysts/ L	C.p. Oocysts/ L	FC CFU/ 100 ml	E CFU/ 100 ml	NTU
OWASA	1/11/88	0.63 (0.90)	ND	97 (NA)	79 (NA)	16.7
High Point	1/15/88	ND	ND	12.8 (19.4)	22.2 (5.0)	18
Durham	2/15/88	ND	(0.03) (0.09)	17.8 (14.1)	6.8 (1.9)	45
Burlington	2/19/88	ND	ND	2.5 (3.8)	1.2 (3.8)	33
Winston Salem	3/04/88	0.09 (0.15)	ND	37.5 (25.2)	3.0 (2.3)	6.0
Raleigh	3/18/88	ND	ND	0.25 (1.0)	ND	5.0
OWASA	3/23/88	0.26 (0.92)	0.26 (0.92)	1.0 (1.6)	0.25 (1.0)	4.4
Durham	7/05/88	0.04 (0.14)	0.05 (0.14)	4.0 (4.3)	1.5 (3.5)	2.5
Winston Salem	7/18/88	0.02 (0.08)	0.02 (0.08)	40.8 (13.1)	48.5 (4.2)	27
High Point	7/18/88	ND	ND	7.8 (4.7)	8.2 (4.4)	9.0
Raleigh	7/28/88	ND	ND	23.3 (15.7)	5.0 (2.8)	1**
Burlington	7/28/88	ND	ND	9.0 (8.7)	0.75 (1.9)	18

* = Mean concentration above, (X) = 2 std. dev.

** = Probably instrumental error

ND = Not detected

NA = Not applicable; single count

Table 9. Corrected Concentrations and Limits of Detection of Protozoans in Raw Water Samples

		Analyte and Concentration	
Sample	Date	G.l. cysts/L	C.p. oocysts/L
OWASA	1/11/88	1.36	<0.17
High Point	1/15/88	<0.28	<0.35
Durham	2/25/88	<0.03	0.07
Burlington	2/19/88	<0.30	<0.37
Winston-Salem	3/04/88	0.19	<0.12
Raleigh	3/18/88	<0.57	<0.70
OWASA	3/23/88	0.57	0.70
Durham	7/05/88	0.10	0.17
Winston-Salem	7/18/88	0.05	0.06
High Point	7/18/88	<0.57	<0.70
Raleigh	7/28/88	<1.42	<1.76
Burlington	7/28/88	<0.57	<0.70

The portion of each total sample analyzed depended on the final pellet turbidity and available time for analyses. Studies in Arizona examined at least 10% of the total sample volumes (Musial et al. 1987). In Washington entire 20L samples were examined for cysts and oocysts (Ongerth and Stibbs 1987; Ongerth et al. 1988). In general, "(s)ample size and frequency have been based on practical and economic considerations" (Craun and Jakubowski 1987). In this case the practical consideration was the amount of time it took to scan each IFA-labelled 13 mm membrane filter. Average time per filter was 1 - 1.5 hrs. Thus, each set of 3 filters took 3 - 4.5 hrs. With very turbid samples, examining 10 percent of the total could take a week or more.

Statistical Analyses. Cursory examination of the data for associations among G. lamblia and/or C. parvum, fecal coliforms or enterococci, and turbidity revealed no apparent relationships (Figures 11 and 12). Therefore, various parametric and non-parametric statistical methods were used to examine associations of the parameters in question and to determine if the percent of total sample analyzed had any effect on the ability to detect protozoan cysts or oocysts.

The types of statistical analyses performed were Pearson correlation, Jacknife analysis, Spearman correlation and tau- beta correlation (Sokal and Rholf 1981; Wu 1986; Bhattacharyya and Johnson 1977). With one exception, none of the methods of analysis showed significant positive associations between concentrations of either protozoan and either bacterial indicator or turbidity. The one exception was a significant correlation of G. lamblia cysts with both bacterial indicators by Pearson correlation analysis. However, this finding was considered invalid because of the presence of an outlier value, the small sample size and the failure of the data to meet the requirement of being normally distributed. Hence, there was no significant

Figure 11. Scatter plot of G lamblia Cyst Concentration versus Fecal Coliform and Enterococci Concentrations in Samples of Raw Waters.

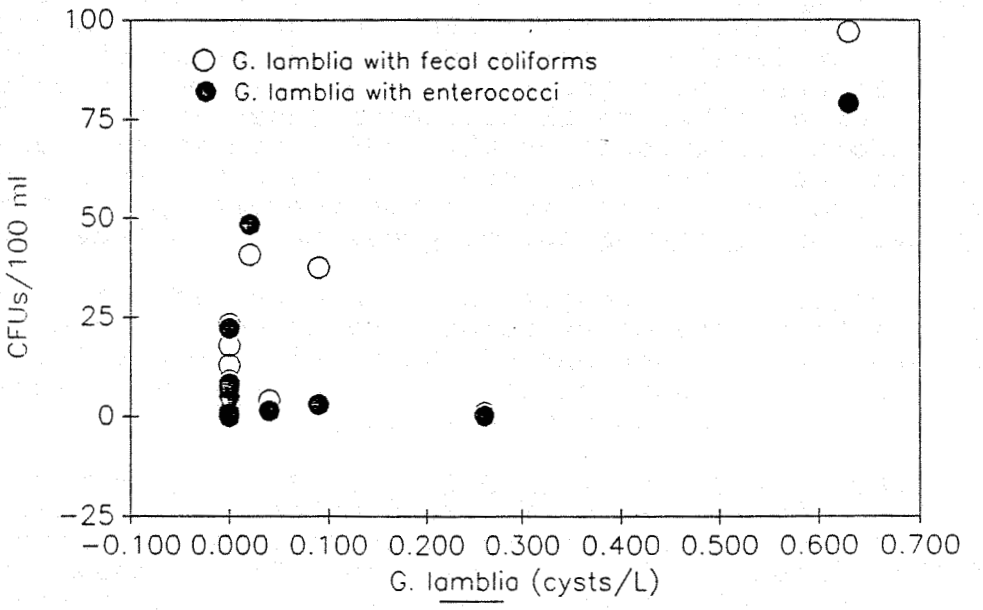
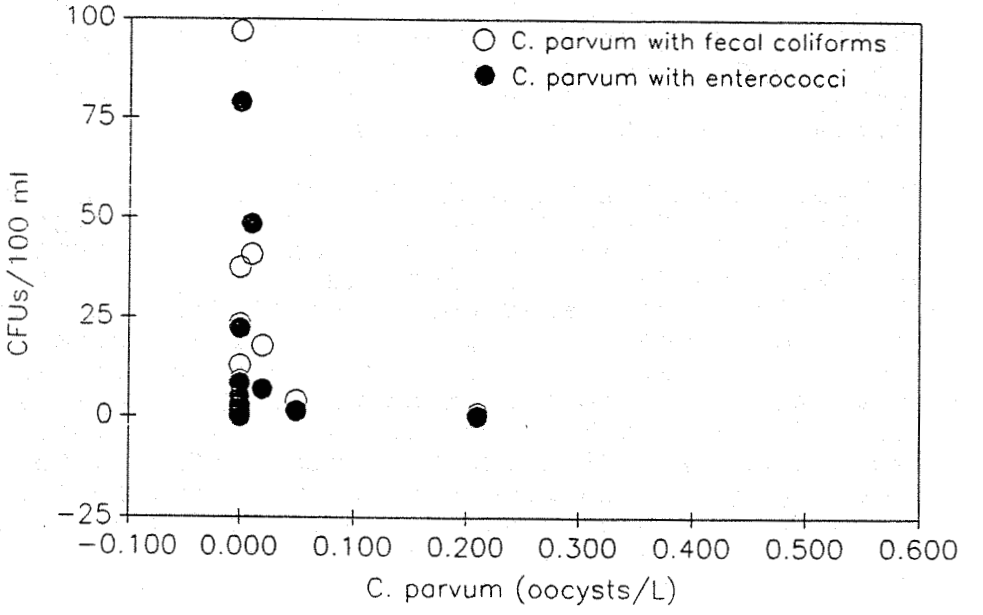


Figure 12. Scatter Plot of C parvum Oocyst Concentration versus Fecal Coliform and Enterococci Concentrations in Raw Water.



association of cysts or oocysts with either bacterial indicator or with turbidity.

Other studies have examined associations of fecal bacterial indicators with G. lamblia cysts and C. parvum oocysts in surface water samples. Associations of cysts with either total coliforms (Akin and Jakubowski 1986; Craun and Jakubowski 1987; NPDWR 1989) or fecal coliforms (Craun and Jakubowski 1987; Rose et al. 1988) were not significant. In addition, associations of oocysts with either total coliforms (Rose et al. 1988) or fecal coliforms (D'Antonio et al. 1985; Rose et al. 1988) were not significant. Thus, this study agrees with other studies that fecal indicator bacteria are not adequate predictors of G. lamblia cyst or C. parvum oocyst presence in surface waters.

To test whether or not sample volume had any effect on cyst or oocyst detection, the correlations and associations of cysts and oocysts with the percent of the total sample volume counted (%) were examined. None of the these tests showed significant correlations or associations ($p > 0.05$).

Finished Water. No G. lamblia cysts or C. parvum oocysts were detected in any of the finished water samples (Table 10). Limits of detection of cysts and oocysts were calculated for all of the finished water samples (Table 11). These ranged from <0.005 - <0.034 cysts or oocysts/L. Because these calculations were based on the recovery efficiencies of cysts and oocysts from the raw water in the seeded sample methods section, the actual limits of detection are probably lower.

No fecal coliforms or enterococci were detected in any of the finished water samples (Table 10). In addition, water treatment plant operators reported no total coliforms in the same water samples on the same days. Therefore, it is not surprising that when there were no total coliforms, there were no fecal coliforms and no enterococci either.

This study shows that "conventional" treatment (NPDWR 1987), consisting of coagulation/flocculation, filtration and chlorine disinfection, appears to be adequate to remove/inactivate G. lamblia cysts, C. parvum oocysts, fecal coliforms and enterococci to below the limits of detection.

Other Potential Sources of Cysts and Oocysts in Source Waters. Wastewater treatment plants (WWTPs) discharge into the watersheds of the following three community water systems in this study: Winston-Salem, Raleigh and Burlington. All four WWTPs in the Raleigh watershed and 11 of 12 WWTPs in the Winston-Salem watershed discharge to the surface waters that were sampled in this study. The only WWTP discharge in the Burlington watershed is to a surface water that impacts the water supply of a second WTP not tested in this study. No strong association of WWTP discharge into surface waters with cyst or oocyst presence is suggested by the data in Table 12. That is, concentrations of cysts and oocysts found in wastewater discharge-impacted raw waters were not higher than the concentrations found in waters not receiving WWTP discharge.

Table 10. Concentrations of Protozoans, Bacteria and Turbidity in Finished Water Samples

Sample	Date	Analyte and Concentration* G.l. Cysts/ L	C.p. Oocysts/ L	FC CFU/ 100 ml	E CFU/ 100 ml	NTU
OWASA	1/11/88	ND	ND	ND	ND	0.31
High Point	1/15/88	ND	ND	ND	ND	0.20
Durham	2/15/88	ND	ND	ND	ND	0.05
Burlington	2/19/88	ND	ND	ND	ND	0.44
Winston Salem	3/04/88	ND	ND	ND	ND	0.20
Raleigh	3/18/88	ND	ND	ND	ND	0.07
OWASA	3/23/88	ND	ND	ND	ND	0.07
Durham	7/05/88	ND	ND	ND	ND	0.05
Winston Salem	7/18/88	ND	ND	ND	ND	0.43
High Point	7/18/88	ND	ND	ND	ND	0.23
Raleigh	7/28/88	ND	ND	ND	ND	0.17
Burlington	7/28/88	ND	ND	ND	ND	0.17

* = ND indicates none detected

Table 11. Limits of Detection of Protozoans in Finished Water Samples*

Samples	Date	Analyte and Concentration G.l. cysts/L	C.p. oocysts/L
OWASA	1/11/88	<0.005	<0.008
High Point	1/15/88	<0.005	<0.008
Durham	2/15/88	<0.005	<0.005
Burlington	2/19/88	<0.029	<0.034
Winston-Salem	3/04/88	<0.005	<0.008
Raleigh	3/18/88	<0.013	<0.018
OWASA	3/23/88	<0.005	<0.008
Durham	7/05/88	<0.005	<0.008
Winston-Salem	7/18/88	<0.005	<0.008
High Point	7/18/88	<0.005	<0.008
Raleigh	7/28/88	<0.005	<0.008
Burlington	7/28/88	<0.005	<0.008

* = These limits of detection are probably high as recovery efficiency assessments were performed on raw, more turbid waters.

Therefore, WWTP discharges did not necessarily have a detectable impact on cyst or oocyst concentrations at the time of sampling.

There is not enough data to determine what influence WWTP discharges had on the presence of cysts and/or oocysts in these waters. All that can be said at present is (1) WWTPs may not be discharging detectable quantities of cysts and/or oocysts into surface waters, (2) WWTPs may be discharging cysts and/or oocysts, but discharge may be only periodic or variable in concentration and discharge or high discharge events may have been missed by the limited sampling schedule, and (3) cysts and/or oocysts may be being discharged in detectable quantities, but they may be destroyed or inactivated over time and distance to the extent that they are not detectable.

Table 12. Concentrations of Protozoans and Bacteria in Raw Waters with Waste Water Treatment Plant Presence

		Analyte and Concentration				
Sample	Date	G.l. cysts/ L	C.p. oocysts/ L	FC CFU/ 100 ml	E CFU/ 100 ml	WWTP upstream (Y/N)
OWASA	1/11/88	0.63	0	97	79	N
HP	1/15/88	0	0	12.8	22.2	N
Dur	2/15/88	0	0.03	17.8	6.8	N
Burl	2/19/88	0	0	2.5	1.2	N*
W-S	3/04/88	0.09	0	37.5	3.0	Y
Ral	3/18/88	0	0	0.25	0	Y
OWASA	3/23/88	0.26	0.26	1.0	0.25	N
Dur	7/05/88	0.04	0.05	4.0	1.5	N
W-S	7/18/88	0.02	0.02	40.8	48.5	Y
HP	7/18/88	0	0	7.8	8.2	N
Ral	7/28/88	0	0	23.3	5.0	Y
Burl	7/28/88	0	0	9.0	0.75	N*

* = One WWTP does discharge into Burlington source waters, but not into the water tested

From the NC Department of Natural Resources and Community Development, Division of Environmental Management 1988

All of these watersheds have agricultural sources, including dairy farms, which may directly and/or indirectly contaminate surface waters. Also, all of these watersheds are inhabited by beaver, muskrat and many other mammals which may act as Giardia and Cryptosporidium reservoirs. No systematic studies have been done on either of these possible cyst or oocyst sources in these areas.

Use of Agricultural Chemicals on SDWA Lists

Agricultural chemicals that are already regulated (Table 5), scheduled for regulation (Table 5) or on the DWPL (Table 6) were investigated for one selected watershed --- that serving the Winston-Salem supply. While none of these contaminants was detected in the finished water, many are applied to crops and therefore, may be present in the raw water supply in one or more of the following forms: sorbed onto sediment, sorbed onto suspended particles (originating from soil erosion) or dissolved in the water. Thus, their absence in finished water samples that were taken during a long drought spell in summer of 1988 is not enough to eliminate them from concern.

Accurate data for application rates of agricultural chemicals are difficult to obtain. Moreover, even knowing the amounts applied does not allow prediction of the concentrations to be found in surface waters, owing to the complexity of the transport and fate processes. The approach taken in this research was to estimate the application rates of the chemicals of concern but not predict transport and fate. This is admittedly an incomplete picture but will at least provide others with a perspective on the extent to which agricultural chemicals of concern to drinking water quality are in use today.

The County Agricultural Extension Service in each of the three counties (Surry, Wilkes and Yadkin) was contacted to obtain estimates of the acreages of each crop grown. Then, the North Carolina Agricultural Chemicals Manual (1988) was consulted to determine the recommended application rates for each chemical listed by the SDWA. The acreage of each crop in each county is given in Table 13, and the chemical application rate calculated from data for each chemical of concern and for each crop using the recommended pounds per acre (NC Agricultural Chemicals Manual 1988) is given in Table 14. The application time is included to provide some indication of the season of the year when runoff events are most likely to bring these chemicals into the watershed.

With about 94,000 acres of various crops, it was estimated that at least 15 agricultural chemicals (insecticides, fumigants, nematocides and herbicides) on the SDWA lists may be in use. Taking all 15 chemicals together, the annual application rate exceeds two million pounds. The amount of these chemicals entering the water supply is open to debate. The mechanisms include stormwater runoff and associated soil erosion but not much is known about the associated transport and fate processes. Nevertheless, the molecular structure of agricultural chemicals suggests a very high affinity for soil particles, thereby making sediments rather than water the logical sink.

Table 13. Crops and Acreage in Each County in the Winston-Salem Watershed

County	Crops	Acreage
Surry		
	Corn	13,000
	Soybeans	6,000
	Tobacco	6,000
	Wheat	2,000
Wilkes		
	Apples	1,000
	Corn grain	4,700
	Corn silage	5,000
	Soybeans	2,000
	Tobacco	710
	Wheat	300
Yadkin		
	Corn	15,300
	Hay	6,500
	Soybean	12,000
	Tobacco	3,283
	Truck & berries	11,300
	Wheat & small grains	4,500

Table 14. Annual Pounds (or Gallons) of Nematicides (N), Herbicides (H), Insecticides (I) and Fumigants (F) Recommended for Use on Crops Grown in the Winston-Salem Watershed and Also Listed by the SDWA (See Table 5 and Table 6).

Agricultural Chemical	Crop Type	Pounds (Gallons)	Time Applied
Alachlor (H)			
	Corn	152,000	pre-plant
		152,000	pre-emergence
		95,000	early post-emergence
	Soybeans	80,000	pre-emergence
Aldicarb			
	Soybeans (N)	200,000	
	Tobacco (I)	200,000	
Atrazine (H)			
	Corn	76,000	pre-plant
		114,000	pre-emergence
		114,000	early post-emergence
Carbofuran (I)			
	Corn	114,000	at planting
	Forage crops	13,000	
	Soybeans	40,000	
	Tobacco	50,000	preventative
	Tobacco (N)	80,000	pre-plant
Chloropicrin + Dichloropro -pene (N)	Tobacco	(105,000)	pre-plant
Cyanazine (H)			
	Corn	76,000	pre-plant
		152,000	pre-emergence
2,4 D amine (H)			
	Corn	19,000	post-emergence post-harvest
	Forage crops	6,500	weeds 4"-8"
	Small grains	13,300	grain 4"-8"
		13,300*	grain 4"-8"
	Apples	1,000	
Dicamba (H)			
	Corn	18,240	post-emergence post-harvest
	Forage crops	52,000	prior to bloom
	Small grains dormancy	1,663	after winter

Table 14. Continued

Agricultural Chemical	Crop Type	Pounds (Gallons)	Time Applied
Dichloropropene (N)	Tobacco	(60,000)	pre-plant
Glyphosate (H)			
	Corn	152,000	pre-emergence
		114,000	post-harvest
	Forage crops	32,500	pre-plant
	Soybeans	20,000	pre-plant
		80,000	pre-emergence
	Apples	5,000	
Methyl bromide (F)	Tobacco	40,000	pre-plant
Metribuzin (H)			
	Forage crops	3,250	late fall
	Soybeans	10,000	pre-plant
		20,000	pre-emergence
		10,000	post-emergence
Methoxychlor (I)	Forage crops	6,500	
Metolachlor (H)			
	Corn	76,000	pre-plant
		114,000	pre-emergence
		95,000	early post-emergence
	Soybeans	60,000	pre-plant
		60,000	pre-emergence
Vydate (Oxamyl) (I)	Tobacco	40,000	preventative
		(30,000)	pre-plant
Simazine (H)			
	Corn	87,400	pre-emergence
	Apples	4,000	
Trifluralin (H)	Soybeans	40,000	pre-plant

* 2-4 D low volatile ester

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