AN ABSTRACT OF THE THESIS OF

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Few studies, and none in Oregon, have examined the presence and change of water quality parameters over time in popular natural swimming areas. This information is necessary to better understand water quality and risk of illness from either fecal contamination or cross-infection from other swimmers. The purpose of this study was to quantitatively measure bacterial and selected physical and chemical parameters, and collect background information for changes to the current state water quality criteria. Five natural swimming areas in Linn, Benton and Polk counties were chosen and sampled biweekly for physical, chemical, and bacterial parameters over a nine week period from June 28 to August 31, 1996. The results showed differences in bacterial levels over the sampling period which often varied by degrees of magnitude between sites. For example, the range in *Escherichia coli* levels was between 0 and 1000 colonies/100mL sample for two sites on the same sampling day. Similarly, the range in fecal coliform levels was between 5 and 500 colonies/100mL sample. The daily colony counts at each site exceeded the state standards at least 10% of the time for *E. coli* and 21% of the time for fecal coliform. At the most popular swimming site, Montieth Park, the fecal coliform regulatory levels were exceeded 79% of the time and *E. coli* levels were exceeded 42% of the time. This may be due to turbidity, high bather load, or a broken sewer line. The 30 day log mean of these values shows consistently elevated fecal coliform problems only at Montieth Park. For the other sites, the log means

did not exceed the state and federal regulatory limits for fecal coliform or *E. coli*. This raises questions about which estimates should be used to assess public health risk. None of the other parameters in this study were correlated with bacterial counts, so it appears that none of these factors is solely responsible for elevated bacterial levels. Further testing should be done at Montieth Park to determine the cause of the elevated fecal coliform levels. Any follow-up studies should test several different indicator organisms in addition to *E. coli* for comparison and assessment of their relationship to public health risk.

INVESTIGATION OF THE PRESENCE AND CHANGE OVER TIME OF WATER QUALITY PARAMETERS IN SELECTED NATURAL SWIMMING AREAS IN OREGON

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Erica Van Ess, Author

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INTRODUCTION

Swimming for recreation has historically been popular in nearly every country in the world. Both marine and non-marine natural swimming areas are considered to be valuable natural resources by local citizens. Most swimmers assume that the water is clean and safe if it appears pristine. However, bacteria are not detectable to the naked eye, and exist in the clearest and healthiest waters (Brock and Madigan, 1991). Most authors conclude that increased monitoring needs to be done in recreational waters, particularly in order to correlate the actual risk of illness to swimmers (Kebabjian, 1994; Blostein, 1991). Some researchers suggest that, "primary prevention requires the elimination of fecal contamination at swimming areas-an effort that may depend more on public cooperation than on governmental regulation" (Keene, McAnulty, Hoesly, Williams, Hedberg, Oxman, Barrett, Pfaller, and Fleming, 1994, p.583).

In all recreational water quality studies involving swimming and disease, swimmers who submerge their heads in bacterially contaminated water are those with highest risk of contracting subsequent illness (Cabelli, Dufour, Levin, McCabe and Haberman, 1979; Favero, 1985; Kay, 1994). The disease-producing potential of fresh water recreational areas is currently being estimated using certain bacteriological indicators that are correlated with the presence of fecal contamination, primarily *Escherichia coli (E. coli)*. These indicators, however, do not distinguish between contamination from humans, and that attributable to soils, vegetation, and animal feces. Past U.S. Environmental Protection Agency (USEPA) regulations tested for fecal coliform, but now are targeting *E. coli* as the proposed bacterial indicator for the future. Freshwater studies in New York by Cabelli et al. (1979), confirmed the findings of similar marine studies, in that the densities of enterococci in bathing water showed strong correlation with swimming-associated gastroenteritis rates and densities of *E. coli* showed no correlation at all. The similarities in the relationships of *E. coli* and enterococci to swimming associated gastroenteritis in freshwater demonstrate that these two indicators are equally efficient for monitoring water quality in freshwater (Cabelli et al., 1979). Few other studies, and none in Oregon, have examined the presence and change over time of water quality parameters in natural freshwater swimming areas. Most natural swimming areas in Oregon are not routinely tested or monitored. Currently, there is very little information available to estimate the bacterial and chemical water quality of these areas. This information is necessary to better understand water quality and risk of potential illness from either fecal contamination or cross-infection from other swimmers.

The uniqueness of this study is that it tested over time for general water quality indicators, such as pH, conductivity and turbidity, and also for specific bacterial indicators associated with human and animal contamination, such as fecal coliform and *E. coli*. This study provides new information about bacterial loads and how these loads change over the summer months when swimmers are more likely to be exposed. This type of information will be of use to the Oregon Health Division and local health departments in their assessment of public health risk from bacterial contamination of water, and to the state regulatory agency (Department of Environmental Quality) as they implement new water quality criteria.

Purpose

The purpose of this study was to quantitatively measure bacterial and selected physical and chemical parameters, at five natural swimming areas in Linn, Benton and Polk counties. The sites are located on the Mary's River, the Luckiamute River, and a slough off the Willamette River.

The research addressed two critical issues of water quality management that directly relate to freshwater recreational swimming areas in Oregon. These research findings may serve as a pilot for future freshwater recreational swimming studies in Oregon and other states. This study sought to quantify the presence and density of microbiologic indicators in freshwater recreational swimming waters and to identify possible factors that may contribute to these levels, such as swimmers, non-point sources, or other sources of contamination. The study also investigated how the water quality indicators changed over the summer sampling period, taking into account the seasonal and human variables.

Research Questions and Study Objectives

The following research questions directed the study:

1) What baseline bacterial levels are present in selected local natural swimming areas?

2) What differences in bacterial levels exist over the summer at these sites?

3) Do bacterial indicators at these sites exceed Oregon state standards? If so, how often?

4) What factors may contribute to changing bacterial levels at these sites?

The objectives of the study were as follows:

1) To determine bacterial levels found in water of *E. coli* and fecal coliforms.

2) To determine changes in bacterial levels over the swimming season.

3) To determine if relationships exist between bacterial indicators and bather density, rainfall, air and water temperature, water pH, and sunlight.

4) To provide information to state and local agencies who advise the public about possible health risks in natural swimming areas.

This study is exploratory research to gather new data that can be used by Linn, Benton, and Polk counties, and the state, in decision-making concerning water management.

Definition of Terms

<u>Enterococci-</u> A commonly used indicator organism, especially in marine waters. It is a group of fecal streptococci that lives in the intestine of warm-blooded animals and in some plants.

Escherichia coli (E. coli)- A major species of fecal coliforms that is specific to warm-blooded mammals. Some species produce toxins that are a common cause of gastroenteritis.

Fecal coliform bacteria- A more specific group of the total coliform bacteria group. The presence of fecal coliform bacteria provides evidence of fecal contamination and is indicative of fecal pollution and the possible presence of enteric pathogens (Csuros, 1994).

Gastroenteritis- An illness that is often used to designate a water- or foodborne disease for which the causative agent has not been specifically identified. It involves inflammation of stomach and intestines, with diarrhea, nausea, vomiting, abdominal cramps and low grade fever.

Indicator organisms- These organisms are naturally occurring in the digestive tract and, if found in water, indicate probable fecal contamination. These organisms should be consistently present in human feces and survive in the water as well as a pathogenic organism could, order to indicate if human wastes are in the water. Some typical indicator organisms are; total coliform, fecal coliform, *E. coli* and enterococci.

Natural swimming area- Loosely termed a "swimming hole". A local body of water where members of the community swim on a seasonal basis.

Water Quality Limited- A listing that a body of water receives when it exceeds State and Federal standards for acceptable water quality (CWA, 1987).

LITERATURE REVIEW

The literature review is divided into the following topics: swimming areas as a natural resource, national and local water quality studies, disease-producing organisms in water, water quality regulations and current changes, and water quality parameters.

Swimming Areas as a Natural Resource

Swimming for recreation has historically been popular in nearly every country in the world. Both marine and non-marine natural swimming areas are considered to be valuable natural resources by local citizens. Because swimming areas are considered a natural resource, there is risk perception involved in the public's use of an area that is aesthetically pleasing. The public generally views a water body that appears clean to be pristine, and that there is no risk associated with swimming there. This perception could be changed by new information, such as warnings that the water is bacterially contaminated. Risk perception toward bacterial water quality problems is not strongly documented. Typically, the potential response of the public is based on studies dealing with other environmental hazards, such as a hazardous waste site or an incinerator (Baird, 1986; Slovic, 1980). In the Corvallis and Albany areas, high levels of bacteria in natural swimming areas are the environmental health hazard of concern for this study, because of the potential risk of illness. Dr. Kenneth Williamson, a water quality expert at Oregon State University, believes the public's perception of health risk involved in swimming hole contamination is so minimal that the public will not even consider swimming there a serious health risk. Furthermore, Williamson thinks the public will expect the health department to post a sign telling of the high bacterial levels and then will simply avoid the posted areas. He also does not suspect that this type of environmental health problem would create much outrage, as, "bacteria are not 'exotic' enough ...and there aren't any 'bad' guys to project their anger upon." (K. Williamson, personal communication, Dec. 2, 1996). He bases his statements on information from the risk perception literature that suggests that the public becomes more alarmed about risks that are less familiar to them and those that they have no control over (Sandman, 1993).

Wade (1989) pointed out that water quality is also important from a cost-benefit standpoint, especially regarding tourism. He states that any operation based on attracting tourists for water activities may lose a good deal of profit by not protecting their water quality from the outset, as water quality problems are usually difficult to deal with. He comments that poor water quality has an negative effect on users and that the tourist industry should become more active in protecting natural waters.

Bacterial Studies in Recreational Waters

Most swimmers assume that the water is clean and safe if it appears so. However, bacteria are not detectable to the naked eye, and exist in the clearest and healthiest of waters (Brock and Madigan, 1991). As early as 1953, an epidemiological study by A.H. Stevenson (1953) showed a correlation between swimming and incidence of illness at two of his study sites. He tested three bodies of water; Lake Michigan, the Ohio River and Long Island Sound for total coliform counts, number of swimmers, number of nonswimmers, and subsequent illnesses. These sites were chosen because they had differing levels of water quality shown by historical data; their water quality was not susceptible to rapid fluctuation; and the areas were near residential populations that used the waters frequently for swimming. Stevenson made bather load observations at the time of sample collection. He found conclusively that levels above 23,000/100mL coliform (using the most probable number method) were highly correlated with increased incidence of illness. He also noted, "higher overall illness incidence may be expected in the swimming group over that in the nonswimming group regardless of the bathing water quality" (Stevenson, 1953). This was the first in a series of studies attempting to demonstrate that certain amounts of bacteria in natural waters could produce illness in swimmers.

Because only few studies have been done involving bacterial levels in non-marine swimming areas, many assumptions must be drawn from sea bathing studies. Many of these studies have found correlations between human illness and swimming in water with high levels of indicator organisms. This may be due a range of factors, from point source sewage pollution to birds defecating in the water (Kebabjian, 1994). Kebabjian (1994) tested for fecal coliform and enterococci in marine water surrounding storm drain outlets along a California beach. The urban runoff produced is generally sewage-free, so the high bacterial levels probably were due to animal wastes. He also found the bacterial levels decreased quickly as they entered deeper water. The author expressed frustration with the lack of research in water quality in areas used for swimming, because the correlations between indicator organisms are poor and none of them seem to consistently predict water quality. Because of this, he states, it is difficult to be sure that water quality standards are being met. He concluded that new, inexpensive tests with indicator organisms specific to humans need to be found and utilized to monitor water quality.

A number of different factors may contribute to elevated coliform levels in water. In a lagoon study by Gersberg, Matkovits, Dodge, McPherson and Boland (1995), rainfall was a significant factor in reducing water quality. The study site was a coastal California lagoon with freshwater inflow that had been managed as a state ecological reserve. The mouth of the lagoon was seasonally blocked by sand (May-October), so that no exchange of water with the ocean could occur. Because of this, the water quality of the lagoon would decrease as the dissolved oxygen, coliform levels and salinity increased. To improve the lagoon's general water quality, the researchers opened the mouth of the lagoon in the summer of 1994. They monitored coliform levels to estimate public health risk to swimmers in the beach area. The lagoon, its mouth, and the immediate ocean were sampled for total and fecal coliform and enterococci using the most probable number method. The sampling took place at low tide to produce a "worst case scenario" of bacterial levels. The researchers found that the bacterial levels dramatically increased after rain events and that the beach required posting one to two weeks after opening the lagoon and after each significant rain event. They found that, "at the surfzone site closest to the lagoon mouth, 40% of the samples exceeded a total coliform bacterial density of 1,000 organisms/100mL" (Gersberg et al., 1995, p.24). In addition, the fecal coliform and enterococci exceeded the California State standards. Similar to Kebabjian, they found the bacterial levels dropped dramatically upon entering the ocean only 15m from the lagoon mouth.

In addition, there is controversy over selecting an appropriate indicator organism for water quality surveys. Other factors, such as close proximity to a wood processing plant can produce a false fecal coliform response, but will not affect *E. coli* levels. This indicates that fecal coliform is not a good indicator of sewage contamination (Corvallis Public Works, 1995). Some studies have found that fecal streptococci may be a better indicator of water quality than coliforms (Kay, Fleisher, Salmon, Wyer, Godfree, Zelenauch-Jacquotte, and Shore, 1994).

Kay et al. (1994) conducted a randomized controlled exposure study in an attempt to eliminate some of the confounding associated with recreational swimming, such as the swimming population selecting itself and controlling for other non-water related risk factors (eg. diet). The researchers sampled swimming areas at UK resorts each half hour at surf, mid- and chest levels for total coliform, fecal coliform, fecal streptococci, *Pseudomonas aeruginosa* and total staphylococci to see which showed higher correlations to illness. The study was a double-blind study, in that all of the swimming volunteers and interviewers were blind to the water quality status and swimming status of the areas and participants. All of the swimmers were assigned an area and duration of swimming, and were interviewed before leaving the beach. The researchers found a linear relationship between the probability of gastrointestinal illness and fecal streptococci at chest level. This was the only bacterial indicator that showed a significant dose-response relationship.

These previously described investigations involved marine water, and studies have shown that marine studies do not necessarily give the same results as those in freshwater (Fleisher, 1991). For example, indicator organisms in marine and freshwater do not always perform similarly, such as enterococci and fecal coliform. Enterococci has shown a superior resistance to die-off in marine environments compared to coliforms (U.S. EPA, 1986). Favero (1985) does not believe that marine and natural water indicators can be the same, due to differing illness rates between the two. He cites a study that observed similar densities of enterococci between a marine and freshwater site, but produced illness rates that were, "approximately three times greater among swimmers using marine waters than those using fresh water" (Dufour, 1984). In light of these discrepancies, Favero suggests it may be necessary to have differing regulatory levels for marine water, freshwater, and swimming pools. In addition, there may also need to be differing indicator organisms for each, but there is still little evidence to suggest the best levels and indicators for overall water quality.

In 1991, Fleisher critiqued the EPA study performed by Cabelli and Dufour (1979) from which the current enterococci standards used by the EPA are based. Fleisher (1991) reanalyzed the data collected in this study and found that, "the probability of gastroenteritis occurred in the individual swimmer...at two to three times the current maximum allowable mean enterococci densities at each of the study locations" (Fleisher, 1991, p.264). This means that the regulatory enterococci levels at these locations could be increased without any additional risk to the swimmer, showing that the EPA may have an overly conservative enterococci standard and unnecessary beach closings may result.

However, Fleisher reported that the level of risk to the swimmer due to fecal coliform is accurately predicted under federal regulations and needs no revision.

Most authors conclude that increased monitoring needs to be done in recreational waters, particularly in order to correlate the true risk of illness to swimmers (Kebabjian, 1994; Blostein, 1991). Keene et al., suggests, "primary prevention requires the elimination of fecal contamination at swimming areas-an effort that may depend more on public cooperation than on governmental regulation" (Keene, McAnulty, Hoesly, Williams, Hedberg, Oxman, Barrett, Pfaller, and Fleming, 1994, p.583).

Local Water Testing Results

Three test sites are located on the Mary's River and the Willamette River, which are routinely tested at specific locations, by the Water Quality Lab in Corvallis, Oregon. The most recent results from local streams were reported in the *1995 Yearly Summary Stream Monitoring Report* (produced by the Corvallis Public Works, Utilities Division). These streams are tested to assess their general water quality and to be sure there are no contamination events that should be controlled. Those included in the report are: Oak Creek, Dixon Creek, Squaw Creek, Sequoia Creek, Mill Race and the Mary's River. Each stream was sampled at one site monthly for pH, dissolved oxygen and fecal coliform. If the coliform levels exceeded 1000 colonies/100mL on a given day, sampling was repeated at that location until the source of contamination could be found. The range of fecal coliform levels among these rivers was approximately <20 colonies/100mL in the winter and 460-several thousand in the summer. Of these six streams, only Sequoia Creek and

Mill Race had levels between 1400 and TNTC, which did not meet the federal or state monitoring standards in 1995.

Rivers, streams, and lakes throughout the state are tested by the Oregon Department of Environmental Quality (DEQ) for determination of placement on the 303(d) list, meaning that the area is water quality limited (CWA 33 U.S.C 303(d)). An area that is water quality limited is not in compliance with state and federal regulations or standards for fecal coliform, temperature, dissolved oxygen, or the presence of toxics. A water body is removed from the 303(d) list when it meets water quality standards, is in violation due to natural conditions, rather than human-created conditions, or when it is anticipated to meet water quality standards in the future through a management plan. Among these rivers are the Mary's River, the Calapooia River, the Luckiamute River and the Willamette River, which encompasses all of the five sampling sites. These are all currently listed as water quality limited due to high levels of fecal coliform and low dissolved oxygen levels by the DEQ. For a water body to be water quality limited for fecal coliform, the geometric mean of bacteria must exceed 200 per 100mL or more than 10 percent of the samples and a minimum of at least two exceedences exceed 400 per 100mL for the season of interest (OAR 340-41, 1996).

Disease-Producing Organisms in Water

There are many disease-producing organisms present in freshwater, such as *Salmonella* species, *Shigella* species, *Vibrio cholerae*, *Escherichia coli*, *Hepatitis A virus*, and *Giardia* species (Csuros, 1994). To test for harmful pathogens, tests for other 'indicator organisms' are used to reduce the time and cost of testing for each pathogen individually. Two common indicators are fecal coliform and *E. coli*, which are "natural inhabitants of the human digestive tract and their presence in water indicates that the water is contaminated with fecal material" (Csuros, 1994). Enterococci is also another commonly used indicator organism, especially in marine waters. Many different indicator organisms exist, as shown in the following studies, and they are used to determine risks for different types of illness. For example, staphylococci appears to be a more consistent indicator of infection of the skin, ear, and respiratory tract than fecal coliform (Favero, 1985). The choice of an appropriate indicator organism for an epidemiological study, depends in part on the particular health effect being measured.

Brief descriptions of some common indicator organisms that could be chosen for a follow-up study are included. *Salmonella* bacteria are Gram-negative rods that inhabit the intestinal tract of humans and some animals. Salmonella cause infections, fever, cramps, nausea and diarrhea. The severity of the infection depends on how may organisms are swallowed and digested (Csuros, 1994). *Shigella* bacteria cause shigellosis, which can be caused by drinking contaminated water. Shigellosis consists of severe diarrhea and destroys intestinal tissue (Csuros, 1994). *Vibrio cholerae* is the causal agent of cholera and is transmitted only by water. *V. cholerae* bacteria are Gram-negative, curved rods. The cholera entertoxin causes a life-threatening diarrhea with can result in dehydration and death if the patient is not given fluids and electrolyte therapy (Brock and Madigan, 1991). *E. coli* is the most well-known of the intestinal microorganisms. "It is usually not dangerous, but some species produce toxins that cause diarrhea" (Csuros, 1994, p. 252).

Hepatitis A is a virus that is ingested, multiplies in the intestinal tract and then moves to the kidney, liver, and spleen. This virus is resistant to chlorine disinfection. The symptoms are jaundice, nausea, diarrhea, and fever (Csuros, 1994). *Giardia lamblia* is a protozoan parasite that causes acute gastroenteritis. *G. lamblia* is a flagellated protozoan that is primarily transmitted through water in a cyst form that is swallowed by the human and germinates in the gastrointestinal tract. The cyst form is very resistant to chlorine disinfection, but is removed by filtration or boiling (Brock and Madigan, 1991).

As reported by the *Morbidity and Mortality Weekly Report* (1993), between 1991 and 1992, 39 outbreaks were reported by 21 different states involving recreational waters. Most of these occurred during June or July, in the peak swimming season. Although these outbreaks may seem small, 1,825 people became ill as a result. Although some resulted from swimming pool exposure, 45% were directly related to lake and river water exposure. The investigators also noted, "Swimming and other recreational activities in which unintentional ingestion of water can occur are known to increase the risk of gastrointestinal illness, even in non-outbreak settings" (MMWR, 1993, p. 19).

The majority of these disease outbreaks were linked to an incontinent swimmer, another mode of fecal contamination, or swimmers repeatedly putting their heads under water. For example, in a study involving a gasteroenteritis outbreak caused by swimming at a campground lake, the researchers found that, "in children, immersing the head or ingesting water was significantly associated with illness" (Drenchen, 1994, p. 9). Blostein (1991) found in his study involving a shigellosis outbreak in a county park in Michigan, "that a growing number of incidents that have been associated with recreational use of water" (p. 317). He also found a significant association between illness and those who submerged their heads. Neither of these studies could measure the time of immersion as they followed an outbreak and only had the post-exposure data that they could gather from the people involved. In most studies, the main factor for subsequent illness is the submersion of the swimmer's head and/or the total length of time spent underwater, some as short as 10 minutes (Fleisher et al., 1996).

In a prospective epidemiological study by Seyfreid, Tobin, Brown, and Ness (1985), a wide range of bacteriological species were tested to determine the indicator organisms that best predict illness in swimmers. The researchers tested for fecal coliform, fecal streptococci, coagulase-positive and coagulase-negative staphylococci, *Psuedomonas aeruginosa* and heterotrophic bacteria along fresh water beaches in Ontario, Canada. This study was unique in that the researchers sampled and analyzed both water and sediment from the swimming areas. Correlations were found between illness and fecal coliform, illness and fecal streptococci and illness and total staphylococci. During this study the levels of fecal coliform never exceeded Ontario's guideline of 100 colonies/100mL, but the levels in the sediment were at least 10 times higher than those in the water. The authors concluded that sediment may also be a potential bacterial source at bathing beaches, that may be resuspended by swimmer or wave action (Seyfreid et al., 1985).

E. coli may be an especially dangerous organism because it has a high survival rate in lake water and a low exposure dose can cause infection. In a continuation of their prospective epidemiological study used to provide information to the EPA, Cabelli et al. (1982) found that, "very low levels of enterococci and *E. coli* (10/100mL) are associated with appreciable attack rates (approximately 10/1000 persons) for "highly credible" intestinal symptoms" (p. 606). All beaches sampled were near large metropolitan areas and were used often on weekends but not on weekdays. At each location, the researchers paired a pristine beach and a contaminated beach that had similar swimming populations for sampling. They tested and interviewed only on the weekends between 11am and 5pm. The water was tested for enterococci, *E. coli, Klebsiella*, Enterobacter, Citrobacter, total coliform, *Clostridium perfringens, Pseudomonas aeruginosa*, fecal coliform, *Aeromonas hydrophila*, and *Vibrio parahemolyticus*. From all of these indicator organisms, they found that enterococci and *E. coli* proved to have the best association with gastrointestinal symptoms (about 10/100mL indicator organism corresponded to 10 gastrointestinal reports).

In the summer of 1991, an outbreak of 21 cases of *E. coli* and 38 cases of *Shigella sonnei* was traced to Blue Lake Park in Portland, OR (Keene et al., 1994). Blue Lake is self-contained and fed by underground springs, so there is no natural circulation of the water in the lake. All cases patients were children who had been swimming, and many who had reported swallowing lake water. The researchers determined the outbreak to be a result of fecally-contaminated lake water. During the time of the outbreak, the levels of indicator organisms did not consistently exceed U.S. EPA regulatory limits, which suggests that the level of indicator organisms was not always predictive of health risk. As a result of this study, infants and toddlers can no longer swim in the lake and are restricted to a water spray play area that drains to city sewers. This is an attempt to reduce the potential for fecal contamination of the lake by children who are not toilet-trained. In addition, a pump was installed to circulate the water in the lake (Keene et al., 1994).

Water Quality Regulations

Natural waters are regulated at the federal level by the U. S. Environmental Protection Agency under Section 304 of the Clean Water Act (CWA 33 U.S.C 304, 1972). States report their water assessments to the U.S. EPA for compilation into a biennial report, called the *National Water Quality Inventory*. This report, however, does not present a complete nationwide picture because only 18% of the total rivers and lakes were monitored (Fisher, 1994). This reports shows the monitoring reports and water quality status summaries produced from these for every state. In Oregon, the rivers are categorized into basins and then sampled by basin. The streams are monitored by the DEQ and the U.S. Geological Survey and U.S. Bureau of Reclamation (under contract to the DEQ). The rivers are originally chosen though ambient and special-project monitoring activities. Another report, the *1988 Nonpoint Source Assessment* was then used to determine in which areas water quality monitoring was lacking (DEQ, 1994). According to the CWA, no action is specifically stated for waters that do not comply with all federal and state standards, but it is understood that the area should at least have a notice of failure posted, which would remain until the water tests showed acceptable results (Pike, 1993).

"The microbiological guideline for direct contact recreational waters recommended by the National Technical Advisory Committee (NTAC) to the Federal Water Pollution Control Administration in 1968, and set forth by the U.S. Environmental Protection Agency in 1976, is a geometric mean fecal coliform density of 200 per 100 mL of water" (Cabelli et al., 1979, p. 690). In Oregon, five water quality standards were recently revised, including bacteria, nitrates, temperature, dissolved oxygen and pH (ACWA,1996). This decision involved changing the bacterial indicator organism from fecal coliform to *E. coli*. The current fresh water guideline for *E. coli* is a geometric mean *E. coli* density of 126 per 100 mL of water. It is believed that swimmers exposed to 126 E. coli colonies/100 mL of water would not exceed a level of 8 gastroenteritis cases per 1000 freshwater swimmers and 19 cases per 1000 marine swimmers (Pike, 1993). In addition, the U.S. EPA (1986) recommends testing of all waters for fecal coliforms or *E. coli* and enterococci, which are appropriate indicators of gastrointestinal illness.

The current regulations for marine waters are highly challenged by Fleisher, as he reanalyzed the original study by Cabelli (1979) which forms the basis for the EPA bacterial water criteria for marine waters. Fleisher (1991) believes that the results may have been skewed due to differences in salinity between the three test sites, potentially producing higher bacterial counts in the areas of lower salinity. He concludes that the standard is too low and does not predict disease for all marine waters and that more testing needs to be done to determine the appropriate standard levels.

Water Quality Parameters

Water quality is evaluated with various tests that measure chemical, biological and physical properties of the water body. These tests generally show if the water body can be classified as healthy or contaminated. Upon completion of testing, the results can be compared to the state and federal standards to determine the health of the water body (Salvato, 1992). The chemical tests used in this study were nitrate, nitrogen-ammonia and phosphorous. These were chosen because they are indicators of human contamination and have a negative impact on water quality in excess amounts. The physical tests used were air temperature, water temperature, dissolved oxygen, conductivity, turbidity and pH. These tests are important because they impact the health of a stream and the appearance of the stream. Finally, the bacterial tests chosen were fecal coliform and *E. coli.* These two are important from a public health standpoint because human illness may result from swimming in contaminated areas (Cabelli et al., 1979).

Conductivity measures the ability of water to carry an electric current, depending on the presence of ions, their total concentrations, mobility, valence, and temperature. Increased ionization takes place as the temperature increases. Inorganic bases, salts, and acids are good conductors. Organic compounds that do not dissociate in water are poor conductors. Conductivity is used as a quick test for the mineral content of a sample (Hach, 1992).

Dissolved oxygen (D.O.) is the amount of molecular oxygen dissolved in water at a given temperature. Solubility of oxygen in water is affected by partial pressure of oxygen gas, temperature, and salinity. It varies inversely with temperature. D.O. is important because it is necessary for flora and fauna, is an index of the health of a stream and is critical in the optimal treatment of wastewater (Csuros, 1994). After a contamination event, the dissolved oxygen content is an important indicator of the stream recovery and purification process. When pollution occurs, the amount of oxygen in the water dramatically decreases in an effort to decompose the organic contaminant, called the 'zone of degradation'. This continues halfway through a 'zone of active decomposition', where the oxygen levels begin to rise. The stream then exhibits a 'zone of recovery' until it regains its previous level of oxygen saturation. If there is continuous pollution, then the water body cannot complete this cycle of recovery, and remains contaminated (Salvato, 1992).

Escherichia coli is specific to warm-blooded mammal fecal contamination. It has been chosen as the new indicator organism for water testing, as it is more specific to human contamination than fecal coliform (OACWA, 1996). Using the approved membrane filtration method, positive results are yellow colonies on a plate after incubation. The current standards for *E. coli* in marine and natural waters are 126 colonies/100mL (APHA, 1989).

Fecal coliform is a test that measures human or animal fecal contamination. The presence of fecal coliform generally indicates a possible pathogenic presence. Using the approved membrane filtration method, positive results are obtained by counting the number of blue colonies on a plate after incubation. The regulated level of fecal coliform is 200 colonies/100mL (APHA, 1989).

Nitrate is generated by the decay of organic matter and from industrial and agricultural chemicals. Nitrate is the most completely oxidized state of nitrogen and is evidence of "previous" pollution. Nitrate can quickly degrade water by encouraging excessive growth of algae (Csuros, 1994). High nitrate levels are most commonly found in bodies of water near leaking septic systems, large animal operations and large agricultural areas.

Nitrogen, Ammonia is produced as the first decomposition product of organic nitrogen-containing compounds and by the hydrolysis of urea. Ammonia is normally found in groundwater, although at low levels because it adsorbs to soil particles and does not leach easily. High levels are toxic to aquatic life, although ammonia is a plant nutrient (Csuros, 1994).

The pH is an indicator of the acid-base neutralization capability of water depending on the temperature. This is one of the most frequently used and more important tests for any type of water. pH measures the acidity and the alkalinity of water, which are enhanced as water temperature increases. A pH below 5 would be too acidic to support most life, and a pH above 8.6 is too alkaline for most animals and humans to drink. Testing pH is standard for all water testing, including wastewater (Csuros, 1994).

Phosphorous is found as both organic and inorganic compounds. It is important to all living organisms. Dissolved phosphorous in the form of phosphates is consumed by living organisms as part of the food chain. Excess levels of phosphates can stimulate growth of plants, such as algae, and can cause them to take over a water system. This contaminates the environment, reducing other organism's ability to survive. High levels of phosphates in surface water are usually due to fertilizers and detergents entering the water (Csuros, 1994).

Turbidity is an important indicator of clarity. This is a result of suspended matter in the water caused by soil particulates, microscopic organisms, or plankton. These particles scatter light waves, making the water appear cloudy, reducing the aesthetic quality of water. These suspended particles can actually shield pathogens from detection. Increased turbidity requires more oxygen to break down any organic material, reducing the amount of oxygen available to aquatic life. (Csuros, 1994)

METHODS

Collection of Background Data

This study was conducted in Benton, Polk, and Linn counties in Oregon, during the summer of 1996. Before beginning the study, maps and general background information about the sites was gathered. In late June and early July 1996, baseline samples were taken in order to establish a 'normal' background level of bacterial counts and other parameters prior to the swimming season, which is normally July through August. At each site, one set of samples was collected for bacterial, physical and chemical analysis.

The physical parameters consisted of air temperature, water temperature, conductivity, turbidity and pH. The chemical parameters consisted of dissolved oxygen, nitrate and nitrogen, ammonia. The daily air temperature was obtained from the Hyslop field site database, along with precipitation data.

Sampling for the study began July 6, 1996 and ended August 31, 1996. Samples were collected twice weekly for nine weeks, on Wednesday and either Saturday or Sunday between noon and 3pm.

Site Selection and Description

The sites for this study were selected based on reports of commonly used "swimming holes", which were identified by local citizens, university students, and public health professionals. After a preliminary list was generated, the sites were visited to see if they were accessible. Once all the potential sites were observed, the list was narrowed to five sites in close geographical proximity so that samples from each site could be taken and processed each sampling day. This decision was made with the consideration that the bacteriological samples should be processed within six hours of collection (APHA, 1986). A map showing the location of all five sites is shown in Figure 1. Pictures of the actual sites are shown as Figures 2-6.

Site #1, the Dow family swimming hole, is located on the Luckiamute River off King's Valley Highway (Hwy. 223), directly outside the town of King's Valley. The Dow family owns the land surrounding the swimming area but the river is public property. This site differed from the others in that the access is limited to persons who are guests of the Dow family. Because the family often hosted large swimming parties, the swimming area was heavily used. The swimming area is a wide place in the river, where the water drops off a small ledge and pools along one bank (see Figure 2). The water at this site was very clear and fairly quick-moving along the opposite bank. The beach consisted of gravel and sand, with the river bottom being mostly gravel. The pool is well shaded around its edges and there is an abundance of heavy foliage along the banks.

Site #2, the 53rd Street site, is located on the Mary's River along 53rd St. south of Corvallis/ Philomath. The samples were taken at a bridge where the pavement turns to gravel. Although our initial contacts with the county health department indicated swimmers used this area, none were seen when the samples were collected. However, there was evidence of use at the site, such as clothing, cigarettes, and wrappers. The water moved slowly, but was clear at this site (see Figure 3). The river bottom was muddy and the banks were high and devoid of vegetation.

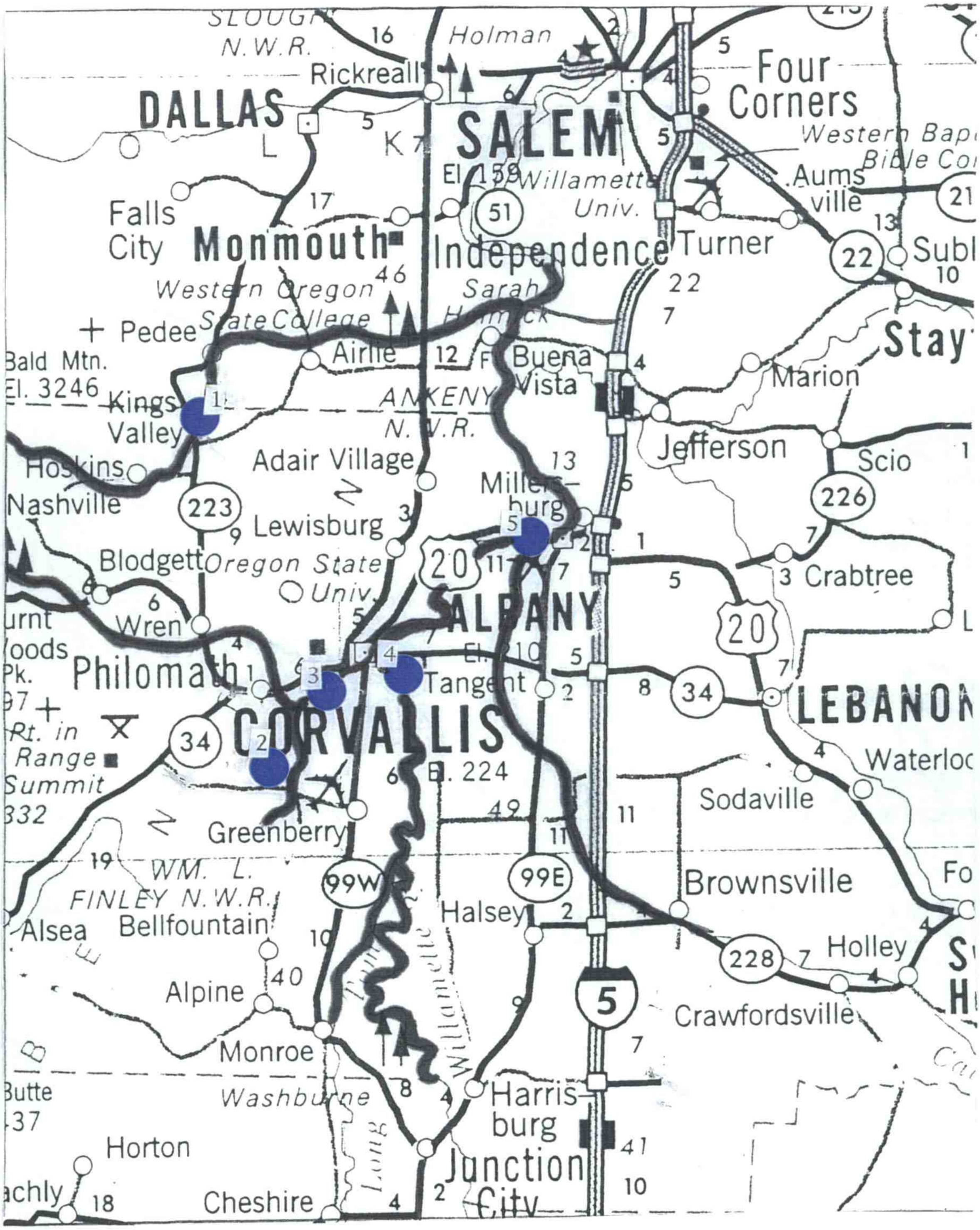

Figure 1. Map of All Sample Sites

Figure 2. Dow Site on the Luckiamute River

Figure 3. 53rd Street Site on the Mary's River

Figure 4. Avery Park Site on the Mary's River

Figure 5. Morse Pond Site

Figure 6. Montieth Park Site on the Calapooia River

Avery Park, Site #3, is also located on the Mary's River. The samples were taken in Avery Park near the Oak Grove picnic area. Avery Park is a public park maintained by the City of Corvallis Parks and Recreation Department. The banks here are very high and eroded, due to the recent flooding. The river bottom is gravelly, with varying sizes of gravel, from large rocks to pea gravel. The river bottom drops off sharply several feet from the beach (see Figure 4). Because of the sharp drop off, most children swam near the shore. The banks have dense tree cover and the water moves swiftly.

Site #4, Morse Pond, is a human-made pond, originally used as an alluvial deposit (gravel) mining area. This site is also called 'Clark Pond' and 'the quarry' by local citizens. The property is owned privately by Morse Brothers Building and Supply and is posted with "No Trespassing" signs, which are ignored by the general public. The pond access is on the south side of Highway 34, across from the Trysting Tree Golf Course. This pond is fed by small inlets from and outlets to the Willamette River causing the water to be very slow-moving. In addition, beavers have created dams in the small adjoining streams, which contribute to the stagnant condition of the pond. This water body is approximately 25 feet deep and the largest of all the sites (see Figure 5). Throughout the course of the summer there were few swimmers present, but there were many people fishing, kayaking and canoeing.

Monteith Riverfront Park, Site #5, is located on the Calapooia River in downtown Albany off Washington Street. Monteith Park is a public riverfront park that is a popular place for summer concerts, weddings, picnicking and swimming. It is maintained by the City of Albany Parks and Recreation Department. The samples were taken just upstream of the confluence of the Calapooia and Willamette Rivers. This location was ideal for young swimmers, as the depth of the water across the swimming area, from beach to beach, was only four feet deep (see Figure 6). This was the most populated site of the five sites. The beach and river bottom are sandy, with some large rocks that were easily visible. The water is clear and swift moving.

Field Technique

The five sites were sampled between 11:30 pm and 2:00 pm each sampling day, which represented peak swimming hours. All sites were tested in the same order each week, from #1 to #5. The sampling required between two and three hours to sample all of the sites. Each site was sampled at approximately the same time of the day every day it was sampled.

Samples collected for physical and chemical tests were obtained in clean, glass bottles and the bacterial samples were collected in autoclaved, sterile glass bottles. The samples were drawn as surface grab samples from the top 12 inches of the swimming area at a depth of approximately three feet as recommended by Csuros (1994). The samples were taken near the surface because that is where the swimmer would most likely be in contact with the water. The sampler waded into the water to a depth of approximately three feet and took a grab sample facing upstream. The samples were then stored in a cooler with ice for transport to the lab.

Water temperature, conductivity, and pH were all measured on site as soon as the sample was collected. Water temperature and pH were measured simultaneously with the Portable Hach One pH Meter, an EPA-approved technique (Hach, 1992). The pH meter was calibrated before each sample run, using buffered solutions of pH 4 and pH 7. Conductivity was measured with the Hach Portable Conductivity/TDS Meter. This instrument does not require weekly calibration, but must be thoroughly rinsed with deionized water prior and following each use. The dissolved oxygen samples were drawn in clean, 60mL BOD bottles and stabilized with two reagent powder pillows, until the sample could be titrated with sodium thiosulfate (0.2 N) in the lab, according to the approved method (Hach, 1992).

Lab Procedures

Samples were collected and analyzed for fecal coliform and *E.* coli. Bacterial samples were analyzed at the Environmental Health Lab at Oregon State University within six hours of collection, using state certified lab technique, according to EPA Standard Methods for Examination of Water and Wastewater (APHA, 1989). In addition, samples were split, with half being analyzed by the Corvallis Treatment Plant Water Quality Lab during the first two weeks of the sampling period to ensure precision in technique (see Figure 7). The membrane-filter technique was used to test for both fecal coliform and *E. coli*. The sterile bottles were well shaken before any sample was pipetted. All samples were run as 10mL dilution, as recommended by the Corvallis Water Quality Lab, with the exceptions of tests performed following high count periods, where the dilutions were 1mL or 0.1mL. Sample dilution is necessary when the bacterial levels in the water are so high that the plates are too numerous to count (TNTC) because so many colonies have grown. Ideal counts are in the range of 20-60 colonies. To achieve this range, natural waters must be diluted, using 10mL of water sample in 90 mL of buffered dilution water.

Chemical analyses were conducted for dissolved oxygen, phosphorus, nitrogen-ammonia, and nitrate. These parameters were tested using the EPA approved, Hach DR2000 Environmental Laboratory. Nitrate, phosphorous, turbidity and color were measured using the spectrophotometer included in the Hach laboratory, according to the instructions in the manual (Hach, 1992). All sample bottles were well shaken before testing. Dissolved oxygen requires the addition of a final powder pillow, and then 20mL were titrated with 0.2N sodium thiosulfate until the solution became clear, counting the number of drops used. Nitrate and phosphorous testing both require the addition of a powder pillow (NitraVer 5 and PhosVer 3, respectively) to the sample, a timed reaction period, and reading using the spectrophotometer. Similarly, nitrogen-ammonia requires the addition of 40 drops (1mL) of Nessler Reagent to the sample before reading with the spectrophotometer. Finally, turbidity and color are measured by the spectrophotometer at differing wavelengths with no reagents added.

Quality Assurance/Quality Control

All Quality Assurance (QA) and Quality Control (QC) procedures were performed in accordance with Standard Methods for the Examination of Water and Wastewater (APHA, 1989). One random duplicate of each chemical/physical test was performed each sampling day and every bacterial test was run in duplicate. In addition, the sites were sampled at approximately the same time each sampling day and in the same order. The temperature of the incubators was checked every sampling day and noted on the lab bench sheet. These temperatures remained constant throughout the sampling period and did not require adjustment. The autoclave was checked for sterility by using autoclave tape and autoclave bags which show a color change to alert if the autoclave was not sterilizing the equipment.

Split samples were run at two separate instances with the Corvallis Water Treatment Lab. Results indicated highly correlated values between the split samples (0.91 for *E. coli* colony counts and 0.76 for fecal coliform counts). See Figure 7.

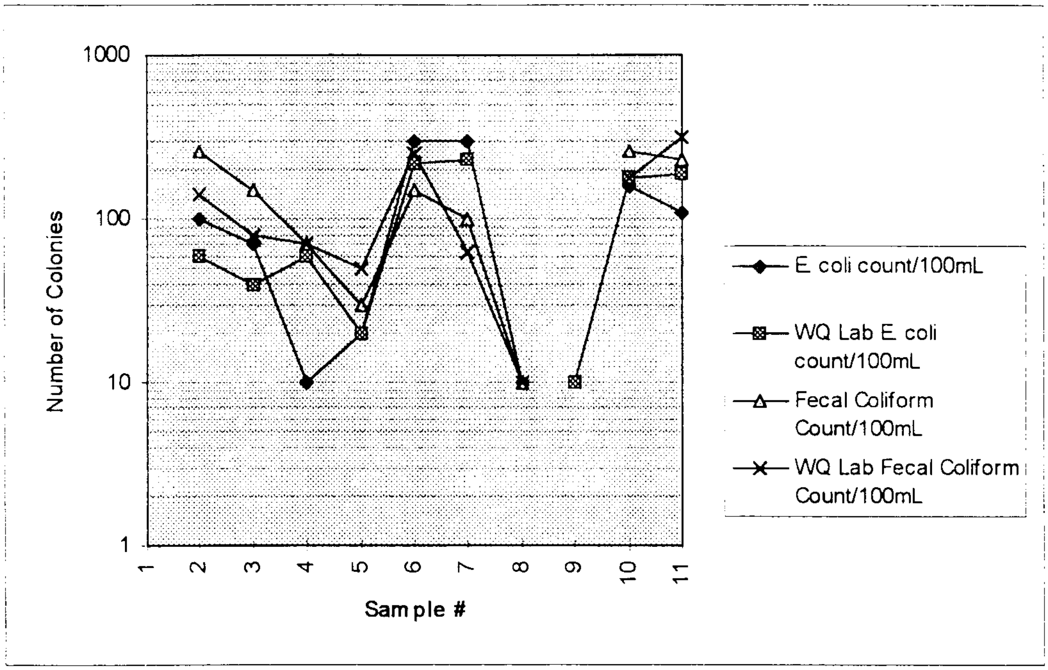

Figure 7. Graph of the split samples processed for QA/QC

Statistical Analysis

Data was entered into an Excel spreadsheet weekly as results were obtained. In order to establish the correlation between the variables, the linear correlation coefficient was determined. Those tested for correlation coefficients were; air and water temperature, air temperature and *E. coli*, fecal coliform and *E. coli*, daily precipitation and fecal coliform, daily precipitation and *E. coli*, number of swimmers and fecal coliform, number of swimmers and *E. coli*, turbidity and fecal coliform, and turbidity and *E. coli*.

For the bacteriological samples an average of each day's values was taken and transformed using the natural log. The natural log was used because the difference between two number's natural logarithms will approximately equal the difference between them as untransformed values. This allows for direct proportional comparison between values in the transformed state (Darlington, 1990). Transformation of the data was necessary as the data values spanned several degrees of magnitude. The use of transformation can also make nonlinear relationships linear (Darlington, 1990).

Median values of bacterial counts per site were also calculated and the data was backtransformed for reporting. As the study sites and samplings were not random, problems arose with regard to dependence through serial effects, or measurements taken over time. These observations close together in time tend to be more similar than those collected farther apart and can skew traditional analysis tools.

RESULTS

This chapter discusses the results of the study in five parts consisting of; the general water characteristics at each site, the bacterial levels at all sites, changes in bacterial levels over time and the bacteria levels present in comparison to the state and federal standards.

General Water Characteristics

All sites could all be classified as "healthy" water bodies, having normal dissolved oxygen levels, pH, conductivity, nitrates, and phosphorous, as shown in Table 1. An exception was Morse Pond, which had a higher pH and was warmer than the other sites. Although Dow Site had the lowest levels of most testing parameters, it had twice the levels of nitrogen ammonia. The overall levels of conductivity, phosphorus, nitrate, and nitrogen-ammonia are all very low, basically at background levels. The pH is also nearly neutral (7.0) at all sites (except Morse Pond) which is normal. There were also differences in turbidity and color, with Monteith Park and Morse Pond having levels twice that of the Dow Site. These differences were visually apparent at the sites. Dow Site was very clear and had the lowest units, while Morse Pond and Montieth Park, were cloudy in appearance and had higher turbidity and color units.

Site	CND (uS/cm)	pH	Temp.(°C) (on site)	D.O. (mg/L O_2)	Temp.(°C) (at lab)	Turbidity FTU	Color (PtCo)	Nitrate (mg/L N-NO_3)	Nitrogen-Ammonia (mg/L N-NH_3)	Phosphorus (mg/L PO_4)	Total # of Swimmers[1]
Dow Site	0.10	7.50	21.29	7.16	14.05	5.58	33.21	0.09	0.22	0.20	0
53rd St.	0.10	7.50	22.78	7.77	13.78	9.06	45.44	0.14	0.12	0.23	30
Avery Park	0.11	7.55	23.32	7.27	14.05	10.84	57.26	0.19	0.15	0.29	60
Morse Pond	0.16	8.77	26.36	7.76	14.21	12.42	66.16	0.15	0.11	0.12	4
Monteith Park	0.08	7.64	23.88	8.17	14.37	11.89	63.95	0.19	0.14	0.24	82

[1]Total swimmer counts were used, not averages

Table 1. Average Values for Each Parameter By Site

Bacterial Levels at All Sites

The first research question sought to determine the levels of bacteria present in the water at each site. The samples taken early in the summer to ascertain baseline levels of bacteria and other parameters were variable with respect to coliforms. High and low peaks appeared on preliminary sampling days that resembled samples taken over the course of the summer. Because of this, and the lack of background data, it is difficult to determine what the actual 'normal' bacterial levels are at the sites. However, the actual levels at the time of sampling at each site have been determined over the ten week sampling period using the mean and median for comparison. The log mean and median bacterial values for the entire sampling period are shown in Table 2. Montieth Park had the highest mean and median levels for fecal coliform and *E. coli*, at almost twice the levels of the other highest site. Similarly, Morse Pond and 53rd Street are still the two lowest sites for both mean and median levels for fecal coliform. For all of the sites, the median and mean values are comparable for fecal coliform. However, for *E. coli* the means are much lower than the medians for all sites, with Dow Site and Avery Park having medians that are almost twice their means. This shows the data is not normally distributed over the sampling period.

The mean and median values shown in Table 2, and in Figures 8 and 9 present an overall and a daily evaluation of the sampling values. For these values to have meaning from a regulatory standpoint, the 30 day log mean must be calculated for comparison to EPA standards for bacteria.

Site	Fecal Coliform (# colonies/ 100mL) Mean	Median	*E. coli* (# colonies/ 100mL) Mean	Median
Dow Site	198.34	184.9	26.05	49.9
53rd St.	117.92	104.58	14.44	25.03
Avery Park	115.58	109.93	26.04	40.05
Morse Pond	68.72	70.11	21.98	27.39
Monteith Park	304.90	327.01	69.41	77.48

Table 2. Mean and Median Values for Bacteria By Site

30-Day Log Means

	Fecal Coliform		*E. coli*	
	7/3-7/31	8/4-8/31	7/3-7/31	8/4-8/31
Dow	259.82	175.91	71.52	8.67
53rd St.	94.63	*172.43	36.23	*4.71
Avery Park	91.84	160.77	20.28	35.16
Morse Pond	*46.53	114.43	*18.17	30.88
Monteith Park	292.95	314.19	107.77	44.70

*Log mean taken from only 8 values

Table 3. Thirty Day Log Means For Fecal Coliform and *E. coli*

The EPA uses a 30 day log mean to minimize occasional days with high counts in order to develop an overall view of the health of a water body over a month's period. Because many things can cause unusually high values for a short period of time, the 30 day log mean is supposed to give a more appropriate evaluation of the bacterial water quality over time. These log means (taken from 9 values) are shown in Table 3.

Changes in Bacterial Levels Over Time

The second research question sought to determine changes in bacterial levels over time. The counts taken over the sampling period at all of the sites are shown in Figure 8 and Figure 9. Again, these sites were sampled every Wednesday and one weekend day each week for a nine week period. There is extensive variation in bacterial levels between each site on a given day. For example, on August 28, Avery Park and Dow had only one *E. coli* colony, 53rd St. had 100 colonies, and Morse and Montieth had 500 colonies/100mL sample.

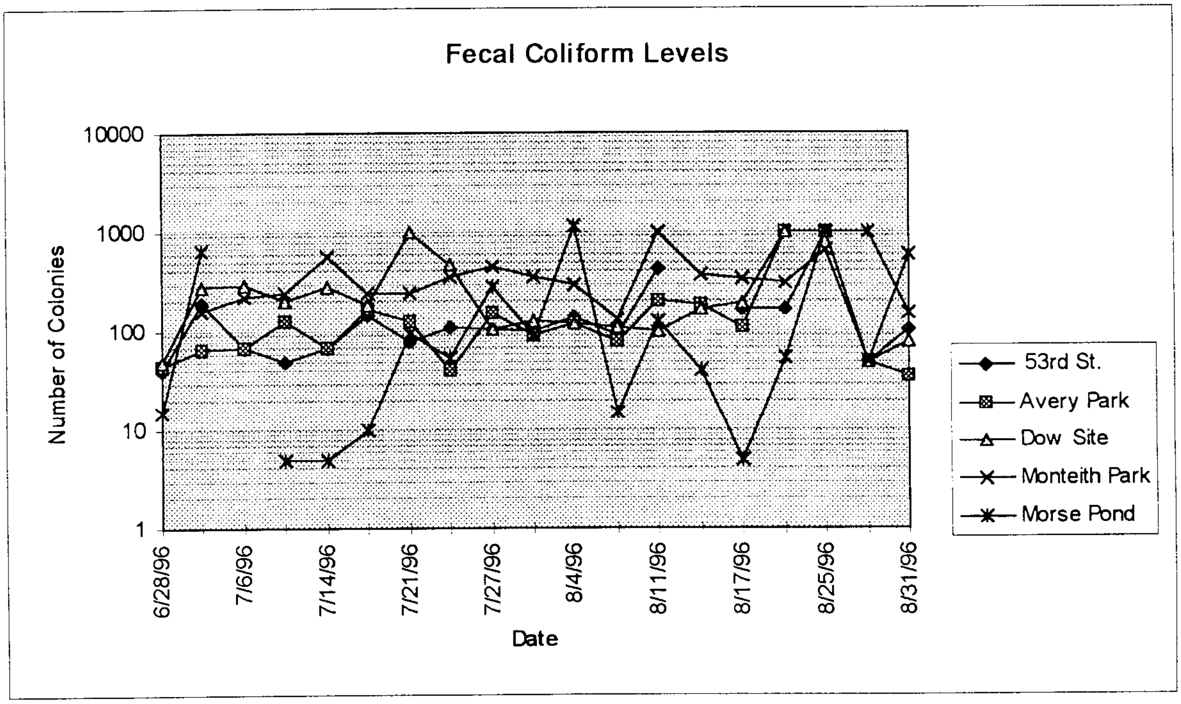

Figure 8. Fecal Coliform Levels At All Sample Sites

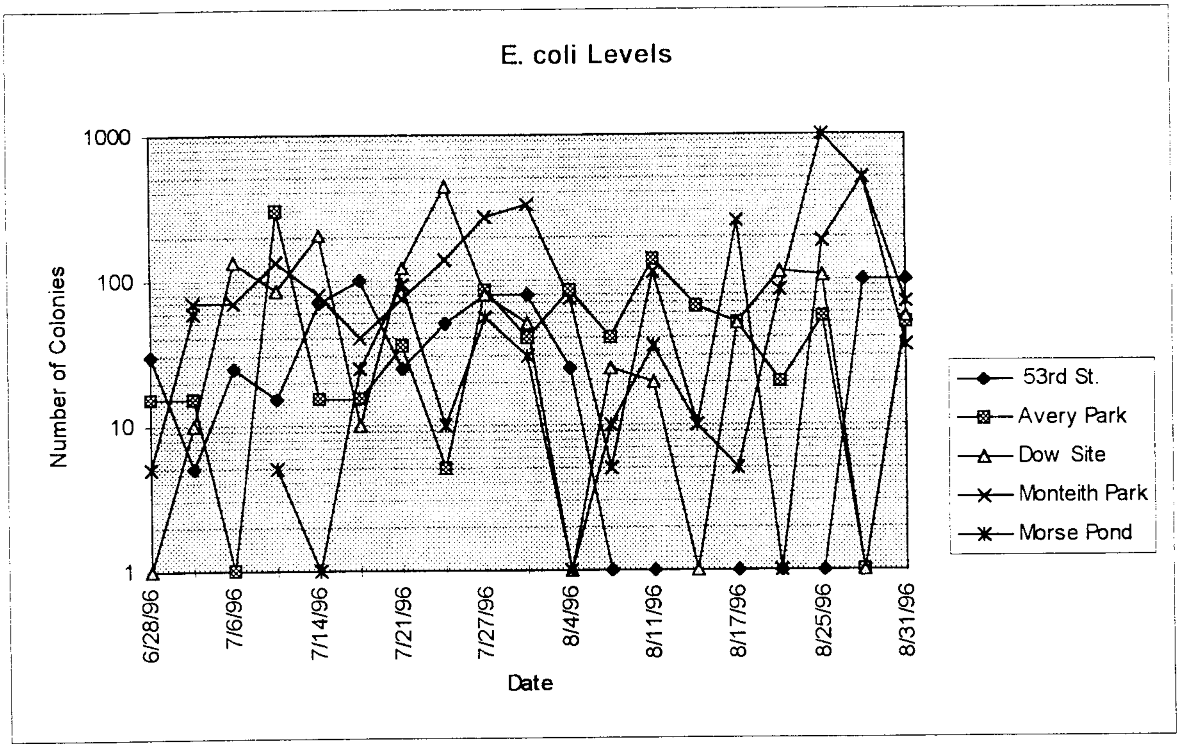

Figure 9. *Escherichia coli* Levels At All Sample Sites

Over the entire sampling period, only Morse Pond and Dow Site had highly correlated bacterial levels. However, if a smaller period of time is used, such as 7/14 to 8/17, Avery Park and Montieth Park also show strong correlations (see Table 4). 53rd Street is an exception, as the values for *E. coli* and fecal coliform 'cross' each other during this time period (see Figure 13).

Correlation Coefficients

Site	Entire Sampling Period 6/28-8/31/96	Sampling Period Between 7/14-8/17/96
Dow Site	.62	.51
53rd St.	-.60	-.52
Avery Park	.36	.74
Morse Pond	.58	.18
Monteith Park	.03	.51

Table 4. Correlation Coefficients Between Fecal Coliform and *E. coli* for All Sites

Bacterial Levels and State Standards

Research question #3 focused on the state and federal standards and how often the bacterial levels at the sites met or exceeded these levels, producing a potential health hazard at those areas. The bacteriological indicators on a daily basis did exceed the state standards at every site at least once during the summer, and some exceeded standards regularly, as shown in Table 5. Monteith Park had the highest fecal coliform counts overall with 79% of the colony counts at or exceeding state standards of 200 colonies/100mL sample. The lowest fecal coliform counts were at Avery Park and Morse Pond, which met or exceeded the standards only one-fourth of the time. Dow and 53rd St., were between the low and high level sites and met or exceeded the standards half of the time. Monteith Park showed the highest counts, meeting or exceeding the *E. coli* standards of 126 colonies/100mL sample, 42% of the time. All of the other sites were under 21%, with Morse Pond being the lowest at 10%.

The 30 day log mean values produce a different picture (Table 3), showing only Dow Site exceeding regulations in July for fecal coliform and Montieth Park exceeding limits for fecal coliform in July and August.

	% Exceeding Standards	
	Fecal Coliform	*E. coli*
Site		
Dow Site	47%	21%
53rd St.	42%	16%
Avery Park	21%	11%
Morse Pond	26%	10%
Monteith Park	79%	42%

Table 5. Percentage of Bacterial Levels That Exceeded State and Federal Standards

For all sites, comparisons for fecal coliform and *E. coli*, fecal coliform and regulatory levels and *E. coli* and regulatory levels were made. The graphs showing these comparisons (Figures 10-24) are shown by site. All of the graphs are logarithmic so that the degrees of magnitude between counts can be seen clearly. The zero values are not shown logarithmic graphs, so the apparent missing data points are dates when the bacterial plates did not have any colonies.

The Dow Site had consistently high values over the course of the summer, but the few zero data points produced an acceptable 30 day log mean value for July and August. The fecal coliform and *E. coli* counts were highly correlated at this site for the entire nine week sampling period, as shown in Figure 10.

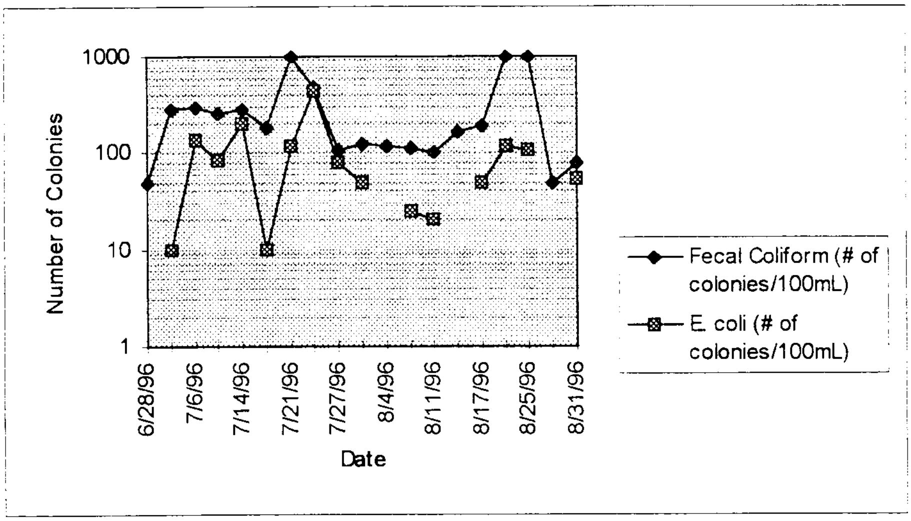

Figure 10. Dow Site. Fecal Coliform and *E. coli* Colony Counts

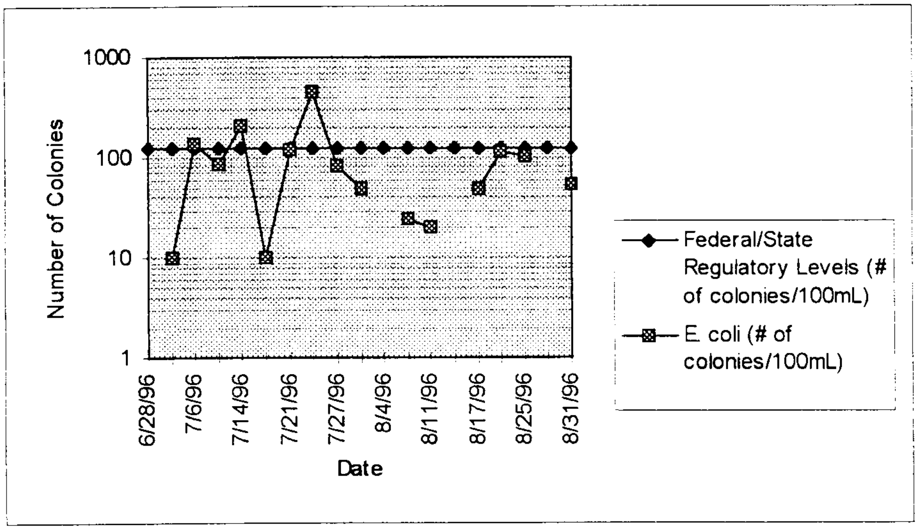

Figure 11. Dow Site. Measured *E. coli* Levels Compared To Regulatory Levels

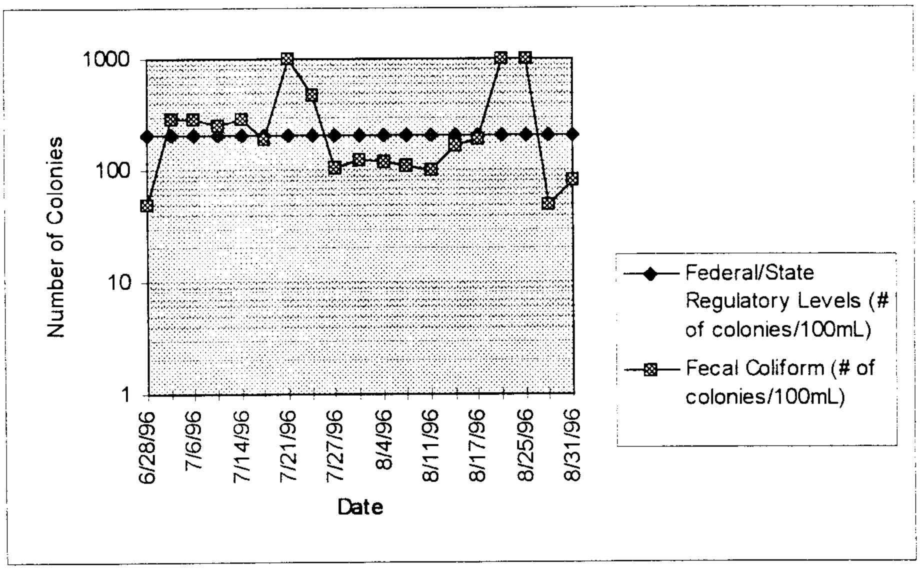

Figure 12. Dow Site. Measured Fecal Coliform Levels Compared To Regulatory Levels

Shown numerically as percentages in Table 5, Figures 11 and 12 illustrate the days that the Dow Site bacterial counts exceeded the state and federal standards.

At 53rd Street, the fecal coliform and *E. coli* values cross several times, unlike the other sites (Figure 13). This site did not often exceed the bacterial limits, as shown in Figures 14 and 15.

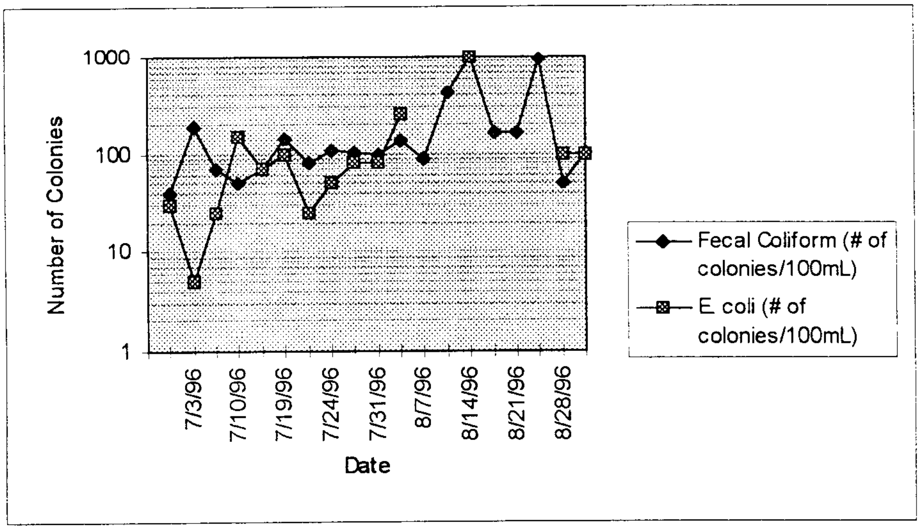

Figure 13. 53rd Street. Fecal Coliform and *E. coli* Colony Counts.

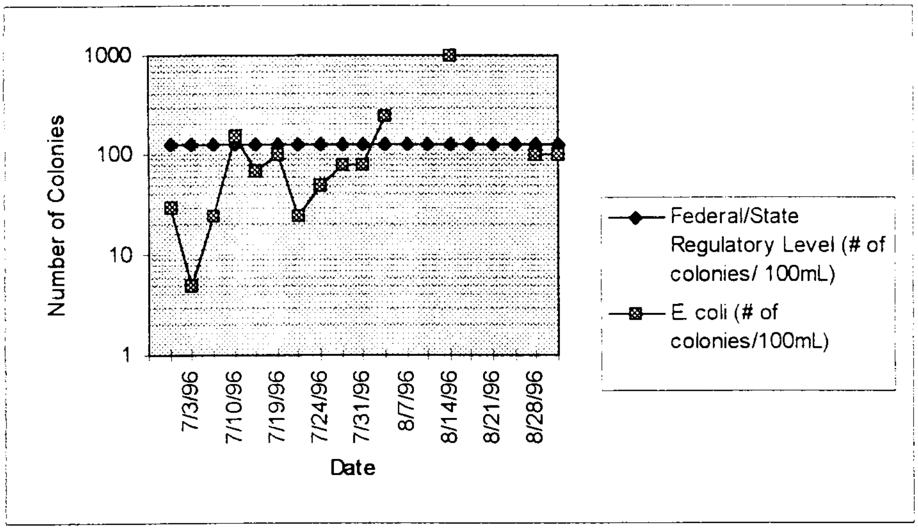

Figure 14. 53rd Street. Measured *E. coli* Levels Compared To Regulatory Levels

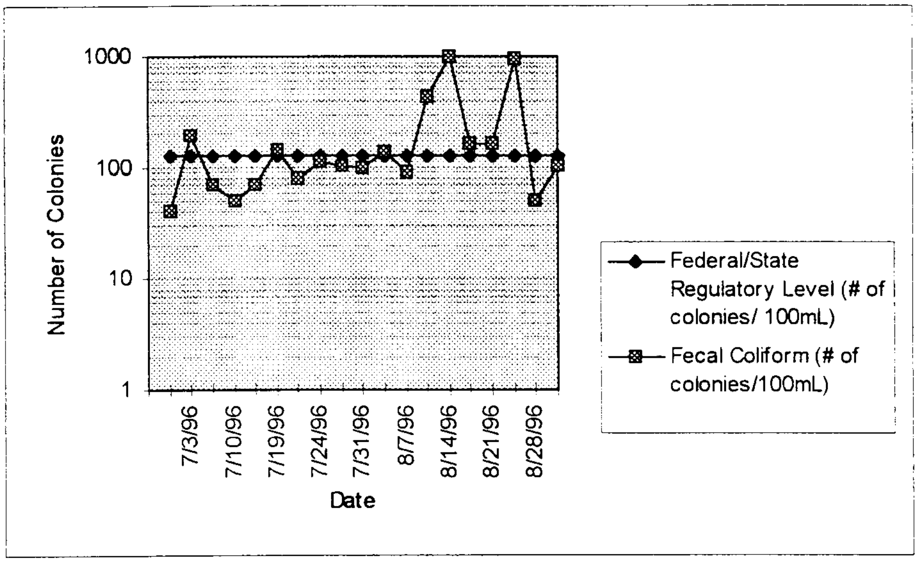

Figure 15. 53rd Street. Measured Fecal Coliform Levels Compared To Regulatory Levels

Avery Park showed fecal coliform and *E. coli* to be correlated between July 14 and August 18, 1996 (see Figure 16). Although the levels at this site did not often exceed the limits (Figures 17 and 18), they were very close to the regulation cutoff point for the majority of the summer for fecal coliform and throughout August for *E. coli*.

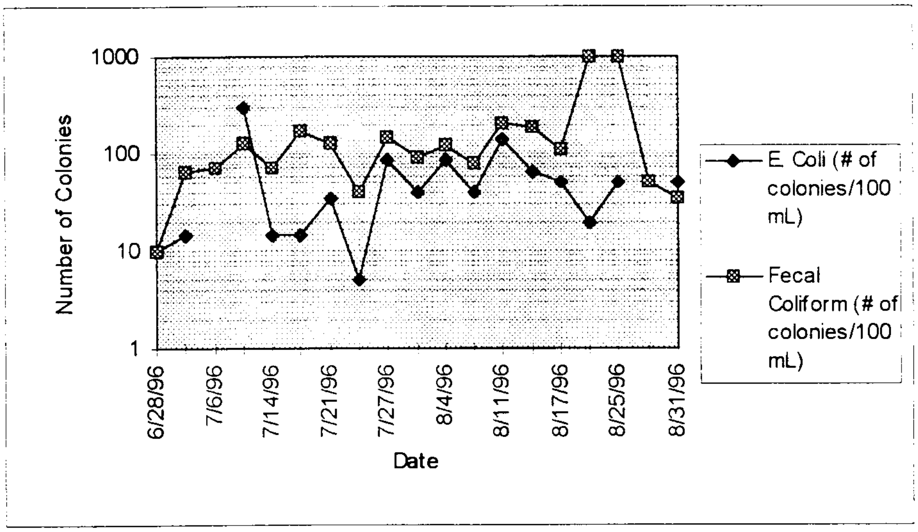

Figure 16. Avery Park. Fecal Coliform and *E. coli* Colony Counts

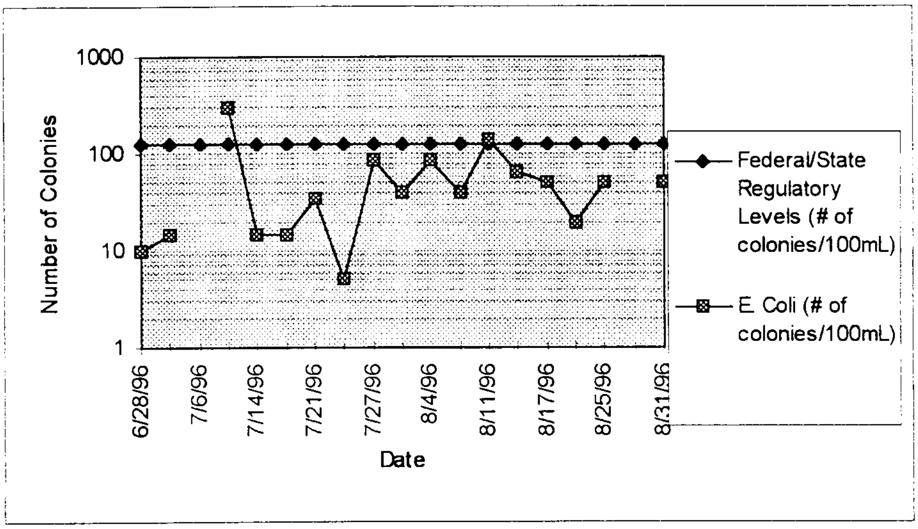

Figure 17. Avery Park. Measured *E. coli* Levels Compared To Regulatory Levels

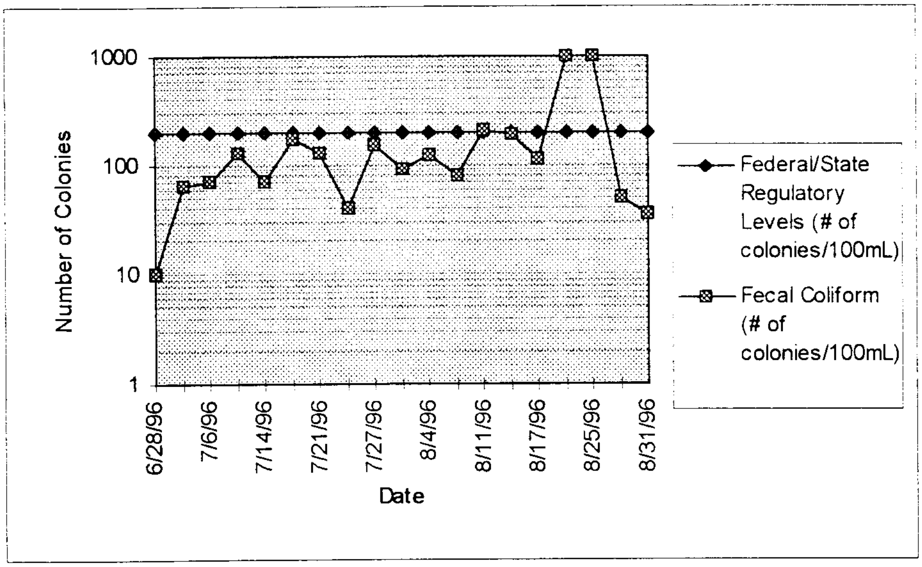

Figure 18. Avery Park. Measured Fecal Coliform Levels Compared To Regulatory Levels

Morse Pond had the most sporadic values of all the sites (see Figure 19). The colony counts were closely correlated between fecal coliform and *E. coli* over the entire summer. This site, like Avery Park, did not exceed the state standard often during the sampling period, but when it did, the values were very high (see Figures 20 and 21).

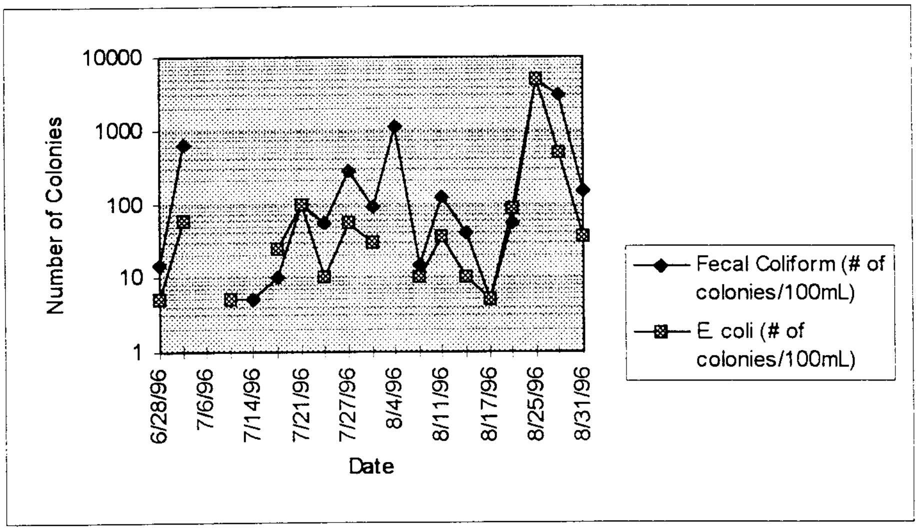

Figure 19. Morse Pond. Fecal Coliform and *E. coli* Colony Counts

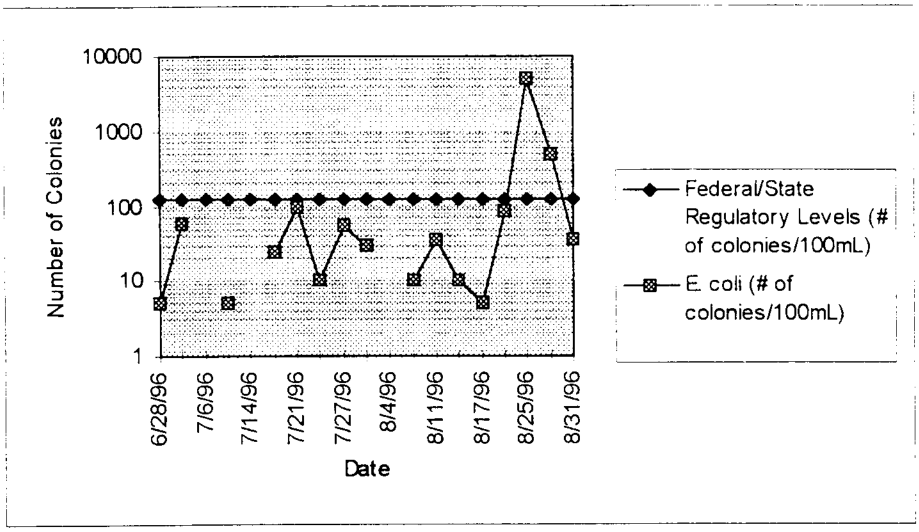

Figure 20. Morse Pond. Measured *E. coli* Levels Compared To Regulatory Levels

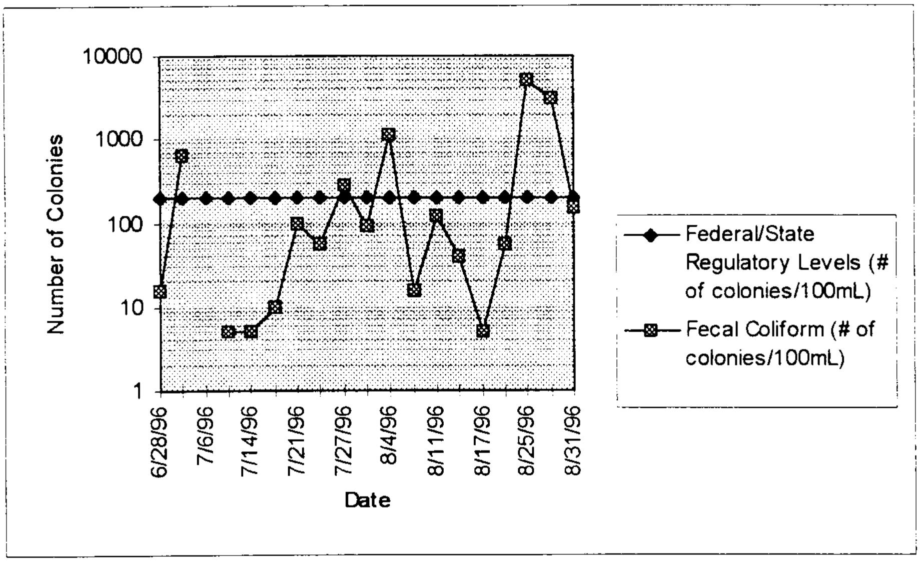

Figure 21. Morse Pond. Measured Fecal Coliform Levels Compared To Regulatory Levels

Montieth Park had the highest fecal coliform and *E. coli* levels of the five sites. The bacterial levels at this site are very similar until August 7, 1996, where they diverge and then cross at the end of the month (see Figure 22). From Figures 23 and 24 it is obvious how often the samples exceeded state and federal limits for *E. coli,* and that they exceeded regularly for fecal coliform.

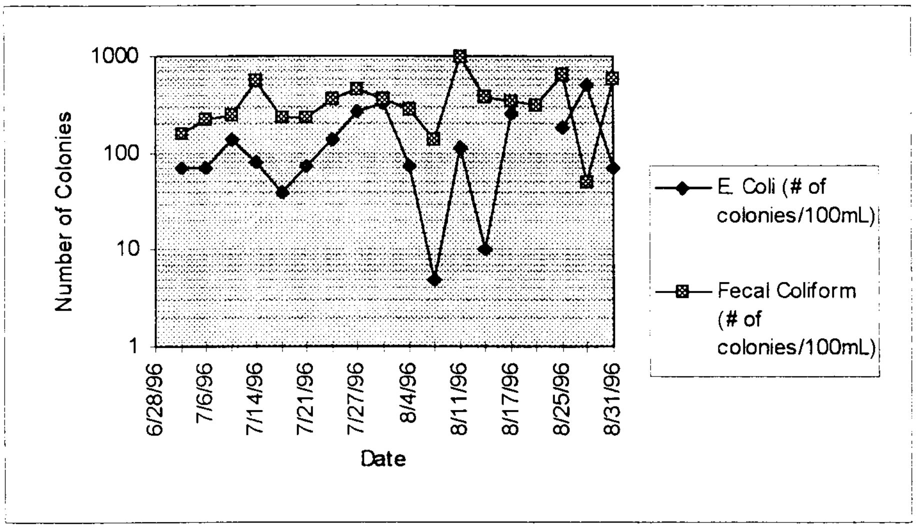

Figure 22. Monteith Park. Fecal Coliform and *E. coli* Colony Counts

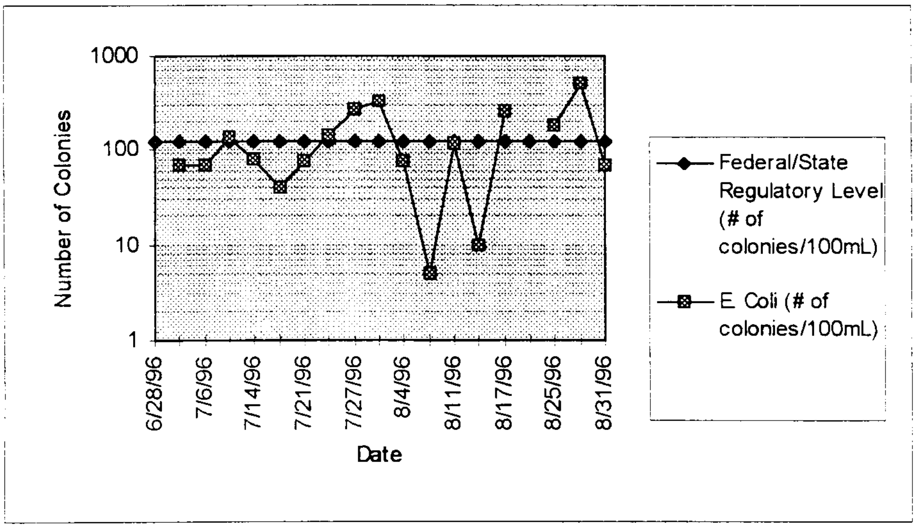

Figure 23. Monteith Park. Measured *E. coli* Levels Compared To Regulatory Levels

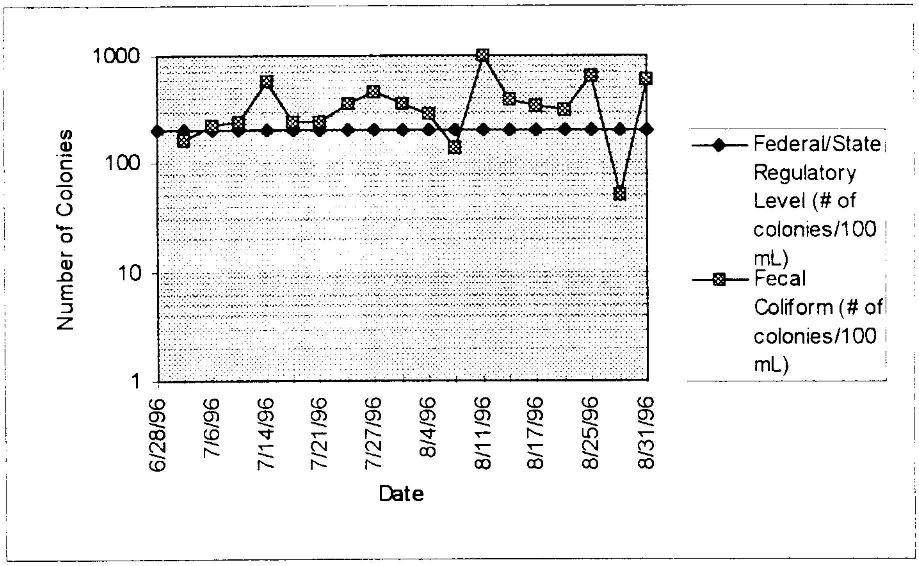

Figure 24. Montieth Park. Measured Fecal Coliform Levels Compared To Regulatory Levels

Bacterial Levels and Other Factors

Many factors were analyzed to attempt to find a correlation between elevated bacterial levels and the other parameters. Turbidity, nitrate levels, number of swimmers, air temperature and water temperature were separately plotted against bacterial levels. Those tested for correlation coefficients were; air and water temperature, air temperature and *E. coli*, fecal coliform and *E. coli*, daily precipitation and fecal coliform, daily precipitation and *E. coli*, number of swimmers and fecal coliform, number of swimmers and *E. coli*, turbidity and fecal coliform, and turbidity and *E. coli*. Of all the parameters, only air and water temperature were shown to be strongly correlated at each site (R=.67). Because swimmers would be more likely to use air temperature as a 'barometer' for going swimming, air temperature was in the correlation tests against bacterial levels. However, the results showed that air temperature did not appear to be correlated with either *E. coli* or fecal coliform levels at any site (R=-.046 to .416).

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

Discussion

The physical and chemical water quality test results from all sites showed Morse Pond to have differences from the other sites, such as a higher pH and water temperature. This site is unique, in that it is groundwater fed and man-made for gravel mining. The average pH at this site was above the levels that are desirable for drinking water for humans and animals (8.6), making this site less desirable for swimming activity than the others. Morse Pond and Montieth Park both have sandy beaches and bottoms, which can account for the increased turbidity at these sites in comparison to Avery Park and Dow Site, which had gravelly beaches and bottoms and lower turbidity measurements. Montieth Park's turbidity levels may have been high due to high swimmer load since it was the highest use site, having as many as 33 swimmers on a sampling day. The appearance of each of the five sites was very different, and the number of swimmers at each site reflects this. The three highest swimmer use sites (Dow Site, Avery Park and Montieth Park) were also the most aesthetically pleasing sites, each having clear water and an appealing beach area. Although the number of total swimmers at Dow Site was zero for the days the site was sampled, the site was heavily used on other days. This study supports the research of Wade (1989), who concluded that the appearance of good water quality enhances the desirability of a natural swimming area.

Montieth Park had the highest mean and median levels for both fecal coliform and *E. coli*. This may be due to a variety of factors, including higher levels of turbidity and a larger number of younger swimmers. Swimmers tend to stir up the water, potentially releasing bacteria that have settled into the sediment on the river bottom (Seyfried et al., 1985). Turbid waters tend to harbor bacteria, because the bacteria cling to suspended particles (Csuros, 1994). Higher levels of fecal coliforms and *E. coli* may also be due to the larger population of younger, diapered swimmers, who have been noted to have contributed to previous outbreaks (Keene et al., 1994).

Although the 30-day log means for bacteria in this study only exceeded the state standards at Montieth Park, that does not mean that the other sites are without public health risk. As shown in the study by Keene et al. (1994), an *E. coli* and *Shigella sonnei* outbreak occurred in a Portland, Oregon park while the levels of indicator organisms were not consistently exceeding the EPA regulatory limits. This raises the question as to whether daily bacterial count values or 30-day log mean values should be used to estimate public risk. As shown in this study, although the log mean values at most sites are under the regulated levels, the daily bacterial levels often exceeded regulatory limits. For example, the Dow Site's 30-day log mean in July for *E. coli* was 71.5 colonies/100mL, which falls below the state standard of 126 colonies/100mL. On July 24, however, the *E. coli* count was 480 colonies/100mL sample. Any swimmers using the site on this day would have been exposed to water with very high bacteria levels, although the log mean showed the area to be within acceptable limits. Other studies have shown correlations between indicator organism density and swimmer illness (Cabelli, et al., 1979; Favero, 1985; Kay, 1994).

Although studies have found temperature to be a factor in *E. coli* growth in natural waters (Neimi, 1991), this did not appear to be the case in this study, as no correlations between water or air temperature and *E. coli* levels were found. The sites with chronically high bacterial levels had other factors that may have contributed to bacterial loading. For example, the Luckiamute River, along the Dow Site, winds through a cattle farm before the site and there were also reports of a dead cow in the stream from the flooding of the previous winter. Most of the homes along the river also use septic systems, which can produce high coliform levels if they are not functioning properly. The researcher also noted that above Montieth Park is a broken pipeline that appears to be leaking sewage effluent along the bank of the Calapooia River. This pipe would be underwater during the winter, but is clearly visible during the spring and summer months. The city of Albany has been notified of the problem, but to date, the pipe has not been repaired. The Mary's River, which runs through both the 53rd Street site and Avery Park has higher counts at the 53rd Street site than further downstream at Avery Park. This may be due to the influence of tributaries, such as Oak Creek, that cause an increase in water flow at Avery Park, which might dilute the bacterial levels.

Conclusions

Bacterial levels did fluctuate over time as shown in Figures 8 and 9. The fecal coliform and *E. coli* levels remained closely correlated over short periods of time, except in the case of the 53rd Street site, where the *E. coli* values exceeded fecal coliform values regularly. The bacterial levels during the course of this study ranged from zero to 1000 colonies/100mL sample for *E. coli*, from 5 to 1000 colonies/100mL sample for fecal coliform. The site with the highest levels of both *E. coli* and fecal coliform was Montieth Park, with a nine week mean of 304.9 colonies/100mL for fecal coliform and 69.4 for *E. coli*, which are nearly double the values for the other sites.

The change of the bacterial levels over time is also shown in Figures 8 and 9. The bacterial levels of *E. coli* were much more variable on a day-to-day basis than those for fecal coliform. At Morse Pond and the Dow Site, both indicator organisms were closely correlated (R=.58 and .62) for the entire nine week sampling period. At Montieth Park and Avery Park, fecal coliform and *E. coli* were closely correlated between July 14 and August 17 (R=.51 and .74). The highest mean bacterial levels for the sampling period were at Montieth Park, with 304.9 colonies/100mL for fecal coliform and 69.4 colonies/100mL for *E. coli*, nearly twice the mean levels for the other sites. The 30 day log means for July also show Montieth Park's bacterial levels to be the highest of all the sites (292.9 for fecal coliform and 107.7 for *E. coli*). The July 30 day log mean for the Dow Site is also above the regulatory limits for fecal coliform at 259.8

Although the levels were high at certain sampling times, the 30 day log means show only Montieth Park to have exceeded the state fecal coliform standards. However, this may not accurately predict the public health risk to swimmers on individual days when the bacterial colony counts exceed the state standards by several orders of magnitude. At Avery Park and the Dow Site, the fecal coliform levels exceeded the standards almost half of the time, while Montieth Park exceeded the standards 79% of the time. Similarly, 20% of the sampling period, Avery Park and the Dow Site exceeded regulatory limits for *E.*

coli, with Montieth Park over the limit almost half of the time. As discussed above, only Montieth Park and the Dow Site exceeded the 30 day log mean limits set by the EPA for fecal coliform. But during July, the 53rd Street site, Avery Park and Morse Pond all exceeded 200 colonies/100mL on certain sampling days, although they were shown to have acceptable water quality by their 30 day log mean values.

Factors that may have contributed to the sporadically high bacterial levels are not identified. The high fecal coliform and *E. coli* levels may be due to a combination of factors that are beyond the scope of this study. Septic systems along the waterways, high turbidity, water temperature and stream flow all may have influenced the overall bacterial levels. Although the study locations were nonrandom and inferences can not necessarily be made to other water bodies in the state, the results are still valuable in that they lend evidence towards causal theories and suggest direction of future research.

Recommendations

Based on the results and conclusions, three main areas of future study should be addressed. Additional research should be done in areas where the bacterial levels are high, such as at Montieth Park. Contributing influences, such as tributaries or failing onsite sewage systems could also be analyzed. Recommendations that have been made by the staff at the City of Corvallis Water Treatment Plant include sampling upstream of the swimming area and measuring stream flow through a swimming area to see if the bacteria are being carried past the area quickly or slowly, thereby decreasing or increasing potential swimmer exposure.

Other bacterial tests should be conducted, now that the correlation between fecal coliform and *E. coli* is fairly well established. Enterococci has been shown to be a better indicator of gastrointestinal illness than fecal coliform, so a test using enterococci and *E. coli* would now be appropriate. In addition, testing for *Staphylococcus aureus* would be valuable, as it is shown to correlate well with swimming associated illness in situations where there is suspected cross-contamination between bathers (Cabelli, 1989). A study testing for these other indicator organisms would be most beneficial as an epidemiological study, so the differing bacteria could be specifically associated with outbreaks and/or swimmer illness.

Because the two highest swimmer use areas in this study were parks, it would be beneficial to inform the public of the bacterial levels present in these areas. Prevention would be one good way to reduce bacterial levels and keep them lower during the summer. Parents should be informed that dirty diapers are a major cause of bacterial problems, especially *E. coli* in swimming areas and that their diapered children should be changed regularly and the diapers should be disposed of properly, not left on the beach. In addition, parents should be alert for any connections between stomach problems and recent swimming by their children. This information could be effectively presented to the public in a flyer format, listing the areas that have had high bacterial counts and then mentioning the prevention methods the parents could use. This includes the need to be aware of potential *E. coli* infection if stomach problems arise. This flyer could be placed in publications that are sent to all households, such as the Linn-Benton Community College Schedule of Classes, Utility Bills, or Parks and Recreation Information pamphlets.

Finally, the site should be posted by public health authorities during the periods when levels exceed the state standards.

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