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DETERMINATIONS AND COMPARISONS OF THE WATER  
QUALITY ABOVE AND BELOW THE WATAUGA  
COUNTY SANITARY LANDFILL

A Thesis  
by  
DANIEL J. S. ROWE

Submitted to the Graduate School  
Appalachian State University  
in partial fulfillment of the  
requirements for the degree of  
MASTER OF SCIENCE

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Major Department: Biology

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APPROVED BY:

Francis Montaldi  
Francis Montaldi  
Chairperson, Thesis Committee

Mary U. Connell  
Mary U. Connell  
Member, Thesis Committee

Edgar D. Greene, Jr.  
Edgar D. Greene, Jr.  
Member, Thesis Committee

J. Frank Randall  
J. Frank Randall  
Member, Thesis Committee

Jeffrey A. Butts  
Jeffrey A. Butts  
Chairperson, Department of Biology

Joyce V. Lawrence  
Joyce V. Lawrence  
Dean of Graduate Studies and Research

ABSTRACT

DETERMINATIONS AND COMPARISONS OF THE WATER  
QUALITY ABOVE AND BELOW THE WATAUGA COUNTY  
SANITARY LANDFILL. (DECEMBER 1989)

Daniel J. S. Rowe

B.S., Appalachian State University

M.S., Appalachian State University

Thesis Chairperson: Dr. F. Montaldi

The effects of the Watauga County Sanitary Landfill leachate on surface water quality at the lower end of the landfill were studied over a 10-month period. Results of the study indicate that the landfill is contributing excessively to the ammonia nitrogen and iron concentrations of the surface water below the landfill. The grand mean for ammonia nitrogen was 82 times greater below the landfill than the grand mean above the landfill. The grand mean for iron below the landfill was 126 times greater than the grand mean above the landfill.

Temperature and dissolved oxygen were inversely related with the exceptions of June, July, and August. The pH of the above and below sites was always close to neutral, with surface waters below the landfill generally having lower values than above the landfill. The alkalinity in surface water below the landfill ranged from seven to nine times

greater than above the landfill. Blue-green bacteria, which may be used as biological indicators for polluted water, were present at all times in surface water below the landfill. Conversely, this same water was free of diatoms, which frequently are used as biological indicators for unpolluted water.

#### ACKNOWLEDGEMENTS

I would like to extend thanks and deep appreciation to the chairperson of my advisory committee, Dr. Francis Montaldi, and naturally to all the other members of my advisory committee. I would also like to express sincere appreciation to Ellen H. Rowe and Phil Miller.

#### DEDICATION

This work is dedicated to my wife, Ellen H. Rowe, who has no equal in patience, encouragement, and love during the course of this study.

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## Introduction

The disposal of solid waste has been accomplished by a variety of methods. The casual dumping of trash on roadsides and in waterways has been common practice for many years and still continues. The open dumpsite was the dominant disposal system for municipal waste until the early to middle 1970's when the need for more sanitary conditions became apparent. Open burning, vermin, scavenging wildlife, and free running pets combined to create unsanitary as well as aesthetically displeasing situations. The sanitary landfill was the method of disposal devised to relieve these undesirable conditions.

Slimak (1978) defined the sanitary landfill as a disposal site that reduces hazards to the general public by compacting refuse to the smallest volume, confining it to the smallest area, and covering it with a layer of soil at the end of each working day. As in any type of waste disposal, there are some problems associated with sanitary landfills, such as; a scarcity of appropriate land for the ever-increasing volumes of wastes, the general public outcry against the unsightly and unsanitary conditions of solid wastes, and the great potential for leachate and its contamination of water supplies.

When water comes into contact with solid waste, leachate develops, which Dilaj and Lenard (1975) viewed as extraction

of waste materials, some of which bind to solid particles. The Hazardous Waste Dialogue Group (1983) pointed out that the major source for leachate water is precipitation. According to Mikuck et al., (1981), leachate may consist of a variety of constituents including organic and inorganic materials, heavy metals, and toxic chemicals.

The Governmental Refuse Collection and Disposal Association (1988) expressed a major concern that landfill leachate will contaminate our water systems. There have been steps made toward alleviating these public concerns. Estes (1986) pointed out that the state requires groundwater monitoring wells at all sanitary landfills. The legislation requiring periodic testing of these wells has been in effect for several years. Due to the character of sanitary landfill leachate, tests for iron, manganese, aluminum, chromium, zinc, lead, selenium, and copper are typically conducted. Iron is commonly found in leachate due to scrap metal deposition. Manganese may be found due to its use in the manufacturing of copper, aluminum and iron alloys. Although plentiful in the earth's crust, aluminum may also result from the breakdown of aluminum products such as cans and foil. Chromium wastes from industry and automotive parts are frequently associated with sanitary landfills. The presence of zinc may originate from the breakdown of galvanized iron, dezincification of brass and industrial waste compounds. Copper leachate may result from the breakdown of copper

pipe and fittings used in plumbing. Sources of lead leachate in sanitary landfills are automotive radiators and batteries, lead-base paint pigments, lead plumbing, and various scrap metals. Selenium, found naturally in some soils in semi-arid areas, may be found in wastes coming from insecticides, photoelectric cells, glass, lubricant and printing materials (Clark and Hawley, 1966; The Farm Chemicals Handbook, 1987).

Various inorganic nutrients are used to assess water quality. Nutrients such as orthophosphate, ammonium nitrogen, and nitrate nitrogen are introduced into water systems by allocthonous and autocthonous input. Phosphate containing products such as detergents and other cleaning compounds are frequently found in landfills. Nitrogen compounds are waste products formed from bacterial and fungal decomposition of organics. Orthophosphate, ammonium nitrogen, and nitrate nitrogen are typical leachate components which may induce enrichment when introduced into aquatic systems (Governmental Refuse Collection and Disposal Association, 1988).

Microbial metabolic action on waste organics results in the release of organic digests, fermentation products and gases such as methane, carbon dioxide, hydrogen, hydrogen sulfide and nitrogen. Release of these products affect the dissolved oxygen, pH, and alkalinity; and as a result of the effects, they are routinely used as parameters to assess water quality. Dissolved oxygen concentrations in an

undisturbed system are generally governed by photosynthetic activities, temperature, diffusion across the air/water interface, turbulence, and organic content of waters. Of the factors, temperature and photosynthesis are the most important moderators of dissolved oxygen concentrations (Reid, 1961). The pH of natural waters may be altered by acid or base materials deposited in landfills. The pH may also be altered by acidic products of biodegradative processes (Cameron, 1978). The Governmental Refuse Collection and Disposal Association (1988) reported that leachate laden water may be reduced in dissolved oxygen content due to gases such as carbon dioxide and methane which displace oxygen out of waters. Not only will the dissolved oxygen decrease as a result of displacement by heavier gases, but the pH will decrease with increasing carbon dioxide concentrations. Changes in the alkalinity, dissolved oxygen, and pH of waters may indicate landfill gas migration and subsequent leachate contamination.

There have been many investigations using various parameters as indicators of leachate contamination. Culhan and McHugh (1969) used temperature, pH, alkalinity, dissolved oxygen, nitrogen, orthophosphate, manganese and iron as determinants of water quality while studying a leachate contaminated stream. They found elevated levels of these metals and nutrients along with decreased pH values. Cameron (1978) used iron, nitrogen, phosphorus, and selenium

as indicators of leachate contamination, noting that elevated concentrations of nitrogen and phosphorus caused algal blooms when the ratio of the receiving water to the typical leachate is 20:1 or less. He also noted that selenium may be toxic to humans. Ellis (1979) used potassium as a leachate tracer due to the large amount of vegetable organics deposited in municipal landfills. Rule (1979) used pH, chlorine, and the metals; copper, zinc, chromium, and lead as leachate indicators at a municipal landfill in Chesapeake, Virginia. He did not find excessive levels of metals in the receiving stream.

The effects of landfill leachate on various organisms was studied by Cameron (1978) who noted that the leachate which contains organics, inorganics, and metals, was toxic to fish and as a result of this toxicity to fish, may be toxic to various animals, humans, and plants. McBride et al., (1979), studied the effects of leachate on rainbow trout. They found no macroscopic changes in the liver, kidneys, digestive tract, skin and gills, but when renal cells were examined, he noticed increased nuclei diameters, cytoplasmic vacuoles, and mitotic changes, which are typical stress responses to increased cellular activity. Cameron and Koch (1980) subjected rainbow trout to serial dilutions of a typical sanitary landfill leachate noting a direct relationship between leachate concentration and mortality. According to Mikuck et al., (1981), leachate poses a possible

threat to sensitive organisms, depending on its contents, and could result in fish, livestock, and plants being unfit for human consumption. This is due to biological magnification in which contaminants such as metals, insecticides and solvents, normally scarce in the environment, are increasingly concentrated at higher trophic levels. Plotkin and Ram (1984), in assessing the effects of sanitary landfill leachate on fathead minnows, zooplankton, green algae and bacteria, found it to be highly toxic to algae and bacteria while moderately toxic to minnows and zooplankton. Donnelly and Scarpino (1984) concluded that some of the potential pathogens, such as fecal streptococci and fecal coliforms, were surviving and leaching from sewage sludge and hospital wastes deposited in landfills.

Cairns (1974) stated that waste discharges and pollution will change the number and diversity of aquatic species. Some algae will increase in numbers while others show decreases, but overall diversity will decrease. Bertalot (1979) used diatoms as indicator organisms for polluted waters. Aquatic organisms such as diatoms and blue-green bacteria are used to assess the condition of an ecosystem. High numbers of diatoms with few blue-green bacteria are indicative of a healthy aquatic system. A high concentration of blue-green bacteria with few or no diatoms present is an indication of polluted waters (Standard Methods, 1985).

Henningson, Durham and Richardson (1980), in attempting to determine the presence of leachate in surface waters at the Watauga County Sanitary Landfill (WCSL), measured pH, alkalinity, methane, iron, manganese, selenium, copper, lead, and zinc. An excess of iron was found in the receiving water and on-site treatment by aeration, settling, filtration and pH adjustments was suggested. An alternative was to pump the leachate to the Boone Wastewater Treatment Plant. Production of leachate at the WCSL continues and threatens to be a perennial problem (Matthews, 1982). Guilford Laboratories (1988) tested for leachate in well and surface water at the WCSL, measuring chromium, copper, iron, lead, manganese, selenium, zinc, and nitrogen. Iron concentrations in the receiving surface water were found to be low, but two groundwater wells had excessive iron levels. It must be noted that these reports of low surface water concentrations for iron from Guilford Laboratories are in direct contradiction to findings by Henningson, Durham, and Richardson (1980).

The purpose of this study was to examine surface water above and below the WCSL and compare general characteristics, selected leachate components, and microorganisms between the two. Though some work has been conducted at the WCSL, a study for an extended period incorporating the above aspects has never been undertaken. The specific hypotheses investigated (in the null form) are:

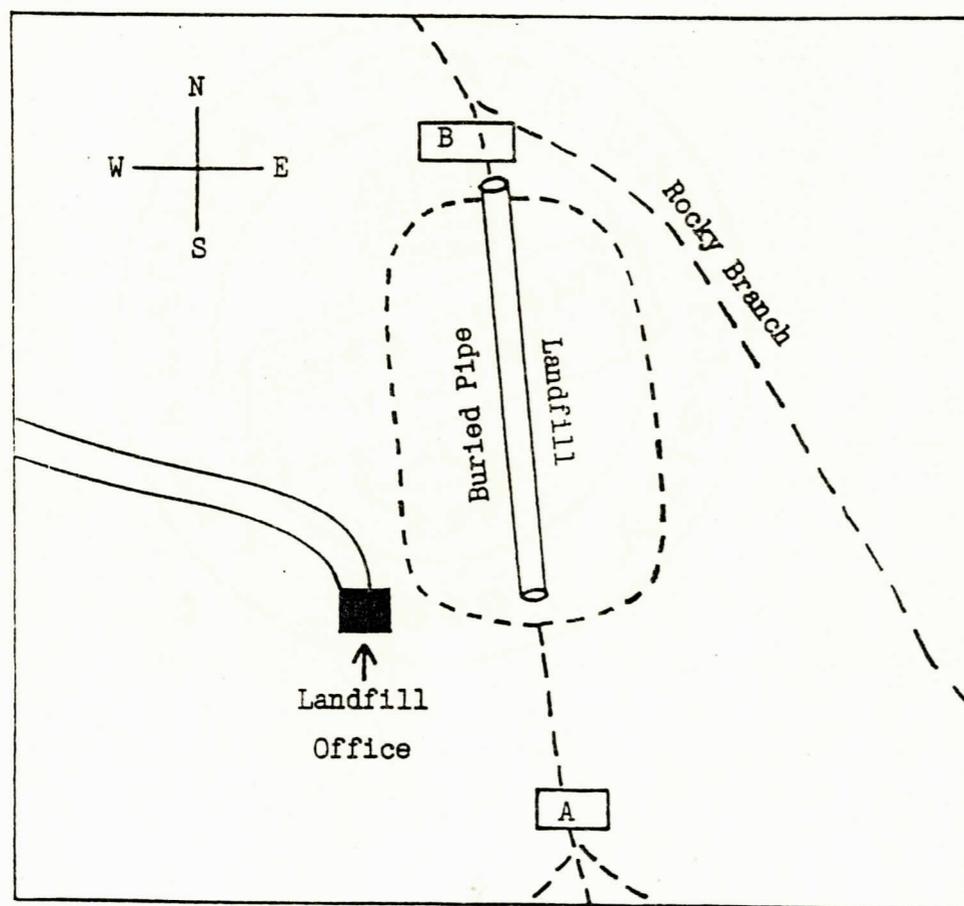
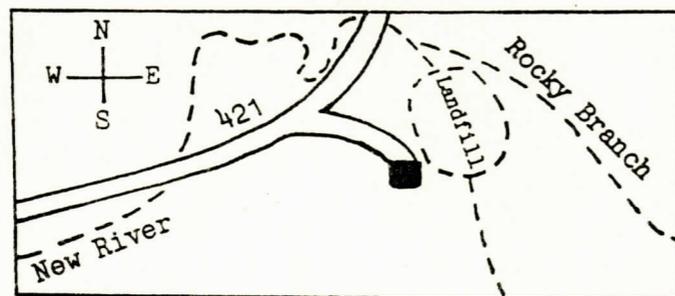
1. There is no significant difference in lead concentrations above and below the WCSL.
2. There is no significant difference in iron concentrations above and below the WCSL.
3. There is no significant difference in selenium concentrations above and below the WCSL.
4. There is no significant difference in manganese concentrations above and below the WCSL.
5. There is no significant difference in aluminum concentrations above and below the WCSL.
6. There is no significant difference in chromium concentrations above and below the WCSL.
7. There is no significant difference in zinc concentrations above and below the WCSL.
8. There is no significant difference in copper concentrations above and below the WCSL.
9. There is no significant difference in ammonium nitrogen concentrations above and below the WCSL.
10. There is no significant difference in nitrate nitrogen concentrations above and below the WCSL.
11. There is no significant difference in orthophosphate concentrations above and below the WCSL.

## Materials & Methods

Water at the WCSL was studied to compare general characteristics, selected leachate components, and micro-organisms. The approximate 100-acre WCSL is located about 2.5 miles east of Boone, North Carolina, off U.S. 421 (Fig. 1 and 2). It serves a resident population of around 35,000 but also receives a large volume of solid waste from the tourist trade and some from eastern Tennessee residents. According to Municipal Engineering Services (1988) the WCSL has an annual deposition of solid waste approaching 45,750 tons which may be maintained or reduced with further development of a newly initiated recycling effort.

During early construction of the WCSL, 6-inch diameter plastic (ABS) pipes and a 2-inch diameter galvanized pipe were installed to divert spring water that would otherwise flow through the fill area. This spring water is diverted to the lower end of the landfill where it exits and flows into Rocky Branch, a tributary of the South Fork of the New River. As a result of shifting and compaction due to fill dirt and heavy machinery, the pipes have apparently ruptured allowing water to exit and re-enter, creating potential leachate problems. There are approximately 4,320 gallons of leachate contaminated water per day flowing out of the WCSL through these pipes. This figure was calculated by using a

Figures 1 and 2. Map of the general location of the Watauga County Sanitary Landfill with an enlarged map showing the location of stations and buried pipes.



container of a known volume, recording the time taken to fill the container, and extrapolating over a 24-hour period.

Figures 1 and 2 show the location of collecting Stations A and B. Station A, located approximately 100 meters above the fill, was the collecting site for control samples. It is separated from the fill area and is a source of spring water similar to that infiltrating the landfill. Station B, located approximately 30 meters below the point at which water resurfaces at the lower end of the fill, was the collecting site for leachate samples. Station B is at a point where there is a mixture of runoff, circumventing and subsurface leachate waters. The questions being asked are: Are there differences between the control and leachate waters in the selected physical and chemical parameters? And, if so, do those differences have an effect on the microbiological parameters chosen?

The selected metals used as parameters were lead (Pb), iron (Fe), manganese (Mn), aluminum (Al), chromium (Cr), zinc (Zn), copper (Cu), and selenium (Se). Approximately 1.7 liters of water were collected in plastic containers from each station on a monthly basis from June 1986 through November 1986. Colorimetric analytical tests were performed for metals using the Hach DR 3000 Spectrophotometer and accompanying lab manual, courtesy of Town of Boone Water Treatment Facility. All tests were performed in triplicate.

The selected inorganic nutrients measured were ammonium-nitrogen (NH<sub>4</sub>), nitrate-nitrogen (NO<sub>3</sub>), and orthophosphate (PO<sub>4</sub>). Approximately 0.25 liters of water were collected on a monthly basis from June 1986 through May 1987 from both stations and triplicate tests were performed. Water samples were analyzed for the presence of ammonium-nitrogen using the Nessler's Method. Nitrate-nitrogen and orthophosphate were measured using the Cadmium Reduction Method and Molybdate Method respectively. These measures were performed using facilities in the Department of Biology, Appalachian State University, with a Bausch and Lomb Spectrophotometer 20 and following the protocols of Standard Methods (1985). Reagents for nutrient and metal tests were purchased from Hach Chemical Company.

Other parameters measured were temperature, pH, dissolved oxygen, and alkalinity. Monthly testings were performed from June 1986 through May 1987. Temperature was taken at both sites with a standard Celsius thermometer. The pH also was tested at both sites with a Fisher Accumet portable field pH meter. Approximately 0.35 liter water samples were collected from both stations each month for dissolved oxygen and alkalinity analyses. Collections for dissolved oxygen (D.O.) were taken in 300 ml sealed B.O.D. bottles and transported in a cooler to the laboratory for D.O. determinations using the membrane electrode method with a YSI Model 57 oxygen meter. Alkalinity was determined

titrimetrically following procedures from Standard Methods (1985).

At one month intervals, between June 1986 and May 1987, slide traps were set for a 48-hour harvest of community organisms. The select microorganisms counted were cyanobacteria, diatoms, ciliates, and flagellates. Slides were removed and transported in the same water to the laboratory to be maintained in cold storage until observations for microorganisms were made. The procedure used for identifying and enumerating the organisms in the slide community was as follows: A typical slide was removed from its collecting container and an 18x18 mm cover slip was placed on the slide. Counts were made of randomly selected fields using a compound light microscope set on intermediate power (45x), for a total magnification of 450x.

Using an IBM personal computer and the software package Statistics With Finese, the 2-way analysis of variance and Pearson's Correlation were employed (Bolding, 1985). Statistical relationships and significance were determined by comparing and interpreting the data on metals and nutrients. The classification variables were time (in months) vs. location (Stations A and B) at the landfill. The measured variables were concentrations of metals and nutrients. A Pearson's Correlation was also employed to determine if the selected microorganisms varied along with variations in metal and nutrient concentrations.

## Results

The design of this study involved measuring and comparing the parameters of the waters below (Station B) and above (Station A) the WCSL to determine what changes, if any, are due to the influx of WCSL leachate. The test results for metals, inorganic nutrients, physical factors, chemical factors, and microorganisms were consistently different between the two stations.

### METAL RESULTS

Lead concentrations varied during the study period with significantly higher levels at Station B allowing a rejection of null hypothesis #1 (Fig. 3). Fluctuations with time were independent except for equal concentrations in July. Lead concentrations increased from August through October at Station B while remaining stable and lower at Station A. The minimum and maximum concentrations for Station B were 0.012 mg/l and 0.048 mg/l respectively, while at Station A, 0.003 mg/l and 0.020 mg/l were the minimum and maximum (Appendix I). The grand means for lead at sites B and A were 0.030 mg/l and 0.010 mg/l respectively (Appendix XIX).

Iron concentrations fluctuated over time and were highest at Station B with sharp increases from August through October followed by a decrease in November (Fig. 4). A

maximum value of 27.100 mg/l was recorded for this station in October with a minimum value of 3.620 mg/l in July. Iron concentrations at Station A were low and stable throughout the testing period where values fluctuated narrowly from a low of 0.030 mg/l to a high of 0.180 mg/l (Appendix II). Grand means for iron at Stations B and A were 12.630 mg/l and 0.100 mg/l respectively showing a significant difference, allowing the rejection of null hypothesis #2 (Appendix XIX).

Selenium concentrations were variable during the study period and highest at Station B (Fig. 5). Selenium increased from July through September but decreased in October and November at Station B. There were equal concentrations at both stations during the months of June and November. The low and high concentrations at Station B were 0.020 mg/l and 0.050 mg/l, while the lows and highs for Station A were 0.010 mg/l and 0.030 mg/l (Appendix III). Grand means for Stations B and A were 0.030 mg/l and 0.020 mg/l respectively which were significantly different, allowing the rejection of null hypothesis #3 (Appendix XIX).

Manganese concentrations varied at both stations during the study period but were always higher at Station B (Fig. 6) where this metal increased sharply from July through August followed by a decrease into November. Station A showed a similar rise in August, a slight drop in September followed by an increase through November. The low and high concentrations at Station B were 1.770 mg/l and 2.400 mg/l,

with the low and high concentrations of 0.010 mg/l and 0.930 mg/l at Station A (Appendix IV). Grand means for Stations B and A were 2.040 mg/l and 0.410 mg/l respectively which were significantly different, allowing the rejection of null hypothesis #4 (Appendix XIX).

The concentrations of aluminum were always higher at station B (Fig. 7). Aluminum gradually increased from June through October at Station B and sharply decreased into November. The low and high concentrations at Station B were 0.010 mg/l and 0.050 mg/l (Appendix V). Concentrations at Station A peaked in August and dropped to a low in October, rising in November. Low and high concentrations for Station A were 0.003 mg/l and 0.040 mg/l. The grand means for Stations B and A were 0.030 mg/l and 0.020 mg/l respectively which were significant, allowing for a rejection of null hypothesis #5 (Appendix XIX).

Chromium concentrations fluctuated over time, with higher values at Station B until October when chromium concentrations at Station A exceeded those at Station B (Fig. 8). Chromium decreased at both stations from October to November. The low and high concentrations for Station B were 0.000 mg/l and 0.070 mg/l (Appendix VI). Low and high concentrations at Station A were 0.010 mg/l and 0.030 mg/l. Grand means for Stations B and A were 0.030 mg/l and 0.020 mg/l respectively which were not different enough for a rejection of null hypothesis #6 (Appendix XIX).

Zinc concentrations at both stations were approximately the same at the beginning of this study. Values rose at both stations in July with zinc concentrations at Station A exceeding those of Station B where a maximum of 0.110 mg/l was recorded. The low value recorded for this station was 0.020 mg/l in November. Zinc levels at Station B fluctuated throughout this study with a maximum of 0.080 mg/l recorded in November and a minimum value of 0.030 mg/l in June (Appendix VII). Grand means for Stations B and A were both 0.050 mg/l which would not allow for a rejection of null hypothesis #7 (Appendix XIX).

Copper concentrations were always higher at Station B with the maximum value of 1.250 mg/l recorded in June. Copper concentrations decreased sharply from July through August at this station, stabilized from August through October, and decreased into November (Fig. 10). The low and high concentrations at Station B were 0.340 mg/l and 1.250 mg/l (Appendix VIII). Concentrations at Station A were low and stable during the course of this study with minimum and maximums recorded at 0.020 mg/l and 0.110 mg/l. The grand means for Stations B and A were 0.780 mg/l and 0.060 mg/l respectively which were significant, allowing the rejection of null hypothesis #8 (Appendix XIX).

#### NUTRIENT RESULTS

While consistently higher at Station B, ammonia nitrogen

concentrations fluctuated over the study period, with crests in April and October and troughs in July and November (Fig. 11). Ammonia nitrogen concentrations were consistently low and stable at Station A for the testing period. The minimum and maximum concentrations at Station B were 10.70 mg/l and 21.30 mg/l, while the low and high concentrations at Station A were 0.15 mg/l and 0.29 mg/l (Appendix IX). Grand means at Stations B and A were 15.60 mg/l and 0.19 mg/l respectively which were significant, allowing the rejection of null hypothesis #9 (Appendix XIX).

Measures of nitrate nitrogen were highly erratic for the entire testing period and generally higher at Station B (Fig. 12). The regular rise and fall continued through September followed by a decrease into November. October and November were months in which there were no concentration differences in nitrogen. The low and high concentrations at Station B were 0.09 mg/l and 0.29 mg/l while the minimum and maximum concentrations at Station A were 0.03 mg/l and 0.09 mg/l (Appendix X). The grand mean at Stations B and A were 0.18 mg/l and 0.05 mg/l respectively which would allow a rejection of null hypothesis #10 (Appendix XIX).

Orthophosphate concentrations at Station A varied over time and exceeded those at Station B during the months of February, June, July and August (Fig. 13). There were no concentration differences between stations for October and November. A minimum value of 0.03 mg/l was noted for

Station B with a maximum value of 0.32 mg/l (Appendix XI). The low and high concentrations at Station A were 0.01 mg/l and 1.00 mg/l. Grand means for Stations B and A were 0.11 mg/l and 0.24 mg/l respectively, which is significant, allowing a rejection of null hypothesis #11 (Appendix XIX).

#### PHYSICAL-CHEMICAL

Temperature and dissolved oxygen were consistently different over the study period and seemed to be inversely related, as expected (Fig. 14 and 15). These inverse relationships were seen in all months except June, July and August. Temperatures were always higher at Station B with the exceptions of June and July. The low and high water temperatures at Station B were 9.0 Celsius and 13.5 Celsius, while at Station A 7.5 Celsius and 13.5 Celsius were the low and high (Appendix XII). The minimum and maximum dissolved oxygen concentrations at Station B were 3.0 mg/l and 8.2 mg/l, whereas the low and high at Station A were 4.5 mg/l and 9.0 mg/l (Appendix XIII).

The pH was relatively stable at both stations for the entire testing period (Fig. 16). It was generally lower at Station B, but equivalent measures were found during the months of September and November. The low and high measures at Station B were 6.8 and 7.1 while those at Station A were 6.7 and 7.3 (Appendix XIV).

There were great differences in alkalinity over the testing period at both stations (Fig. 17). Alkalinity was always much higher at Station B than Station A. The minimum and maximum concentrations at Station B were 132 mg/l and 179 mg/l, and the low and high concentrations for Station A were 18 mg/l and 23 mg/l (Appendix XV).

#### MICROORGANISM RESULTS

Blue-green bacteria were more prominent at Station B with the highest counts during the spring and lowest during the fall and winter (Fig. 18). Counts at Station A were consistently low relative to Station B for the testing period and more elevated during the summer. The low and high counts at Station B were 14 and 234 for approximately 12% of the slide area, while the low and high counts at Station A were 0 and 11 for the same size area (Appendix XVI). Blue-green bacteria were not significantly related to any of the metals or nutrients but a significant positive correlation was seen with flagellates (Appendix XVIII).

Diatoms were not found at Station B (Fig. 19) during the test period, while Station A had diatom counts ranging from a peak of 282 cells per slide area in March to 0 from July through November (Appendix XVI). The highest numbers were recorded during the spring.

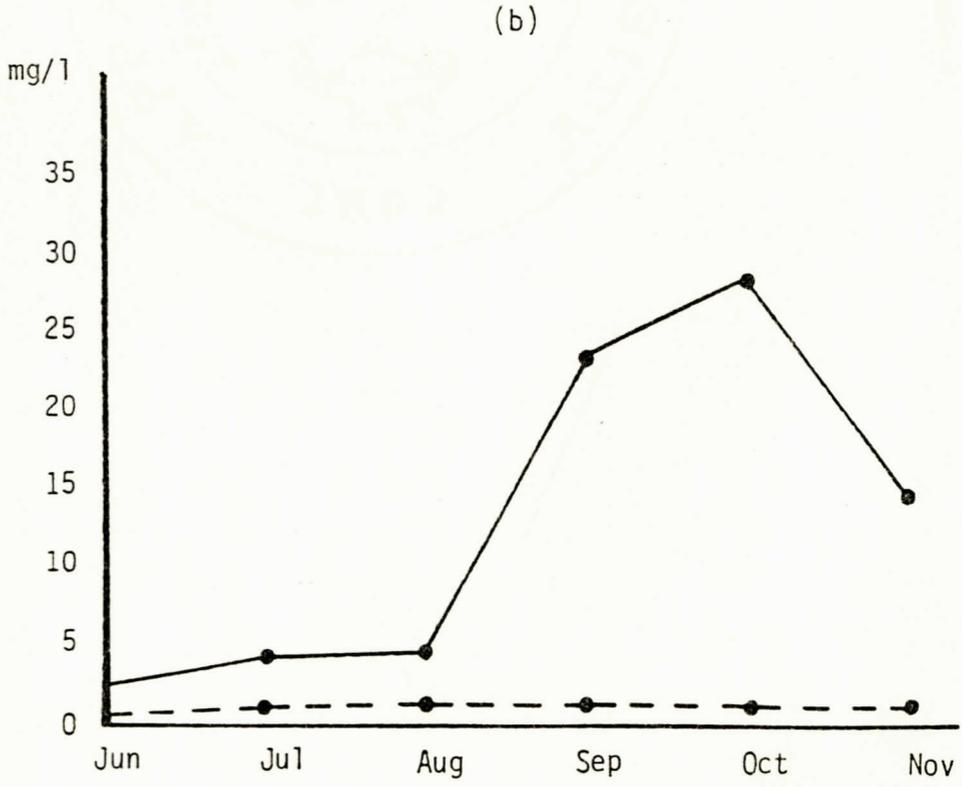
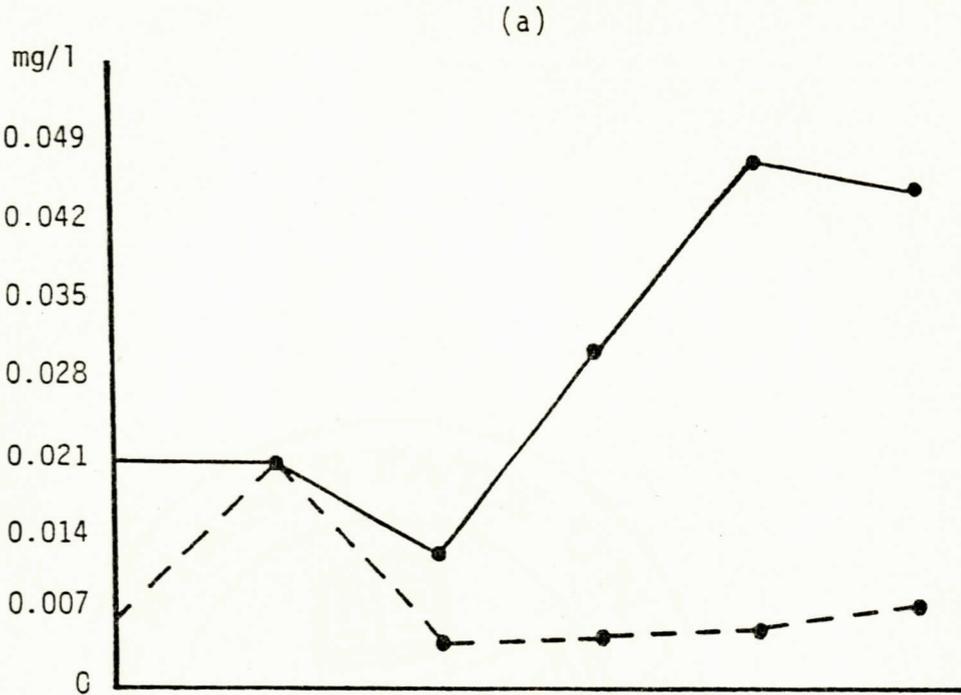
Ciliated protozoans were present at both stations with counts higher at Station B than Station A during the spring

and early summer while lower at Station B than Station A during the summer and fall (Fig. 20). Low and high counts per slide area were 2 and 15 at Station B and 0 and 16 at Station A (Appendix XVI). Ciliated protozoans were significantly related to flagellated algae and manganese (Appendix XVIII).

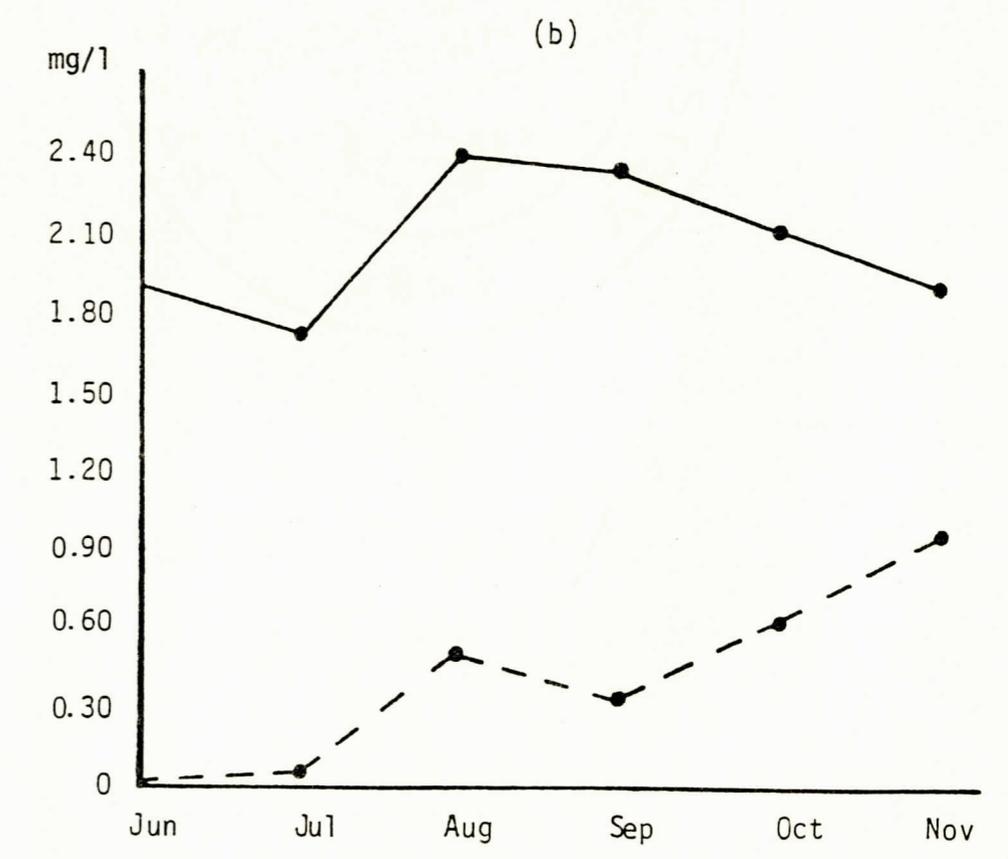
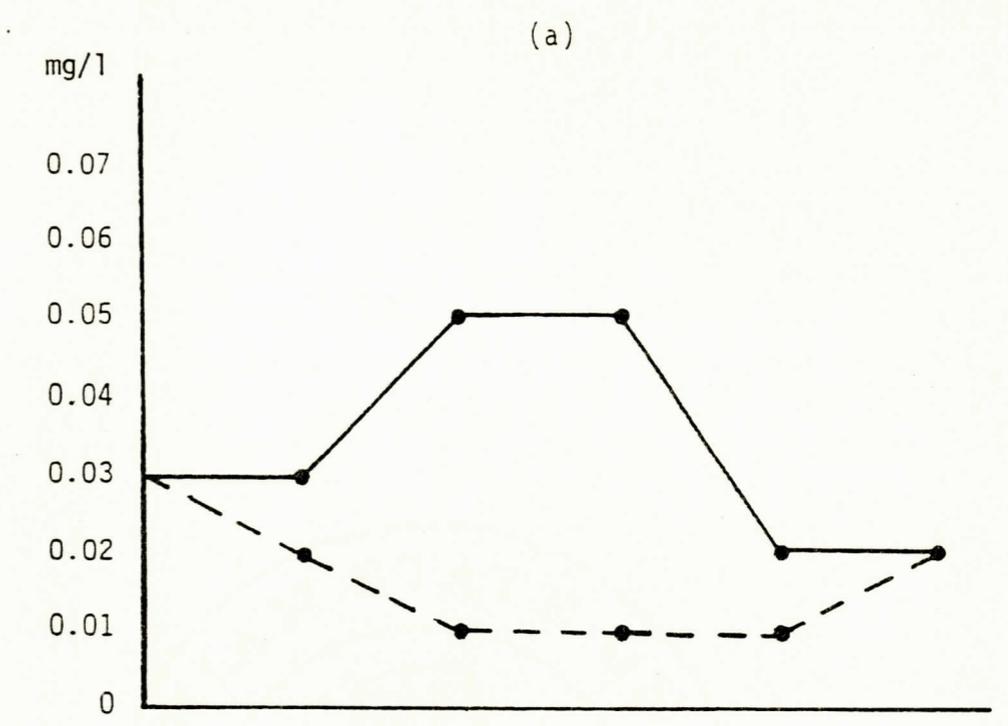
Flagellated algae were present at both stations with counts higher at Station B than Station A during the spring and early summer (Fig. 21). Counts were lower at Station B than Station A during the summer and fall. The high and low counts per slide area at Station B were 0 and 10 while those at Station A were 0 and 29 (Appendix XVI). These algal counts related significantly to blue-green bacteria and ciliated protozoans (Appendix XVIII).

From the data it is clear that the landfill is contributing significant amounts of nutrient and metal leachate except for chromium, zinc, and orthophosphate. Although orthophosphate concentrations were significant, they were significantly higher at Station A. As a result, a rejection of the null hypotheses is in order with the exception of chromium and zinc.

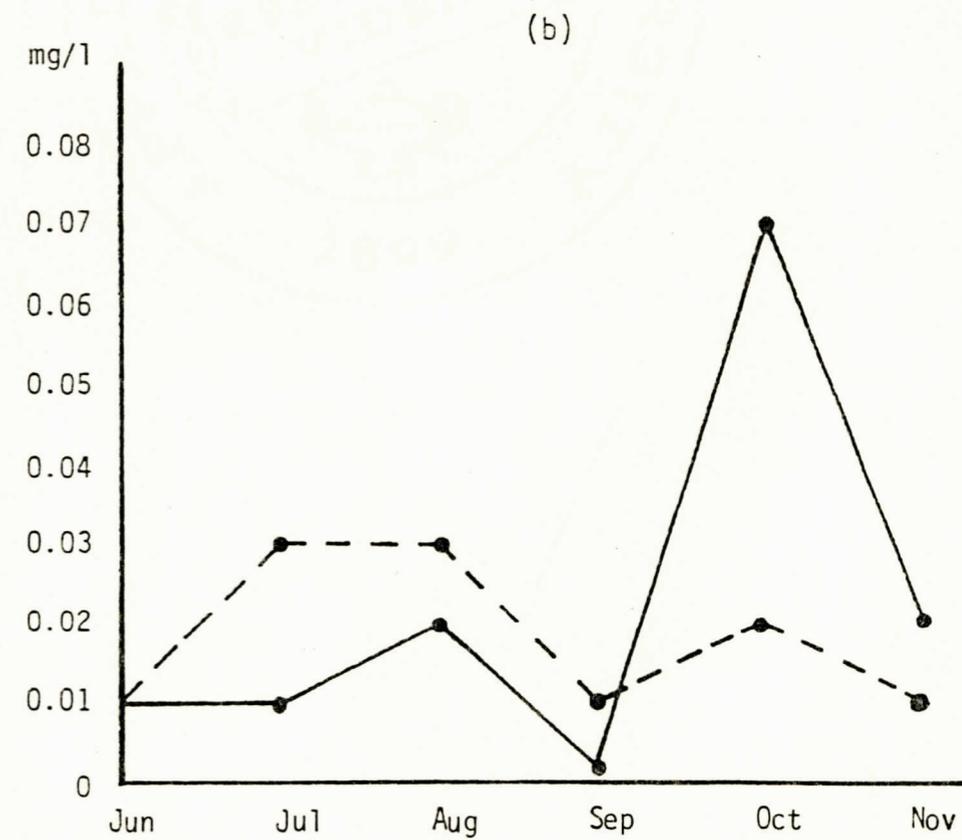
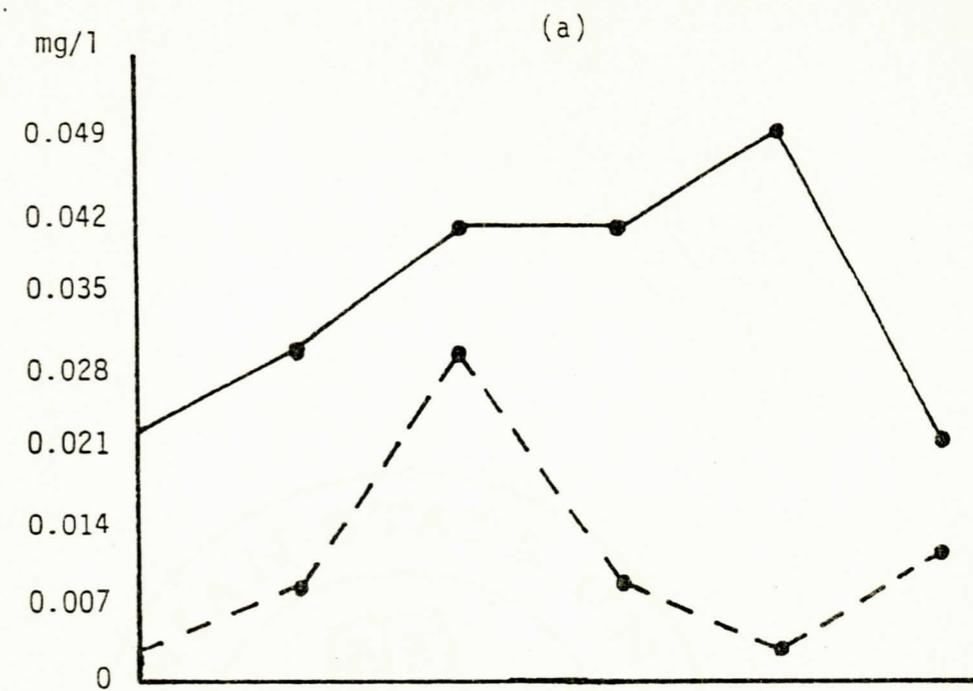
Figures 3 and 4. Mean concentrations (mg/l) of lead (a) and iron (b) above (---) and below (—) the Watauga County Sanitary Landfill.



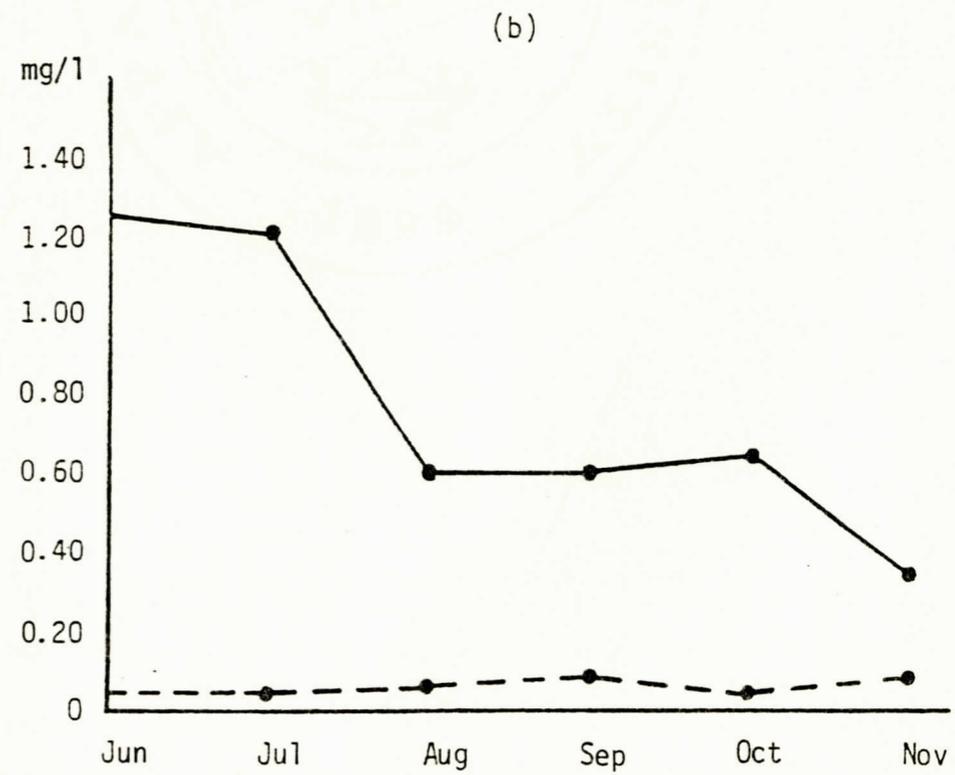
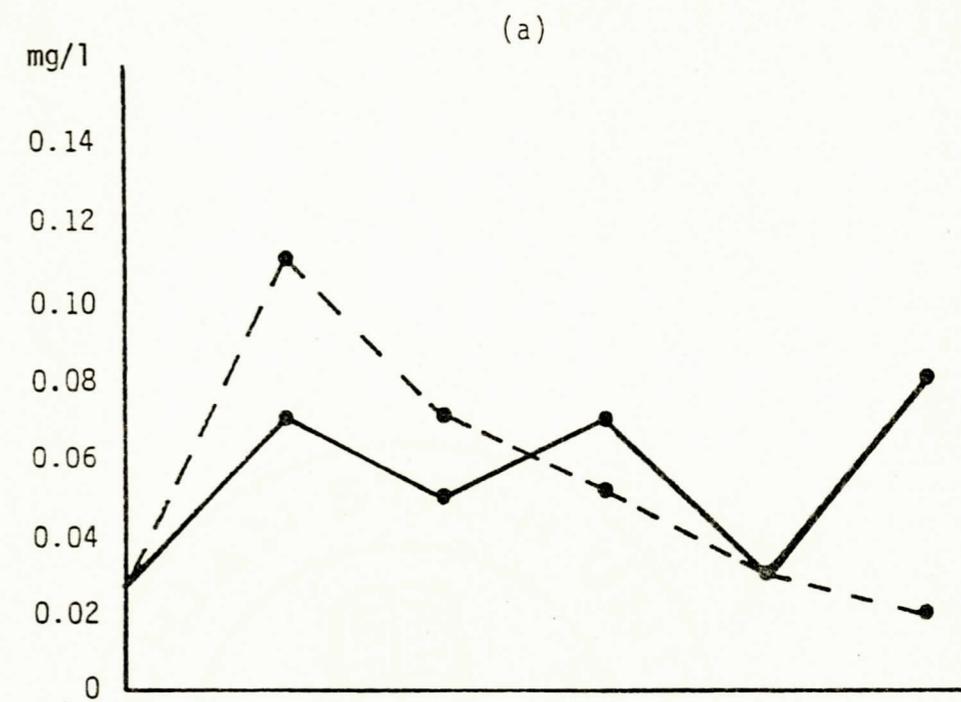
Figures 5 and 6. Mean concentrations (mg/l) of selenium (a) and manganese (b) above (---) and below (—) the Watauga County Sanitary Landfill.



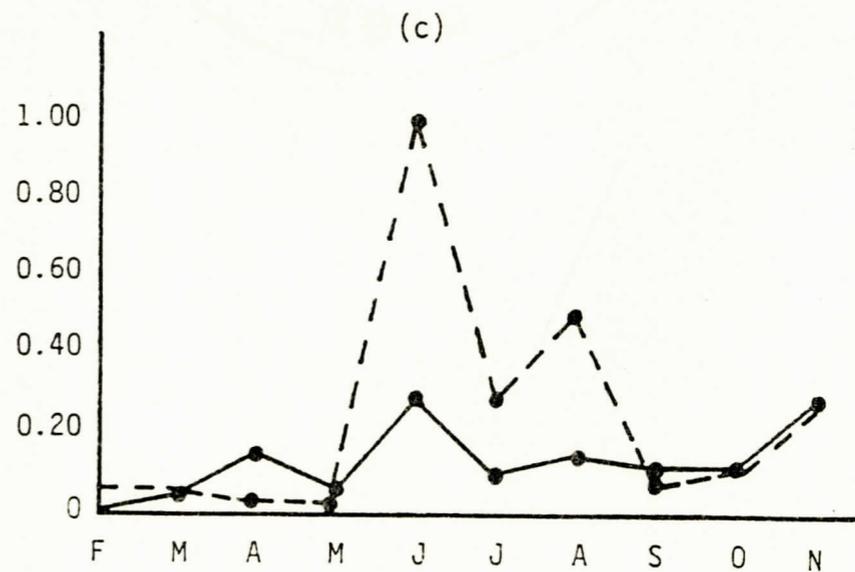
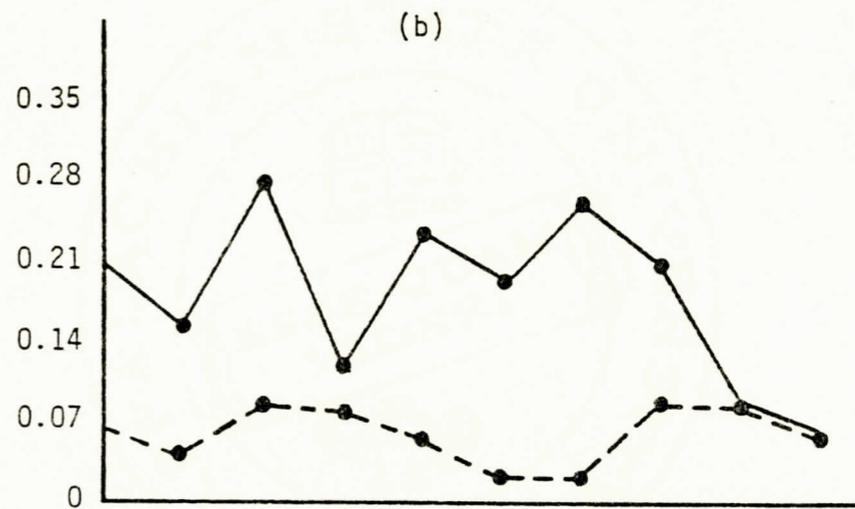
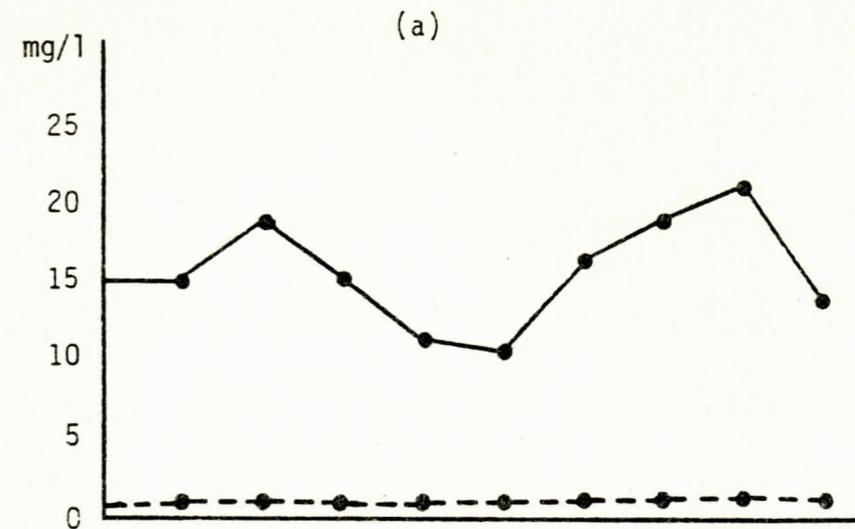
Figures 7 and 8. Mean concentrations (mg/l) of aluminum (a) and chromium (b) above (---) and below (—) the Watauga County Sanitary Landfill.



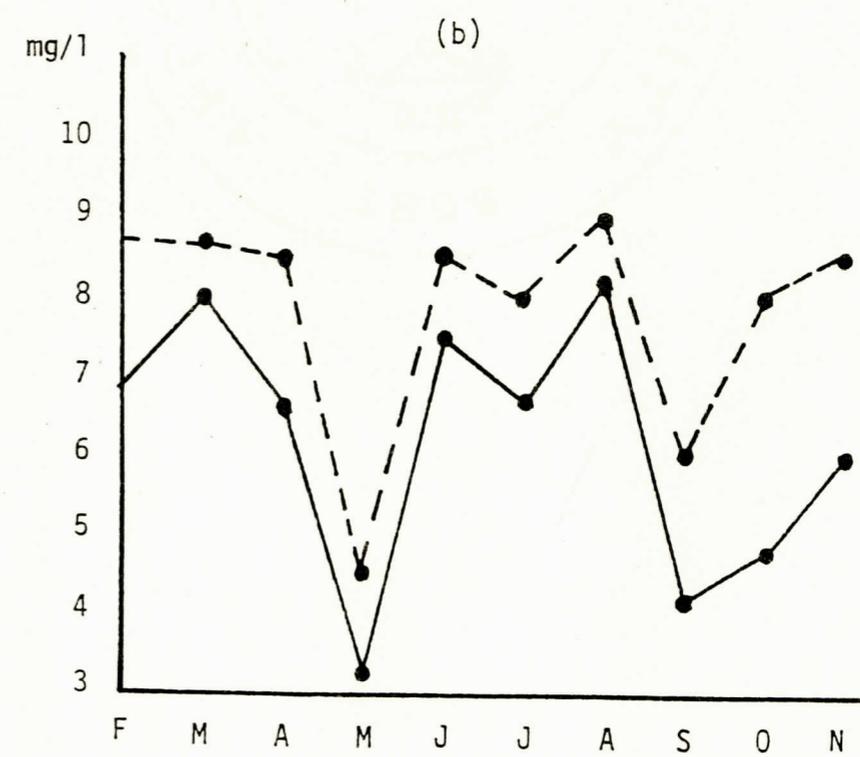
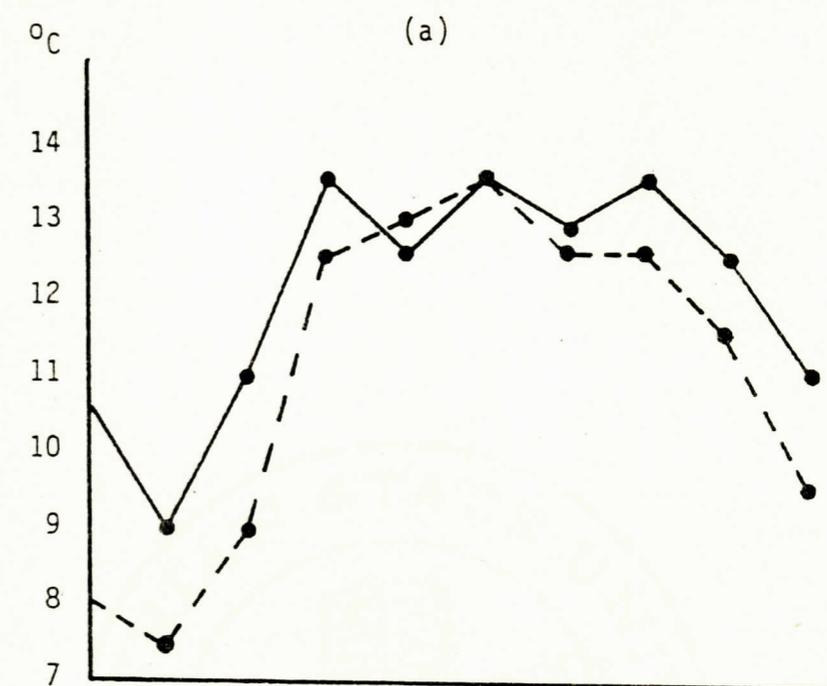
Figures 9 and 10. Mean concentrations (mg/l) of zinc (a) and copper (b) above (---) and below (—) the Watauga County Sanitary Landfill.



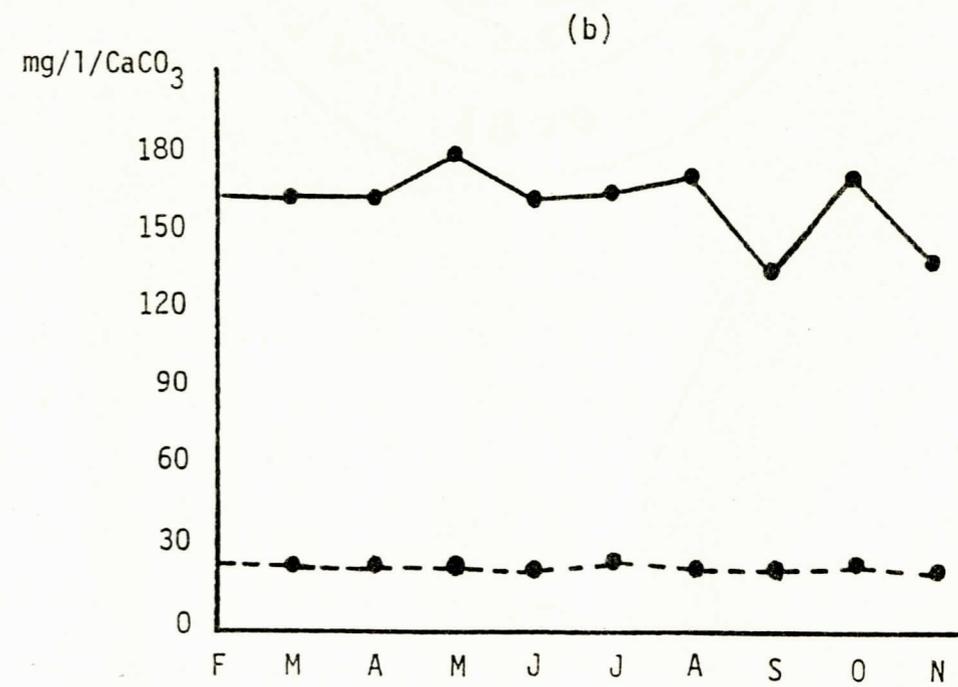
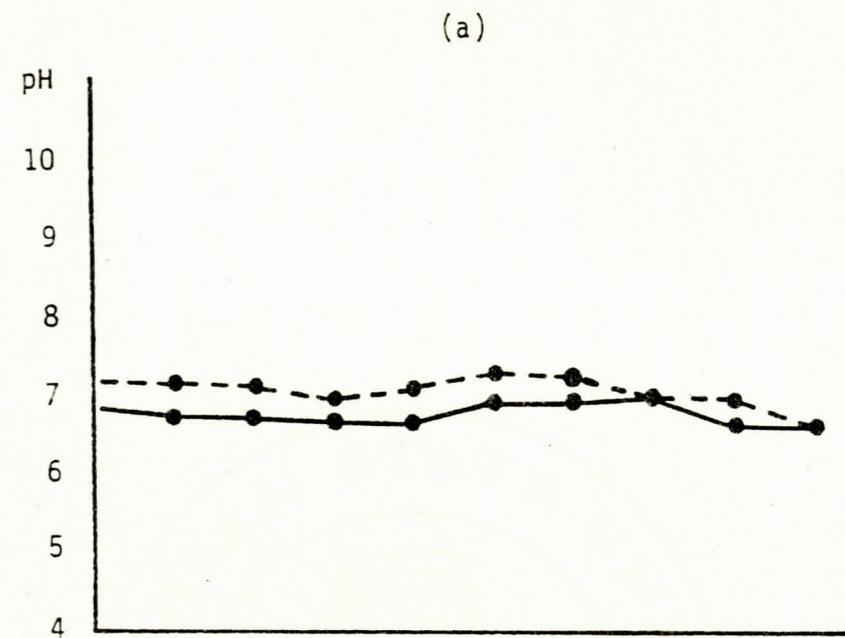
Figures 11, 12 and 13. Mean concentrations (mg/l) of ammonia nitrogen (a), nitrate nitrogen (b) and orthophosphate (c) above (---) and below (—) the Watauga County Sanitary Landfill.



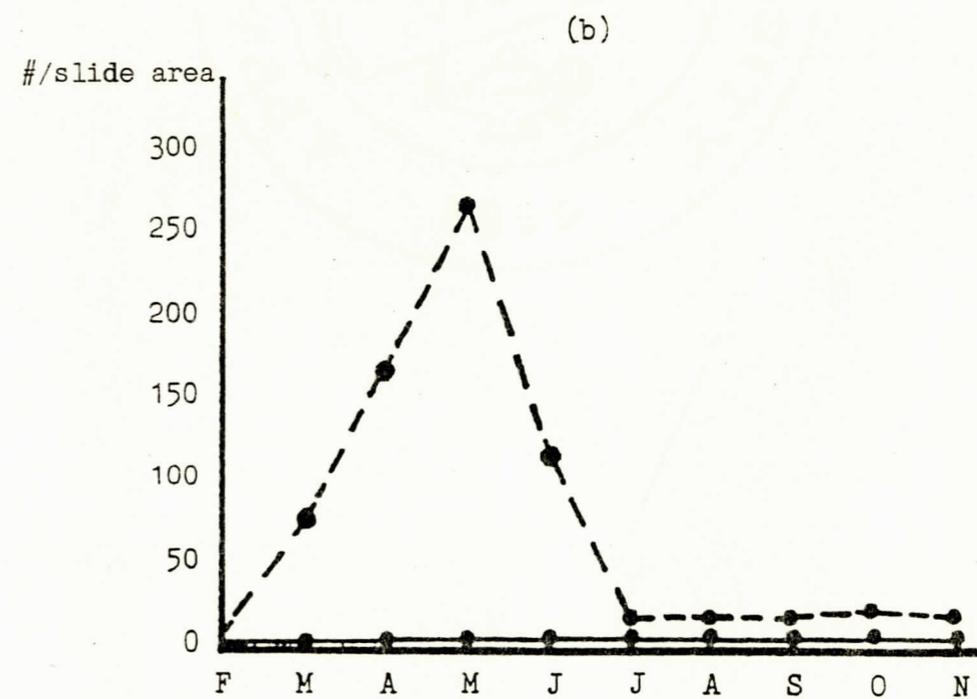
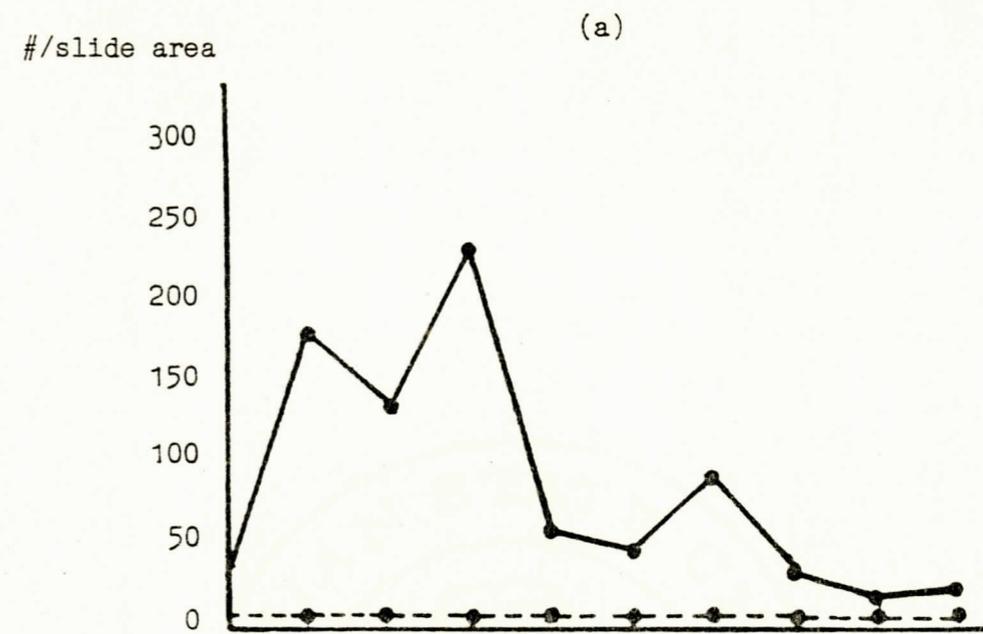
Figures 14 and 15. Water temperatures (a) in (Celsius) and dissolved oxygen concentrations (b) above (---) and below (—) the Watauga County Sanitary Landfill.



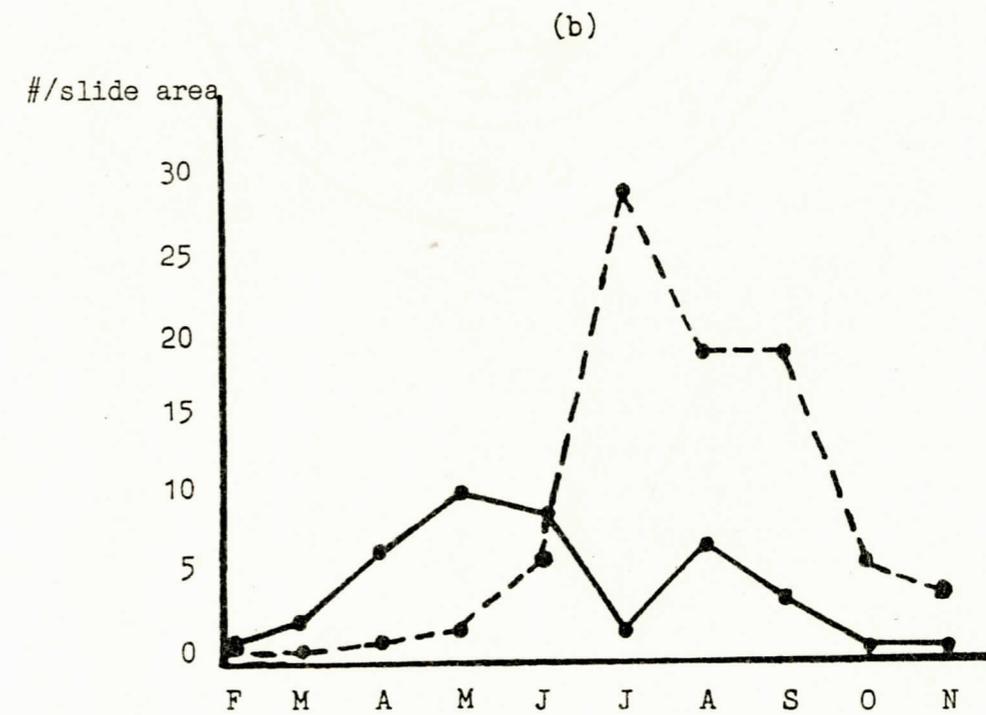
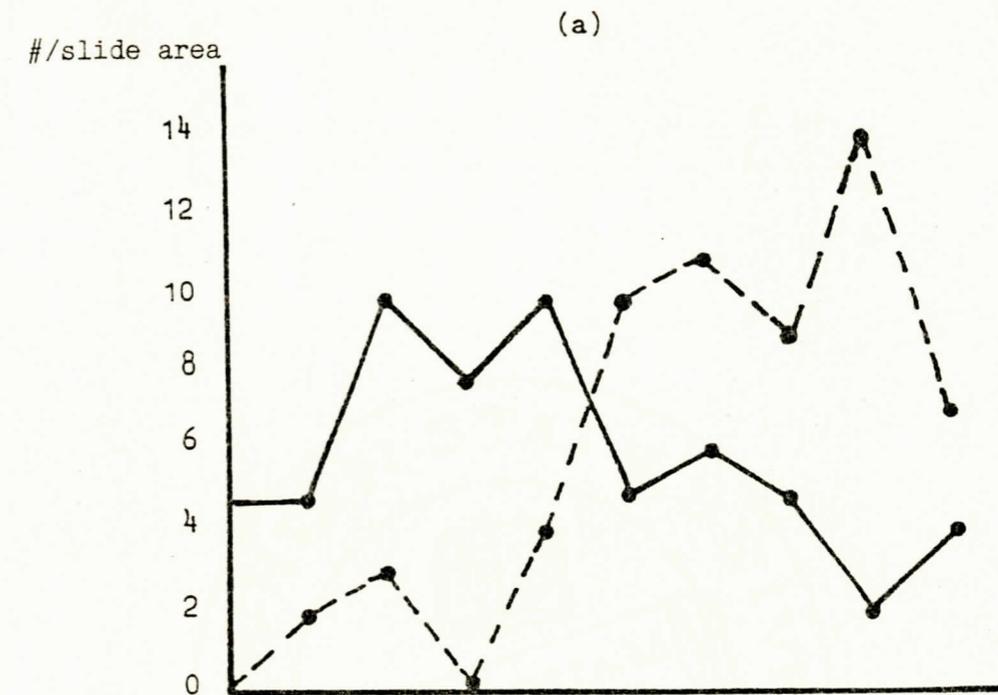
Figures 16 and 17. The pH (a) and alkalinity (b) above (---) and below (—) the Watauga County Sanitary Landfill.



Figures 18 and 19. Blue-green bacteria counts/slide area (a) and diatom counts/slide area (b) above (---) and below (—) the Watauga County Sanitary Landfill.



Figures 20 and 21. Ciliate counts/slide area (a) and flagellate counts/slide area (b) above (---) and below (—) the Watauga County Sanitary Landfill.



### Discussion

When considering the effects of a sanitary landfill on the environment of the immediate area, there may be several contributing types of leachate. With no order of importance intended, there could be hazardous chemicals such as solvents and selenium compounds coming from industrial processes and known for their toxic effects on biological systems (Gabriel and Witschi, 1976; Hach, 1983b; Marshall, 1986; Norris, 1986; Steinhart, 1986), herbicides, insecticides and other synthetics (Mikuck et al., 1981). A second type is made up of compounds of lead, mercury, copper and other heavy metals which have the potential for toxic effects in biological systems (Aposhian, 1983; Hach, 1983a; Raloff, 1987). And third, are the hydrolysates and end-products of microbial metabolism, among which are found nitrates, nitrites, ammonia nitrogen, orthophosphate and sulfates. These, when introduced to surface waters, result in eutrophication and stagnation of that water. The lack of industrial activities in the region of the landfill may rule out the need for dealing with the first type of release in the form of solvents and synthetic compounds.

### METALS

There is a general elevation in the level of metals in

the recipient waters below the Watauga County Sanitary Landfill. Iron concentrations were excessively high at Station B for the entire testing period, and this supports previous findings at the WCSL by Henningson, Durham, and Richardson (1980) and Matthews (1982). Increased water flow due to precipitation leads to leachate problems (Lu et al., 1984; Shultz, 1985; Department of Human Resources, 1987). Iron concentrations at Station B increased from summer to fall by approximately 500 percent and thereafter decreased in the fall showing a related rise and fall with that of precipitation. Station B grand mean concentrations were 126 times greater than those of Station A. These excess concentrations result from the voluminous metal deposition and may be a contributing factor to the lack of diatoms, according to Smith (1950).

Lead concentrations increased extensively at Station B in the late summer and early fall, and these increases corresponded to increased precipitation. Grand mean concentrations for Station B were three times greater than those of Station A. The grand mean values for lead from both stations were comparable to previous results by Henningson, Durham, and Richardson (1980), and Guilford Laboratories (1988). The data suggest that lead and iron were leaching from the landfill during the same periods and with increasing rates.

Selenium and manganese increased at Station B during the late summer and early fall, then decreased in late fall and it appears that levels of these metals correlated with precipitation. Selenium grand means from Station B were some 50 percent higher than A, while manganese grand means from station B were approximately five times greater than Station A. Selenium and manganese concentrations from both stations compared favorably to those found on a one-time basis by Henningson, Durham, and Richardson (1980), and Guilford Laboratories (1988).

Aluminum and chromium at Station B increased from September to October and decreased thereafter, a pattern similar to that of lead and iron. Chromium was anomalous between June and September when Station A concentrations actually exceeded Station B concentrations by an average of three times. These differences are considered trace, however.

Zinc and copper were the least predictable metals analyzed with the possible exception of chromium. Zinc at station B fluctuated throughout the test period and was anomalous between June and August when Station A zinc concentrations exceeded those at Station B by an average of 40 percent. Although zinc grand means were equivalent from Stations A and B, copper was some 13 times greater at Station B than Station A. Zinc and copper grand means compared favorably to results obtained by Henningson, Durham, and

Richardson (1980), and Guilford Laboratories (1988). Precipitation did not appear to markedly affect concentrations of these metals.

#### NUTRIENTS

Inorganic nutrients such as nitrogen and phosphorus are routinely used as parameters for leachate contamination due to their abundance in sewage products and fertilizers. Eutrophication or enrichment of local waters may occur causing algal blooms which may reduce their nutrient supply resulting in die-off of the algae, decomposition of the organic material by aerobic bacteria, and finally fish kills (Hartig and Gannon, 1986; Stuller and Rokeach, 1987; Beardsley, 1987; Sun, 1985 and 1986; Powers, 1986; McAdams, 1986). Inorganic nutrients were generally higher at Station B than Station A, except for nitrate nitrogen in which Stations A and B had equal concentrations from October to November and orthophosphate which was anomalous in February, June, July and August. Waters having concentrations of ammonia nitrogen exceeding 1.0 mg/l are considered polluted (Reid, 1961; Standard Methods, 1985). The grand mean for Station B exceeded this figure by nearly sixteen times while Station A was well under 1.0 mg/l. The excess nitrogen found at Station B probably results from several factors including leachate from sewage humus dumped at the landfill, and nitrogenous waste in the form of ammonia excreted by

decomposers. Nitrate nitrogen, as noted, was generally higher at Station B than Station A but the grand means for both stations fell below the 0.30 mg/l concentration average for unpolluted freshwaters (Reid, 1961). Orthophosphate concentrations for unpolluted freshwater are low; often on the order of < 0.001 mg/l (Reid, 1961; Standard Methods, 1985). The grand mean for Station A was over twice as great as the grand mean for Station B. This may be attributed to the fact that there is a graded area (upslope, not upstream) from Station A that may contribute to phosphorous runoff and a subsequent dilution effect downstream causing reduced concentrations in Station B.

#### PHYSICAL-CHEMICAL

Temperature and dissolved oxygen measurements were typically related to the season and inversely related to one another with the exception of June, July and August. Although the green algae were not a study group, the increase in dissolved oxygen at both stations during these same months corresponded to an increase in the green alga Chlorella, which may have bloomed in response to increased orthophosphate concentrations (Welch, 1935; Hynes, 1971; Fogg, et al., 1973; Lee, 1973; Walker and Hillman, 1982). Temperatures at Station B were generally higher than Station A during the fall and winter but lower during summer. This may be partly attributable to heat produced at sanitary

landfills due to exothermic bacteria. More importantly, this may be due to the volume difference between the stations. The smaller volume of Station A would be more likely to respond to the ambient temperature. Dissolved oxygen was always lower at Station B than Station A. This is probably due to more organic decomposition and less primary productivity at Station B than Station A.

The pH in general was lower at Station B than Station A. These slightly less than neutral (7) readings at Station B may be due to biological fermentation products as well as some acidic materials deposited in the fill. The pH will also decrease with increasing carbon dioxide concentrations formed by aerobic decomposition (Governmental Refuse Collection and Disposal Association, 1988). Alkalinity was always much higher at Station B than Station A and ranged from seven to nine times as great. This increased alkalinity may be a combination of methane, alkaline products deposited at the fill, and periodic liming that occurs at the landfill. It is probably not related to carbonate rocks at the landfill due to the fact that the area is not known to contain limestone.

#### MICROORGANISMS

Algae have been frequently used to assess the condition of aquatic environments. The diatoms and blue-green bacteria may be used as indicators for water quality (Sullivan, 1976;

Marcus, 1980; Hoagland, 1983; Grimes et al., 1984; Shubert, 1984; Standard Methods, 1985). A water system with few blue-green bacteria and an abundance of diatoms may be indicative of unpolluted or relatively unpolluted water, while that with many blue-green bacteria and few or no diatoms may indicate the converse. Seasonal periodicity occurs in plankton with diatoms preferring cooler season water while blue-green bacteria prefer the warmer summer month waters (Welch, 1935; Smith, 1950; Hynes, 1971; Fogg, et al., 1973). It is widely agreed that factors involved in the growth of algae include sunlight, temperature, and nutrient variations. Both stations were located in close proximity to the origins of their waters, which would explain the narrow temperature range. The stations had fairly constant temperatures with a range over the study period of 6.5 degrees celsius for Station A and 5.5 degrees celsius for Station B. This narrow range of temperatures may be a reason why there was not a high seasonal periodicity in the blue-green bacteria. Diatoms did show some periodicity with high counts in the late winter and spring, lowered counts during the summer, but uncharacteristically low in the fall as well. These spring highs corresponded to low inorganic nutrient concentrations. The low diatom population in the summer and fall may also be partly due to competitive pressures by the dominant green alga Chlorella blooming in response to increased orthophosphate. Lighting was fairly indirect due

to the woody locations of the stations, possibly being a factor in algae growth.

There was, however, a big difference in the iron and ammonia nitrogen content of the two stations which may have led to the lack of diatoms at Station B and a dominating presence of blue-green bacteria. According to Smith (1950), there is a toxic effect on algae when iron exceeds 5.0 mg/l. The grand mean for iron at Station B was over twice this amount. The high concentration of blue-greens at Station B may be due to the high ammonia nitrogen concentrations and low nitrate nitrogen and orthophosphate, but high concentrations of nitrogen and phosphorus do not preclude the presence of blue-greens (Pearsall, 1932; Standard Methods, 1985). This difference in iron and ammonia nitrogen between Stations A and B may have also led to the dominance of diatoms over blue-green bacteria at Station A. Station B was also characteristic of polluted water, having fewer categories of microorganisms than Station A.

The Watauga County Sanitary Landfill is an excellent site for continued work. Analyses using additional parameters such as PCB's, mercury, arsenic, cadmium and total organics would be appropriate. A study of the macroinvertebrates may also be useful in revealing the effects of leachate on natural waters. Tubifex worms and midge fly larvae have been observed during the course of this study and are indicative of polluted water.

An investigation of stream recovery would also be of importance here. This study could be taken to where Rocky Branch enters the New River or further downstream to determine any effects that the leachate may have on that aquatic system. Finally, according to Municipal Engineering Services (1988), this landfill has approximately 5.5 years of operation left, given recycling continued at its present level. The developmental design of this landfill promises leachate problems beyond its closure, and in fact, they may intensify as changes occur in buried fill pockets over time. Some type of treatment of this leachate is necessary to restore Stony Brook to a natural state.

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## APPENDIX I and II

MEAN CONCENTRATIONS (MG/L) OF LEAD (Pb) AND IRON (Fe)  
AT STATIONS A AND B AT THE WATAUGA COUNTY SANITARY LANDFILL

<u>Pb</u>		
<u>DATE</u>	<u>STATION A</u>	<u>STATION B</u>
JUN	0.007	0.021
JUL	0.020	0.020
AUG	0.003	0.012
SEPT	0.004	0.030
OCT	0.006	0.048
NOV	0.008	0.044
<u>Fe</u>		
<u>DATE</u>	<u>STATION A</u>	<u>STATION B</u>
JUN	0.030	3.620
JUL	0.140	4.200
AUG	0.180	4.310
SEPT	0.170	22.500
OCT	0.040	27.100
NOV	0.030	14.100

## APPENDIX III and IV

MEAN CONCENTRATIONS (MG/L) OF SELENIUM (Se) AND  
MANGANESE (Mn) AT STATIONS A AND B AT THE  
WATAUGA COUNTY SANITARY LANDFILL

Se

<u>DATE</u>	<u>STATION A</u>	<u>STATION B</u>
JUN	0.03	0.03
JUL	0.02	0.03
AUG	0.01	0.05
SEPT	0.01	0.05
OCT	0.01	0.02
NOV	0.01	0.02

Mn

<u>DATE</u>	<u>STATION A</u>	<u>STATION B</u>
JUN	0.01	1.87
JUL	0.05	1.77
AUG	0.53	2.40
SEPT	0.33	2.33
OCT	0.63	2.10
NOV	0.93	1.87

## APPENDIX V and VI

MEAN CONCENTRATIONS (MG/L) OF ALUMINUM (Al) AND  
CHROMIUM (Cr) AT STATIONS A AND B AT THE WATAUGA COUNTY  
SANITARY LANDFILL

Al

<u>DATE</u>	<u>STATION A</u>	<u>STATION B</u>
JUN	0.003	0.020
JUL	0.010	0.030
AUG	0.030	0.040
SEPT	0.040	0.010
OCT	0.004	0.050
NOV	0.010	0.020

Cr

<u>DATE</u>	<u>STATION A</u>	<u>STATION B</u>
JUN	0.010	0.010
JUL	0.030	0.010
AUG	0.030	0.020
SEPT	0.010	0.000
OCT	0.020	0.070
NOV	0.010	0.020

## APPENDIX VII and VIII

MEAN CONCENTRATIONS (MG/L) OF ZINC (Zn) AND COPPER (Cu)  
AT STATIONS A AND B AT THE WATAUGA COUNTY SANITARY LANDFILL

<u>Zn</u>		
<u>DATE</u>	<u>STATION A</u>	<u>STATION B</u>
JUN	0.03	0.03
JUL	0.11	0.07
AUG	0.07	0.05
SEPT	0.05	0.07
OCT	0.03	0.03
NOV	0.02	0.08

<u>Cu</u>		
<u>DATE</u>	<u>STATION A</u>	<u>STATION B</u>
JUN	0.03	1.25
JUL	0.02	1.22
AUG	0.06	0.62
SEPT	0.10	0.63
OCT	0.02	0.65
NOV	0.11	0.34

## APPENDIX IX

MEAN CONCENTRATIONS (MG/L) OF AMMONIUM NITROGEN (NH<sub>4</sub>)  
AT STATIONS A AND B AT THE WATAUGA COUNTY SANITARY LANDFILL

<u>DATE</u>	<u>STATION A</u>	<u>STATION B</u>
FEB	0.29	15.0
MAR	0.29	15.0
APR	0.15	18.30
MAY	0.15	15.40
JUN	0.24	12.0
JUL	0.19	10.70
AUG	0.17	16.70
SEPT	0.25	18.30
OCT	0.17	21.30
NOV	0.18	13.40

## APPENDIX X

MEAN CONCENTRATIONS (MG/L) OF NITRATE NITROGEN (NO<sub>3</sub>)  
AT STATIONS A AND B AT THE WATAUGA COUNTY SANITARY LANDFILL

<u>DATE</u>	<u>STATION A</u>	<u>STATION B</u>
FEB	0.06	0.20
MAR	0.05	0.16
APR	0.09	0.29
MAY	0.07	0.11
JUN	0.04	0.23
JUL	0.03	0.19
AUG	0.03	0.26
SEPT	0.07	0.21
OCT	0.08	0.09
NOV	0.06	0.13

## APPENDIX XI

MEAN CONCENTRATIONS (MG/L) OF ORTHOPHOSPHATE (PO<sub>4</sub>)  
AT STATIONS A AND B AT THE WATAUGA COUNTY SANITARY LANDFILL

<u>DATE</u>	<u>STATION A</u>	<u>STATION B</u>
FEB	0.05	0.03
MAR	0.04	0.03
APR	0.01	0.18
MAY	0.02	0.05
JUN	1.00	0.31
JUL	0.30	0.11
AUG	0.50	0.15
SEPT	0.10	0.13
OCT	0.12	0.12
NOV	0.32	0.32

## APPENDIX XII

WATER TEMPERATURES (CELSIUS) AT STATIONS A AND B  
AT THE WATAUGA COUNTY SANITARY LANDFILL

<u>DATE</u>	<u>STATION A</u>	<u>STATION B</u>
FEB	8.0	10.5
MAR	7.5	9.0
APR	9.0	11.0
MAY	12.5	13.5
JUN	12.0	12.5
JUL	14.0	13.5
AUG	12.5	12.5
SEPT	12.5	13.5
OCT	11.5	12.5
NOV	9.5	11.0

## APPENDIX XIII

DISSOLVED OXYGEN CONCENTRATIONS (MG/L) AT STATIONS A  
AND B AT THE WATAUGA COUNTY SANITARY LANDFILL

<u>DATE</u>	<u>STATION A</u>	<u>STATION B</u>
FEB	8.8	7.2
MAR	8.8	8.2
APR	8.4	6.8
MAY	4.5	3.0
JUN	8.4	7.4
JUL	8.2	6.8
AUG	9.0	8.2
SEPT	6.2	4.2
OCT	8.2	4.8
NOV	8.6	6.0

## APPENDIX XIV

A TABLE OF THE pH AT STATIONS A AND B AT  
THE WATAUGA COUNTY SANITARY LANDFILL

<u>DATE</u>	<u>STATION A</u>	<u>STATION B</u>
FEB	7.1	6.9
MAR	7.1	6.9
APR	7.1	6.9
MAY	7.0	6.8
JUN	7.2	6.9
JUL	7.3	7.0
AUG	7.2	7.1
SEPT	7.0	7.1
OCT	7.0	6.9
NOV	6.7	6.8

## APPENDIX XV

MEAN ALKALINITY (MG/L/CaCO<sub>3</sub>) AT STATIONS A AND B AT  
THE WATAUGA COUNTY SANITARY LANDFILL

<u>DATE</u>	<u>STATION A</u>	<u>STATION B</u>
FEB	19	163
MAR	19	162
APR	18	163
MAY	20	179
JUN	20	159
JUL	23	165
AUG	21	168
SEPT	20	132
OCT	22	166
NOV	19	135

## APPENDIX XVI

TOTAL COUNTS OF MICROORGANISMS AT STATIONS A AND B AT  
THE WATAUGA COUNTY SANITARY LANDFILL

STATION A										
	F	M	A	M	J	J	A	S	O	N
<u>Blue-Green</u>	0	0	0	0	11	6	7	5	0	4
<u>Ciliates</u>	0	2	3	0	4	10	16	11	14	7
<u>Flagellates</u>	0	0	2	3	6	29	2	19	6	4
<u>Diatoms</u>	0	83	170	282	12	14	6	2	16	6

STATION B										
	F	M	A	M	J	J	A	S	O	N
<u>Blue-Green</u>	45	105	145	234	64	50	91	35	14	23
<u>Ciliates</u>	5	15	10	8	10	5	6	5	2	4
<u>Flagellates</u>	1	3	7	10	9	2	8	4	0	0
<u>Diatoms</u>	0	0	0	0	0	0	0	0	0	0

## APPENDIX XVII

RESULTS OF THE 2-WAY ANALYSIS OF VARIANCE PERFORMED ON SAMPLES TAKEN  
AT STATIONS A AND B AT THE WATAUGA COUNTY SANITARY LANDFILL

Chemicals and Metals	F-Ratio Months	F-Ratio Stations	F-Ratio Interaction	P		
				Months	Stations	Interaction
Lead	39.51	472.19	47.28	0.00	0.00	0.00
Iron	935.37	8346.11	939.95	0.00	0.00	0.00
Selenium	5.28	31.15	5.28	0.00	0.00	0.00
Manganese	20.22	1357.07	13.14	0.00	0.00	0.00
Aluminum	2.08	6.62	4.10	0.10*	0.02	0.00
Chromium	7.84	2.25	5.03	0.00	0.15*	0.00
Zinc	13.54	0.05	7.70	0.00	0.8*	0.00
Copper	73.28	2031.91	100.58	0.00	0.00	0.00
NO <sub>3</sub>	42.58	1719.56	53.62	0.00	0.00	0.00
NH <sub>4</sub>	63.06	15126.30	64.58	0.00	0.00	0.00
PO <sub>4</sub>	443.22	574.24	367.10	0.00	0.00	1.00*

\*Not significant at .05 level.

APPENDIX XVIII

Correlations Between Microorganisms, Metals, and Nutrients

Variable	BG	Cil	Flag	NH <sub>4</sub>	NO <sub>3</sub>	PO <sub>4</sub>	Pb	Se1	Al	Mn	Cu	Fe	Zn	Cr
BG	1.00	0.51	0.62*	-0.03	0.21	-0.17	-0.42	0.78	-0.39	0.41	0.07	0.03	0.47	-0.50
Cil	0.51	1.00	0.84**	0.45	-0.18	-0.13	0.06	0.36	0.64	0.84*	-0.43	0.47	-0.39	0.54
Flag	0.62*	0.84**	1.00	0.51	-0.09	-0.22	0.19	0.45	0.26	0.79	-0.43	0.70	-0.10	0.33
NH <sub>4</sub>	-0.03	0.45	0.51	1.00	-0.08	-0.23	0.46	0.11	0.48	0.70	-0.56	0.81*	-0.33	0.63
NO <sub>3</sub>	0.21	-0.18	-0.09	-0.08	1.00	-0.28	-0.92**	0.81*	-0.31	0.36	0.38	-0.69	-0.01	-0.72
PO <sub>4</sub>	-0.17	-0.13	-0.22	-0.23	-0.28	1.00	0.50	-0.49	-0.27	-0.32	-0.60	0.07	0.57	-0.03
Pb	-0.42	0.06	0.19	0.46	-0.94**	0.50	1.00	-0.71	0.13	-0.20	-0.54	0.81*	0.04	0.61
Se1	0.78	0.36	0.45	0.11	0.81*	-0.49	-0.71	1.00	-0.27	0.72	0.03	-0.22	0.17	-0.57
Al	-0.39	0.64	0.26	0.48	-0.31	-0.27	0.13	-0.27	1.00	0.20	-0.08	0.13	-0.64	0.85
Mn	0.41	0.84*	0.79	0.70	0.36	-0.32	-0.20	0.72	0.20	1.00	-0.48	0.28	-0.11	0.04
Cu	0.07	-0.43	-0.43	-0.56	0.38	-0.60	-0.54	0.03	-0.08	-0.48	1.00	-0.56	-0.36	-0.28
Fe	0.03	0.47	0.70	0.81*	-0.69	0.07	0.81*	-0.22	0.13	0.28	-0.56	1.00	-0.03	0.55
Cr	-0.50	0.54	0.33	0.63	-0.72	-0.03	0.61	-0.57	0.86	0.04	-0.27	0.55	-0.54	1.00
Zn	0.47	-0.39	-0.10	-0.33	-0.01	0.57	0.04	0.17	-0.64	-0.11	-0.36	-0.03	1.00	-0.54

\*Significant at 0.05 level

\*\*Significant at 0.01 level

BG = Blue-green  
Flag = Flagellates  
Cil = Ciliates

APPENDIX XIX

THE GRAND MEANS (MG/L) OF SELECTED NUTRIENTS AND METALS AT STATIONS A AND B AT THE WATAUGA COUNTY SANITARY LANDFILL

Nutrients and Metals	Station A	Station B
NH	0.19	15.60
NO	0.05	0.18
PO	0.24	0.11
Al	0.02	0.03
Cr	0.02	0.03
Cu	0.06	0.78
Fe	0.10	12.63
Mn	0.41	2.04
Pb	0.01	0.03
Se	0.02	0.03
Zn	0.05	0.05

## VITA

Daniel John Shufford Rowe was born in Marion, North Carolina, on October 22, 1959. He attended McDowell High in Marion, North Carolina and graduated from there in June 1977. He entered Appalachian State University in 1981 and received a Bachelor of Science degree in Biology in December 1985. In 1986 he began work on a Master's degree in Biology.

Mr. Rowe's address is 204 Hill Street, Boone, North Carolina. His parents are Dr. and Mrs. Oehmig Daniel Rowe of Marion, North Carolina. He married the former Ellen Elizabeth Hood of Martinsville, Virginia.