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Attached is a copy of a report entitled: "A Comprehensive Study on The Microbicidal Properties of Stabilized and Unstabilized Chlorine and The Relationships of Other Chemical and Physical Variables in Public Swimming Pools; A Report on A Study Carried Out in Pinellas County, Florida, Summer/Fall, 1992". As indicated by the title page, the study was conducted by the Pinellas County Public Health Unit and Occidental Chemical Corporation.

The purpose of the report is to not only summarize the results of the study but also to serve as an information repository for the Pinellas County Public Health Unit. As a consequence, the report is much larger than most technical reports. Hence, the report was subdivided into four sections so that figures and tables in the appendices could be easily referenced while reading the text of the report. A complete report therefore consists of four notebooks with the: 1) Report Text; 2) Appendices A - N; 3) Appendices O - EE; and 4) Appendices FF - VV.

Please feel free to contact the principals if you have any questions about the report.

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Note: In 2004, this report was reformatted and a number of typographical errors were corrected. As a result, the page numbers vary slightly from the original copy. No significant changes in the content have been made. Please contact Occidental Chemical Corporation at 877-873-4767 if you have any questions about the report.
(Thomas C. Kuechler, Occidental Chemical Corporation, June, 2004)

Report Title: **A Comprehensive Study on The Microbicidal Properties of Stabilized and Unstabilized Chlorine and The Relationships of Other Chemical and Physical Variables in Public Swimming Pools; A Report of A Study Carried Out in Pinellas County, Florida, Summer/Fall, 1992**

Date: November 1, 1994

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Special Acknowledgement: **Thomas C. Kuechler,** PhD, Associate Scientist, Occidental Chemical Corporation for his editorial assistance.

Abstract:

This report summarizes the results of a study conducted on public swimming pools in Pinellas County, Florida from July to November, 1992. The study was conducted by a team of personnel from the Pinellas County Public Health Unit and the Occidental Chemical Corporation. The purpose was to: a) generate data to help the Pinellas County Public Health Unit better understand the effect of various variables on the operation of public swimming pools, and b) determine the effect of cyanuric acid on the bactericidal properties of free chlorine. These objectives were achieved by conducting statistical analyses on data generated from monitoring the bacteriological, algal, chemical and physical conditions of 486 pools which provided a statistical cross-section of the variables in the study.

The results of the study showed that: a) a typical public swimming pool is located in condominium, apartment or tourist facilities and has an average volume of < 35,000 gallons; b) trichloroisocyanuric acid tablets are the predominate sanitizer; and c) free chlorine had by far more influence on the bacteria populations (disinfection conditions) than any other variable. They also demonstrated that regardless of the cyanuric acid concentration, a swimming pool was bacteriologically satisfactory for swimming as long as the free chlorine was maintained above 1.0 ppm. In addition, they showed that if a free chlorine range of 1.0 - 5.0 ppm was used, a pool was more likely to be bacteriologically satisfactory for swimming than if the typically recommended 1.0 - 3.0 range was practiced.

Models based on bacteria and water chemistry as criteria were developed to assess the relative effectiveness of various pool judgment procedures typically used by pool operators and public health units to determine whether a pool is satisfactory for swimming. The results demonstrated that using 1.0 - 5.0 ppm free chlorine and clear water as criteria was as effective as procedures which employed additional criteria e.g., pH, cyanuric acid, etc.

Algae data analyses were also conducted. The results showed that it was entirely possible for a swimming pool with algae to be bacteriologically satisfactory for swimming. Another algae data analysis showed that free chlorine concentrations of 3.0 ppm or more were required to minimize incidences of algae thereby demonstrating that higher free chlorine concentrations were required to minimize algae infestations than were needed to maintain satisfactory disinfection conditions in swimming pools. Although the results of this study verified the results of a previous study in Pinellas County on 1500 pools, this study was more complex and provided the facts needed to carry out discussions on the cyanuric limits in public swimming pools with regulatory agencies.

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I. Introduction

The chlorinated derivatives of cyanuric acid, commonly known as chlorinated isocyanurates, were introduced as chlorine sanitizers for swimming pools in 1960 when R. J. Fuchs of FMC Corporation discovered that the cyanuric acid formed by these products prolonged the lifetime of hypochlorite chlorine (free chlorine) in outdoor swimming pools exposed to sunlight.[1] This unique property became known as "stabilization" and cyanuric acid became known as "stabilizer" or "chlorine stabilizer" in the swimming pool trade.

Continuous treatment of swimming pools with chlorinated isocyanurates can result in the buildup of cyanuric acid to concentrations of over 100 ppm, the current limit in public swimming pools. Some concern was voiced about the bactericidal effectiveness of free chlorine in pools where the cyanuric acid concentrations were significantly higher than 50 ppm when J. R. Anderson and Swatek, et al observed that the presence of cyanuric acid increased the kill time for free chlorine for Streptococcus faecalis and Staphylococcus aureus bacteria in distilled water.[2,3] However, **Swatek, et al[3] found that higher levels of free chlorine were required in pool water to achieve the same kill time as in distilled water.** In addition, Swatek, et al demonstrated that **free chlorine concentrations of 1.0 - 5.0 ppm produced satisfactory kill times for Escherichia coli, Streptococcus faecalis (now called Enterococcus), Staphylococcus aureus and Pseudomonas aeruginosa bacteria in the presence of cyanuric acid over a concentration range of 0 to 200 ppm.[3]**

Other investigators demonstrated in outdoor swimming pool tests in Pittsburgh, Pennsylvania; Baltimore County, Maryland; St. Louis County, Missouri and in Pinellas County, Florida that 1.0 - 3.0 ppm of free chlorine was a satisfactory range for maintaining sanitary conditions in public swimming pools.[4,5] The results obtained with the Pinellas County research work[5] were of particular interest because the work was comprehensive as evidenced by the fact the study involved about 1500 pools over an 8 year period (1973-81). Parameters such as pool structure, equipment, daily chlorine sanitizer usage and water characteristics which could affect disinfection were monitored regularly. H. Leadbetter, G. D. Nelson and R. A. Russell presented a paper summarizing the results of the studies in the period 1973-75 at the National Swimming Pool Institute Convention in New Orleans in November of 1975.[6] **They showed that as long as a minimum of 1 ppm of free available chlorine was present, algal growth was controlled and coliform bacteria were absent, even for pools containing up to 800 ppm of cyanuric acid. In addition, they showed that pools maintained the desired minimum of 1 ppm of free available chlorine more readily when cyanuric acid was present.**

Thus, the results of the Swatek, et al[3] and Leadbetter, et al[6] studies clearly demonstrated that with adequate (1.0 - 5.0 ppm) concentrations of free chlorine, satisfactory kill times were achieved with the various types of bacteria even at cyanuric acid concentrations significantly above 100 ppm and the swimming pools were bacteriologically satisfactory for swimming. Hence, the studies of Swatek and

Leadbetter clearly refuted the position of the "chlorine lock" proponents that contended that "too much cyanuric acid in the water ties up the free chlorine thereby making it bacteriologically ineffective and the pools unsafe for swimming".

The problem with the "chlorine lock" position is that it is based on bacteria kill times for free chlorine in distilled water whereas the results of Swatek and Leadbetter are based on a "real world" basis. In swimming pool water, the bacteria kill times of free chlorine are much slower due to contaminants in the water that interfere with the killing of the bacteria. Thus, the results of the swimming pool tests are more practical and clearly indicate that swimming pools with sufficient concentrations of free chlorine will be bacteriologically satisfactory for swimming even at cyanuric acid concentrations significantly above 100 ppm. Hence, the public is not in imminent danger if they swim in pools with cyanuric acid concentrations significantly above 100 ppm. In fact, if there was a problem with high cyanuric acid pools, the problem would have surfaced many years ago and the chlorinated isocyanurates would have not have grown to become the sanitizer of choice for swimming pools. As a matter of fact, the chlorinated isocyanurates might have failed due to poor product performance, but clearly this is not the case.

The cyanuric acid content of public swimming pools in some areas has been limited by regulations to 100 ppm. This limit was derived from toxicity studies carried out by Dr. Joseph Svirbely of the U.S. Public Health Service Taft Engineering Center in 1960.[7] He concluded from animal ingestion studies that a 100 fold margin of safety would be provided to swimmers, as long as the cyanuric acid concentration did not exceed 100 ppm. This limit was based on the assumption that a child accidentally ingests up to 250 ml of pool water/day per 150 day pool season.

Since the publication of Svirbely's work, many more comprehensive toxicity studies have been conducted using test protocols and laboratories sanctioned by the EPA. The results of the studies are summarized by Hammond, et al.[8] The most salient results clearly demonstrated that cyanuric acid:

1. is a very stable molecule and does not seem to be altered in the human body;

2. does not accumulate in the human body. Instead all of the cyanuric acid ingested by swimmers from pool water is eliminated from the body within 24 hours after ingestion;

3. did not exhibit any toxic effect in a human study with swimmers;

4. is not carcinogenic in studies with mice and rats;

5. did not exhibit increased mutagenicity in short-term tests;

6. did not demonstrate teratogenic or fetotoxic effects in studies with rabbits and rats;

7. did not interfere with rat reproduction through three generations;

8. did not appear to exhibit any significant toxic effects in subchronic and chronic studies on rats and mice; and

9. did form insoluble deposits (calculi) in the urinary tracts of male rats only when the rats drank water containing 5,375 ppm of cyanuric acid. This finding has been attributed to anatomical features particular to the male rat urinary tract. Formation of urinary tract calculi was not observed in female rats or in male or female mice chronically exposed to 5,375 ppm of cyanuric acid in their drinking water. Urinary tract deposits were not observed when the male rats drank water containing 2,400 ppm or less of cyanuric acid.

Thus, the above results clearly indicate that cyanuric acid shows no carcinogenic, mutagenic or teratogenic effects at levels considerably above any level expected in drinking water or swimming pools and spas. Moreover, the results clearly demonstrate that chlorinated isocyanurates are safe to use as sanitizers for pools and spas and do not expose swimmers and bathers to undue health risks. The EPA has agreed that the test results are valid and can be cited by all parties wanting to obtain EPA registrations for swimming pool products.

As a consequence of these results, EPA and public health officials responsible for monitoring public swimming pools became less concerned about the limit of 100 ppm for cyanuric acid, and permitted many pools to have higher levels, as long as the water was sanitized satisfactorily. Also, many knowledgeable technical experts feel that the current cyanuric acid limit of 100 ppm is not warranted and should be raised to higher levels. The results of the 1973-81 Pinellas County study[6] provided strong support for this position as evidenced by the findings that public swimming pools containing 1 - 3 ppm of free chlorine are satisfactorily sanitized at residual cyanuric acid levels of up to 800 ppm.

Nevertheless, the authors felt that it was important to continue to develop more factual information about the effects of higher concentrations of cyanuric acid on overall pool operation, particularly its effect on the bactericidal and algicidal (algistatic) properties of free available chlorine. As a consequence, the decision was made to update the knowledge on the use of chlorinated isocyanurates in public swimming pools.

Pinellas County was selected for this study because:

1. The swimming season is longer in Florida than anywhere else in the United States.

2. Nearly 10 % of the public swimming pools in Florida are in Pinellas County.

3. It is difficult to maintain the proper disinfection conditions in Pinellas County pools because of the hot, rainy weather and high bather load as a result of the high volume of tourists.

4. The results of the proposed study could be used to determine the validity of the 1973-81 Pinellas County swimming pool disinfection study.

The initial plans were to conduct statistical analyses on the data contained in a computer database maintained by the Pinellas County Health Unit. However, it was discovered that the Pinellas County Public Health Unit had discontinued routine bacteriological analyses of all public swimming pools because:

1. The 1973-81 Pinellas County swimming pool test results had clearly demonstrated that the swimming pools would be sanitized satisfactorily regardless of the cyanuric acid level as long as the free chlorine concentration and pH were maintained at 1 - 3 ppm and 7.2 - 7.8, respectively, and the filtration system was operating properly.

2. Bacteriological testing by the Pinellas County Public Health Unit after the 1973-81 Pinellas County swimming pool test verified the conclusions of the test.

3. It was not cost effective to continue routine bacteriological analyses on every swimming pool.

Therefore, a test program was developed to generate a comprehensive database that could be used to determine the effect of several variables on the disinfection conditions and the chemical and physical characteristics of swimming pools.

The primary objectives of the proposed study were:

- To generate data that would enable the Pinellas County Public Health Unit to increase their knowledge about the pools in their district.
- To confirm the disinfection results achieved in the 1973-81 studies using coliform bacteria and algae as indicators of efficacy, and to add Heterotrophic bacteria as an additional indicator of free chlorine efficacy.
- Determine the effects of cyanuric acid on the bactericidal properties of free chlorine in pools, especially those sanitized by trichloro-s-triazinetrione (trichloroisocyanuric acid) products.
- Observe the incidence of algae, Staphylococcus and Pseudomonas organisms in the test pools.
- Observe the effect of variables on the chemical and physical characteristics of swimming pools.

It was reasoned that the objectives and design of the test program would provide additional factual information which would serve to dispel any questions that remained in the minds of public health officials and consumers about the effects of cyanuric acid levels, especially > 100 ppm, on microbicidal efficacy of free chlorine provided by the chlorinated isocyanurates.

II. Summary

This report summarizes the results of a comprehensive study on public swimming pools in Pinellas County, Florida. The study was a conducted by a team from the Pinellas County Public Health Unit and the Occidental Chemical Corporation from July through November, 1992. The purposes of the study were to:

- determine the relative microbicidal effectiveness of stabilized and unstabilized free chlorine, especially the effect of cyanuric acid concentration, in outdoor public swimming pools; and
- generate data that would help the Pinellas County Public Health Unit to better understand the effect of pertinent chemical and physical variables on the operation of the public swimming pools in their district.

The results of the study were obtained by collecting data on 486 of the 2207 public pools, subjecting the data to several statistical analysis techniques and interpreting the results of the statistical analyses. Achievement of the objectives required that the data be statistically analyzed so that the results provided a realistic picture on all aspects of the study.

Data were collected on variables in the following categories: 1) bacteria populations; 2) water chemistry; 3) turbidity; 4) type of sanitizers; 5) environmental characteristics (bather load, rain, etc.); 6) swimming pool characteristics; 7) time; and 8) algae. The data collection tasks involved: a) taking grab samples of the pools to determine the water chemistry and the populations of bacteria used as indicators of disinfection conditions, and b) recording data on the other variable categories. All of the data, except those in the bacteria category, were obtained by a team of personnel from the Pinellas County Public Health Unit at the pool sites during unannounced visits. The bacteria data was generated from analyses of water samples by the microbiologists at the Pinellas County Water Systems Laboratory. The data were then transferred from data sheets to a master computer data base.

The data were statistically analyzed by several techniques. These techniques enabled the pool study team to:

- determine the location and average volume of typical public swimming pools and the sanitizers typically used;
- generate general statistical characteristics for each variable for all test pools and those pool categories specifically covered in this report;
- identify which variables had (or did not have) statistically significant relationships with other variables;
- focus their data analysis efforts on the statistically significant relationships and not waste their energies on the statistically insignificant relationships;
- generate graphs illustrating the statistically significant relationships between variables;

- use the characteristics for statistically significant variables to categorize the pools as satisfactory and unsatisfactory for swimming;
- utilize the statistically significant relationships as a means to assess the relative effectiveness of the methods typically employed by public health units and pool operators to judge whether pools are satisfactory or unsatisfactory for swimming;
- determine the relative bactericidal and algicidal effectiveness of stabilized and unstabilized free chlorine;
- determine the effect of the other chemical and physical variables on the conditions of the pools; and
- develop guidelines for the management of public swimming pools.

The statistical analyses produced a long list of excellent results. The most salient ones were:

- Public swimming pools were typically located in condo, apartment and motel facilities.
- Public swimming pools had an average volume of < 35,000 gallons.
- Trichloroisocyanuric acid was the most popular sanitizer used.
- Free chlorine had, by far, a more statistically significant influence on the disinfection conditions and the incidence of algae than any other variable (pH, cyanuric acid, etc.).
- Free chlorine and clear water could be used as the only criteria to judge whether a pool was bacteriologically satisfactory for swimming; it was not necessary to know the pH and cyanuric acid concentration.
- The use of complicated pool judging methods did not change the ratio of bacteriologically satisfactory to bacteriologically unsatisfactory pools; it simply reduced the number of pools that would be judged satisfactory for swimming.
- A free chlorine range of 1.0 - 5.0 ppm resulted in: a) more pools that were bacteriologically satisfactory for swimming, and b) less pools with black algae than a range of 1.0 - 3.0 ppm.
- The average free chlorine concentration was higher in pools with cyanuric acid than in pools with little or no cyanuric acid to stabilize free chlorine residuals. As result, pools with cyanuric acid were more bacteriologically satisfactory for swimming.
- Most pools with black algae were bacteriologically satisfactory for swimming if the free chlorine was at least 1.0 ppm, regardless of the cyanuric acid concentration.
- An average free chlorine concentration of at least 3.0 ppm was required to minimize the incidence of algae, regardless of the cyanuric acid concentration or the type of sanitizer used.
- The Florida swimming pool code is more effective than other states' swimming pool codes. The free chlorine range of 1.0 - 5.0 ppm in the Florida code increases the

probability that the pools will be properly disinfected continuously compared to the narrower range of 1.0 - 3.0 ppm in other states' codes.

- Cyanuric acid concentrations up to 800 ppm in pools did not result in a decrease in the disinfection conditions or an increase in algae incidence.
- The surface finish of the pools deteriorated with decreases in pH indicating that the pool operators were not controlling total alkalinity within the proper range of 80 – 125 ppm to prevent pH excursions below 7.2.

In summary, the results clearly demonstrated that it was more important to maintain the proper level of free chlorine in the swimming pool than to be concerned about the cyanuric acid limit of 100 ppm. Thus, it is feasible to raise the cyanuric acid limits significantly above the current limit of 100 ppm and still have the swimming pools sanitized satisfactorily. In addition, the results indicated that the 1.0 - 5.0 ppm free chlorine standard of the Florida code was a more effective free chlorine standard than the 1.0 - 3.0 ppm free chlorine standard applied by other state regulatory agencies and recommended by the EPA on the label of swimming pool sanitizers. For these reasons, the EPA and the state regulatory agencies should be petitioned to make changes in their free chlorine standards and consider increasing the cyanuric acid limits in public pools. This latter objective is apropos since it appears that the most public swimming pools appear to be located in apartment, condominium and tourist facilities where the pool volumes are < 40,000 gallons and the bather loads are significantly less than municipal swimming pools. Since the use of trichloroisocyanuric acid tablets would result in the eventual build up of cyanuric acid concentrations beyond the current limit of 100 ppm, swimming pool operators must discard some water periodically to be in compliance with this regulation. Some areas are under water usage controls and cannot use add fresh water to pools for this practice. For this reason, allowing cyanuric acid concentrations above the 100 ppm limit would contribute to the conservation of water.

III. Conclusions

1. The results of this study verified the results of the 1973-81 Pinellas County study.

2. Free chlorine was, and still is, the most important variable to control in order to maintain the proper disinfection conditions and minimize incidence of algae in swimming pools.

3. The average free chlorine concentration in pools with cyanuric acid was higher than in pools with low levels of cyanuric acid.

4. Pools with higher average free chlorine concentrations were disinfected better and had less incidence of algae.

5. There was no evidence that cyanuric acid, even at concentrations much higher than 100 ppm, had an influence on whether a swimming pool was bacteriologically satisfactory or unsatisfactory for swimming or had algae.

6. The use of additional criteria besides free chlorine and clear water does not change the ratio of bacteriologically satisfactory to bacteriologically unsatisfactory pools; the practice only reduces the number of pools that the public health units would approve for swimming.

7. The free chlorine standard of 1.0 - 5.0 ppm of the Florida swimming pool code increases the probability that a swimming pool will be bacteriologically satisfactory for swimming. Hence, this standard is a more effective than the 1.0 - 3.0 ppm free chlorine standard employed by some of the other state regulatory agencies.

8. The results of this study combined with those of the 1973-81 Pinellas County study indicate that the cyanuric acid limit in public pools can be raised significantly above the current 100 ppm limit without adversely affecting the bacteria contaminant levels in the pools and exposing the public to any bacteriological risks.

IV. Recommendations

1. Review the results of this study and the risk assessment study with state regulatory agencies and the Environmental Protection Agency.

2. Recommend to other states to adopt the 1.0 - 5.0 ppm free chlorine standard of Florida's swimming pool code.

3. Recommend to the EPA that the maximum free chlorine pool re-entry limit in the label instructions of chlorine sanitizer products be increased from 3.0 to 5.0 ppm.

4. Review with state regulatory agencies and the EPA the feasibility of increasing the cyanuric acid limit in public pools.

V. Experimental

A. Description of Test Program

The Pinellas County Public Health Unit currently monitors 2207 pools. The records for all of the variables except bacteria contamination are maintained in a computer database by the Pinellas County Public Health Unit. Since bacteria analyses of water samples is the only way to determine the effects of various variables on the disinfection conditions of pools, the Pinellas County database could not be used to generate this critical data. However, it was used to select the test pools for this study so that the statistical distribution of the pertinent variables in the 2207 pools would be preserved in the test pools.

Due to the cost of the bacteria analyses, the test program was designed to collect data from only 500 test pools. However, due to mitigating circumstances, data was collected on only 486 pools.

The data collection phase of this study was designed to generate data that would enable the pool study team to determine:

1. if and why the pool was or was not properly sanitized;

2. what effect did cyanuric acid or other variables have on the bacteria populations and the incidence of algae in the pools; and

3. what effect did the variables have on the chemical and physical characteristics of pools.

Achievement of these objectives required the collection of data on the following variable categories: 1) bacteria populations; 2) water chemistry; 3) turbidity; 4) sanitizers; 5) environmental characteristics (bather load, rain, etc.); 6) swimming pool characteristics; 7) time; and 8) algae.

The Pinellas County Public Health Unit sanitarians were involved in all of the above data collection tasks. They collected the water samples, determined the water chemistry, carried out the other data collection tasks and transported the water samples to the Pinellas County Water Systems Laboratory for the bacteriological analyses.

The values of those variables dealing with the chemical and physical characteristics of the pools were recorded on data sheets by the Pinellas County Public Health Unit sanitarians. The results of the bacteriological analyses were reported on the data sheets by the Pinellas County Water Systems Laboratory. The data from both sources of information were entered in a computer database by professional data entry personnel. The database was then properly formatted and subjected to the statistical analysis techniques described below. The results of the statistical analyses were then used to derive the conclusions presented in this report.

It is important to note that all of the personnel involved in this program were professional chemists, engineers, microbiologists or statisticians. Also, no attempts were made to influence the data collection process. The data were collected from the pools without prior notification of inspection by the sanitarian. Thus, the water samples were collected from the pools on an "as is basis", in other words, a "real world basis".

B. Water Sample Collection and Custody Procedures

The water samples were collected in sterilized sampling bottles. One water sample was used by the sanitarian to determine the water chemistry (e.g., free and total chlorine, pH, total alkalinity, hardness, cyanuric acid, etc.) at pool side. The other water samples were dechlorinated with sterile thiosulfate pills. The bottles were then sealed and placed in a rack that was partially immersed in ice contained in an insulated ice chest. The ice-cooled water samples were transported to the Pinellas County Water Systems Laboratory after 5 - 6 samples had been collected. Bacteriological analyses were conducted on the ice-cooled water samples within 24 hours of collection. This custody technique enhanced the chances of the bacteria populations remaining representative of those at the time of the collection of the water sample.

C. Variables

Data on each test pool were compiled on the variables shown in **Table 1, Appendix A**.

D. Water Chemistry Analyses

The water chemistry of each pool was determined by the sanitarian at the pool site with the test kits contained in a Lovibond field engineer's kit. The procedures used for each of the water chemistry variables are tabulated in **Table 2, Appendix A**.

E. Bacteriological Examination of Water Samples

E.1. Background

Historically, drinking and swimming pool water have been examined for Total coliform bacteria as an indicator of disinfectant efficacy. Heterotrophic bacteria count is also a satisfactory indicator of disinfectant efficacy. However, it has typically been used in drinking water systems only when disinfectant residuals are low or non-existent, as an alternate method of proof of proper disinfection. Both types of bacteria were used in this study as indicators of disinfection efficacy. **In many cases, it was necessary to rely on the Heterotrophic bacteria results as the primary indicator and not on the Total coliform bacteria results because of the effect that**

the Non-coliform bacteria population can have on the Total coliform bacteria analysis results (See discussion on Non-coliform bacteria below).

Heterotrophic bacteria are an empirical indication of the total bacteria populations in a water sample. However, the Heterotrophic bacteria examination procedure, Heterotrophic Plate Count (HPC for short), does not indicate the presence of every type of bacteria, since some bacteria require very specific media or conditions which are not provided by this test. Also, the HPC does not differentiate between single bacteria and clumps or chains, which will all be counted as one (1) colony forming unit (CFU). However, **under conditions of zero (0) disinfectant residual, whether originally zero (0) or after dechlorination, HPC can increase very quickly and dramatically. Thus, the potential for false positives can be high. In spite of these deficiencies, the method is considered as a very reliable indicator of disinfection conditions of the water. Heterotrophic Plate Counts of 500 CFU or less per ml of water meet the disinfection standard for drinking water.[9] Thus, it is reasonable to assume that if the Heterotrophic bacteria in a swimming pool is < 501 CFU/ml, the sanitary conditions are satisfactory for swimming.**

The **Total coliform bacteria group** belongs to the family Enterobacteriaceae **(Figure 1, Appendix B)** and is commonly called the "enteric group". The Total coliform group includes not only many bacteria found in the intestinal tract of warm-blooded animals, e.g., Escherichia, Klebsiella, Enterobacter, etc., but also species associated with plants, soils and water. The Fecal coliform bacteria are a subgroup of the Total coliform bacteria group **(Figure 1, Appendix B)**. Unlike the remainder of the group, the Fecal coliform bacteria grow at the higher temperatures found in warm-blooded animals. The Total coliform bacteria are not necessarily pathogenic, but their presence indicates that pathogens from similar sources, i.e., warm-blooded animals, may also be present. **Total coliform bacteria, and Fecal coliform bacteria in particular, normally do not multiply in the environment, but rather tend to die off over time even if there is no disinfectant. Thus, it is reasonable to assume that most pathogens will normally be present in lower numbers than the Total coliform bacteria, since only a small portion of the Total coliform bacteria population will be pathogenic bacteria.**

Specific testing for pathogens is very difficult, and normally unwarranted if coliform bacteria are absent. **The Maximum Contaminant Level (standard) for Total and Fecal coliform in drinking water has been set at 0 CFU per 100 ml of water by the US EPA.[10] The same standard has often also been applied to swimming pools.**

Non-coliform bacteria may belong to the Enterobacteriaceae bacteria family or other bacteria families which grow under similar conditions. **These bacteria also grow on the selective media under the conditions used for coliform bacteria detection, but do not possess all of the same biochemical characteristics.** This group includes a range of bacteria, including nonpathogens as well as certain pathogenic strains such as Shigella, Salmonellas, etc. **(Figure 1, Appendix B)**.

Although there is **no current standard** for the **Non-coliform bacteria** in either drinking or swimming pool water, **Non-coliform bacteria analyses were conducted on every water sample to determine the population in relation to the other bacteria, especially Total coliform bacteria**. These analyses were conducted because Total coliform and Non-coliform bacteria bacteriological examinations are estimated from the same sample of water and the same culture. **If the examination indicates that the population of the Non-coliform bacteria exceeds 200 CFU/100 ml, the results of the bacteriological examination for the Total coliform bacteria are deemed to be inconclusive.** This is because high levels of Non-coliform bacteria may suppress coliforms and mask detection. Since the standard for Total coliform bacteria is < 1 CFU/100 ml it is practically impossible to make an accurate determination when the Non-coliform bacteria population is of this magnitude. Therefore, **the Total coliform bacteria bacteriological examination result was used as a primary indicator of the disinfection conditions of the water only when the Non-coliform bacteria population was < 201 CFU/100 ml.**

The Pseudomonas aeruginosa bacteria belong to the Pseudomonadaceae bacteria family. Since Pseudomonas bacteria are common inhabitants of soil and fresh water, they are commonly found in swimming pools. This particular bacteria is of concern because **it is an opportunistic pathogen, sometimes causing eye, ear and skin infections**. Pseudomonas aeruginosa is also known to multiply rapidly in water, even at very low nutrient levels. Due to its importance in swimming-related illnesses, some water samples were examined to determine the Pseudomonas aeruginosa bacteria population in the satisfactory and unsatisfactory pools.

Total staphylococci and Fecal staphylococci bacteria are seldom used as a group of indicator organisms for the possible presence of pathogens. However, the staphylococci bacteria include some pathogens of concern, particularly Staphylococcus aureus, which is a common cause of skin infections. Thus, some water samples were examined for these bacteria. **No standards have yet been set for these microorganisms.**

E.2. Bacteriological Examination Routine

Figures 2 and 3, Appendix B are flow diagrams illustrating the routine that the Pinellas County Water Systems Laboratory used to conduct the bacteriological examinations on each sample of water collected by the sanitarians from the test pools.

E.3. Heterotrophic Bacteria Analysis

The pour plate method (Method 9215 B) was used to determine the Heterotrophic bacteria population and is called the Heterotrophic Plate Count (HPC) method. It is approved by the Standard Methods Committee, 1988 and a description of this method is provided in the "Standard Methods For The Examination Of Water And Waste Water".[9] **The Heterotrophic bacteria standard, Maximum Contaminant Level for drinking water is 500 CFU/ml.**

E.4. Total Coliform Bacteria Analysis

The Membrane Filtration Method (Method 9222 B)[9] was used to carry out the Total Coliform bacteria analyses on the water samples taken from all of the test pools. In this method, all colonies with a golden-green metallic sheen were counted as coliforms. For drinking water, the quality of the public water supplies is judged in terms of the 1975 U.S. Environmental Protection Agency Interim Primary Drinking Water Regulations.[10] These regulations provide for a minimum number of water samples to be examined per month and establish the maximum number of coliform organisms, Maximum Contaminant Level (standard), allowable per 100 ml of finished water. Certified laboratories must be used for these analyses.[11] **Although EPA is in the process of adopting permanent regulations, no bacteriological standard is listed in reference 9.**

E.5. Fecal Coliform Bacteria Analysis

The Fecal Coliform bacteria determinations were conducted by the Membrane Filtration Method (9222 D) using mFC broth as described in references 9 and 10. The bacteria standard for drinking water is 0 CFU/100 ml. This bacteria standard is sometimes applied to outdoor swimming pools.

E.6. Non-coliform Bacteria Analysis

The Non-coliform bacteria bacteriological examinations were conducted by the Membrane Filter Method 9222 B[9] on the same water sample and the same culture as used for the Total coliform bacteria determinations. **Colonies without a golden-green sheen were counted as Non-coliform bacteria.** The Non-coliform bacteria analysis was done on a different sample than the Heterotrophic bacteria. In general, the Non-coliform bacteria result is not equal to the difference between the Heterotrophic bacteria and the Total coliform counts since the medium used is selective for coliforms. However, the Non-coliform bacteria do contribute to the counts in the Heterotrophic bacteria analyses.

It is important to remember that the Non-coliform bacteria are considered to be "background" colonies and high levels may suppress and mask detection of the coliform bacteria in the Total coliform bacteria analyses. This is why microbiologists consider the Total coliform analysis inconclusive when the Non-coliform bacteria count is > 200 CFU/100 ml. Although resampling is often required as a "Replacement Sample" in these situations, it is not a violation, but still is considered an unacceptable sample nonetheless.

E.7. Fecal Streptococci Bacteria Analysis

The Fecal Streptococci bacteria analyses were carried out with the Membrane Filter Method for Fecal Streptococci using KF Streptococcus agar as described in reference 9. No bacteria standard is listed in references 9 - 11.

E.8. Total Staphylococcus Bacteria Analysis

According to the EPA Environmental Monitoring Support Laboratory, there is no standard procedure for the determination of Total Staphylococcus bacteria. The proposed Mannitol Salt agar procedure cited in reference 9 will be deleted from the next (18th) edition. EPA recommended the use of the modified multiple tube procedure (Method 9213 B) described in reference 11 and a membrane filter method using Baird-Parker agar. The latter method was used because it is expected to be adopted in the next edition of reference 9.

E.9. Pseudomonas Aeruginosa Bacteria Analysis

The membrane filtration method using modified M-PA agar was used for determination of Pseudomonas aeruginosa bacteria. No standard is listed in reference 9.

F. Algae

No microbiological analyses for the various species of algae were conducted because the procedures are very time consuming and costly. Therefore, the data on this parameter were generated by visual observations of the sanitarians during each pool visit. The criteria used to make these judgments were the same as those of the Florida swimming pools code[15]:

1. Algae - yes or no.

2. Type - black, yellow, green or pink.

3. Extent of growth
   a. Light - Algae not noticeable on approach to pool and inspector must get down and look for algae.
   b. Heavy - Algae covers 25 % or more of the pool surface (walls, floor, gutter) and could present a safety (slipping) hazard.
   c. Medium - Algae growth is between the light and heavy extremes.

G. Turbidity

Turbidity of the pools was judged on the basis of the following criteria:

1. No turbidity - Water is crystal clear.

2. Light turbidity - Water is clear but has a milky look.

3. Heavy turbidity - Main drain cannot be seen from the pool deck. Pool closure is required.

4. Medium turbidity - Turbidity is between the light and heavy extremes.

H. Data Collection and Custody

The data generated by the sanitarians during each pool visit were recorded on data sheets **(Table 3, Appendix C)**. The data for bacteriological analyses were recorded in notebooks and summarized on data sheets for each test pool **(Table 4, Appendix C)**. The data from both data sheets were collected by the Pinellas County Health Unit pool test program manager and stored in a master database by professional data entry personnel. The data were checked for accuracy by comparing the entries against the data contained in the original data sheets, recopied on computer diskettes and rechecked for accuracy by selected members of the pool study team. The database was then formatted and subjected to statistical analyses by Occidental Chemical Corporation personnel.

I. Data Analyses

The results and conclusions of this study were derived from statistical analyses of the data generated from the test pools. **Table 5, Appendix D** is a tabulation of the data, contained in the master database on the 486 test pools as reported by the Pinellas County Public Health Unit sanitarians. Note that the variables had numeric or alphanumeric values. The alphanumeric values were converted to numeric values by devising the appropriate code for each variable. **Table 6, Appendix E** is a tabulation showing the numeric values assigned to those variables. **Table 7, Appendix E** is a tabulation of the variable abbreviations used in the statistical analyses.

The statistical analyses were carried out by subjecting the data to the following SAS (Statistical Analysis System) statistical analysis techniques.[12]

- **PROC FREQ**
- **PROC MEANS**
- **PROC CORR**
- **PROC GPLOT**
- **PROC GCHART**
- **PROC TTEST**

SAS is a registered trademark for the statistical analysis programs provided by the SAS Institute, Inc., Cary, NC. Explanations of some of the SAS data analysis techniques are provided in appropriate places in the report to assist in comprehending the data.

The **first phase** of the data analyses concentrated on the selection of the test pools. The selection process was carried out by the Pinellas County Public Health Unit. It was designed so that data would: a) be collected on approximately 500 test pools, and b) have a representative weighting of the pertinent parameters for the 2207 public pools in Pinellas County.

The **second phase** of the data analyses involved the generation of statistics for each variable monitored in the study. The data was stored in a master dataset entitled **ALL POOLS-486**. This data analysis task was achieved by subjecting all of the data for each variable in the master dataset to the **PROC FREQ** technique. The **PROC MEANS** technique was utilized to calculate the means of each variable when appropriate. The **PROC GPLOT** technique was used to generate graphical illustrations of the results of the **PROC FREQ** analyses. The results of this data analysis phase were useful in a) obtaining an understanding of the distribution range of values for the variables and b) determining how to construct the most effective graphical illustrations. Also, the results provided the pool study team with: a) an overview on how well the pools were managed, b) useful information on sanitizers used in various facilities, and c) the effects of various parameters on the conditions of the pools. Finally, and most importantly, they provided insight as to how to conduct the subsequent phases of the data analyses.

The **third phase** consisted of subjecting the data in the master dataset **(ALL POOLS-486)** to the SAS **correlation analysis technique (PROC CORR)**. The purpose was to determine what pairs of variables had statistically significant linear relationships. **This data analysis technique also enabled the pool study team to identify what relationships were statistically significant and which ones were not.** This, in turn, allowed the pool study team to concentrate their efforts on the most pertinent relationships having statistically significant influences on the conditions of the pools.

The results of the correlation analyses were printouts of mathematical coefficients. Therefore, it was difficult to envision the statistically significant variable relationships identified by the correlation analyses. As a result, a special technique was used to illustrate the existence of a relationship between a pair of variables. It involved calculating the statistical average of the dependent variable at specific values of the independent variable with the **PROC MEANS** technique and then plotting the averages of the dependent variable as a function of the specific values of the independent variable using the **PROC GPLOT** technique.

Since the results of the correlation analyses and the special data analysis technique in phase three demonstrated that free chlorine had by far the greatest influence on the bacteria populations and hence, disinfection conditions, the **fourth phase** of the data analysis involved the use of bacteria and free chlorine to **develop a reference model** that enabled the pool study team to assess:

- the effectiveness of the procedures typically used by pool operators and public health units to judge whether a pool are satisfactory for swimming and

- the relative importance of the variables commonly used in pool judgment procedures.

This was accomplished by determining the relative percentage of pools that would: a) be bacteriologically satisfactory and unsatisfactory for swimming, and b) have a free chlorine concentration of 1.0 - 5.0 ppm. The results were used in **phases 8 and 9** to carry out the evaluation of the various pool judgment methods.

The **fifth phase** involved examination of the statistical characteristics of each variable of the bacteriologically satisfactory pools identified in the fourth phase in much greater detail. The bacteriologically satisfactory pools category was labeled **SAT 1-5CL2-290**. The **PROC FREQ** technique was utilized to generate the statistical characteristics of each variable in this pool category. The results were used in **phase 7** to determine what variables in the bacteriologically satisfactory pools were significantly different statistically from those in the bacteriologically unsatisfactory pools identified in phase 4.

The **sixth data analysis phase** involved a detailed statistical analyses of the **UNSAT** pool category generated in phase 4. This data analysis was carried out because it was not readily apparent why some pools fell into this category. This analysis was carried out by subdividing the pools in the UNSAT pool category into UNSAT pool subcategories. This was achieved by defining the criteria for each UNSAT pool subcategory in such a manner that a given UNSAT pool could fall into one and only one subcategory. The UNSAT pool subcategories were labeled **UNSAT A, B, C, etc.** The statistical characteristics of each of the subcategories were generated by the **PROC FREQ** technique. These were then compared with both the statistical characteristics of the **SAT 1-5CL2-290** pools and the **other UNSAT pools** in **phase 7**.

It is important to note that the **only purpose of phases 5 and 6** was simply to provide background information on the statistical characteristics of the **SAT 1-5CL2-290 pools** and the **UNSAT A - F pools**.

The **seventh phase** consisted of comparing the statistical characteristics of the variables of: 1) the **SAT** pools **(SAT 1-5CL2-290)** with those of each **UNSAT** pool subcategory, and 2) those of a particular UNSAT pool subcategory with those of the other UNSAT pool subcategories. This was achieved by using the SAS **T Test of the means** technique which determined if the mean of a given variable in one pool category (or subcategory) was significantly different statistically than the means for the variable in other categories (or subcategories).

Public health units and pool operators do not routinely use bacteria analyses to judge whether a pool is satisfactory for swimming because bacteria analyses are prohibitively expensive. Instead, they rely on the most common judgment methods which use free chlorine, pH, water clarity and other standards that are mandated by their state codes. Most of the state codes have cyanuric acid concentration limits as a standard which is usually 100 ppm. The **eighth phase** therefore consisted of generating data that would allow the team to determine how many pools would be deemed satisfactory for swimming by pool judgment methods typically used by public health units and pool operators. These analyses were conducted by defining the criteria for each judgment method **(Models A - F)** and using the **PROC FREQ** technique to determine the number of satisfactory pools for each category. The relationships between the bacteriologically satisfactory pools and the various judgment models were also established by using the frequency distribution analysis technique.

Since all pool judgment methods used by public health officials and pool operators do not use bacteria as criteria, the **ninth phase** involved the determination of the ratio of bacteriologically satisfactory pools to bacteriologically unsatisfactory pools present in the pools judged to be satisfactory for swimming by each pool judgment method. The results were used to assess the effectiveness of each judgment method in determining whether a pool was bacteriologically satisfactory or unsatisfactory for swimming.

Although algae may not have an influence on the disinfection conditions of the pools, public swimming pool codes do have algae standards. For this reason, the **tenth phase** of the data analysis consisted of generating statistics on this parameter. This was accomplished by determining the number of incidents of algae, the types (black, yellow, green and pink) and the extent of growth of each algae species. The resulting data were then utilized to determine if the algae had any statistically significant influence on the disinfection conditions of the pools. These results were generated by defining the algae statistical parameters for each algae pool category and using the frequency distribution analysis technique to sort the pools into the appropriate categories. The **PROC TTEST** technique was used to determine if any particular variable had a statistically significant influence on the growth of algae in pools.

The **eleventh phase** determined the ratio of the pools with algae to those without algae in the pools identified as being satisfactory for swimming by the various pool judgment models. These results were used to assess the effect of algae on disinfection conditions.

The results of all of the data analysis phases are presented and discussed in the following sections.

VI. Discussion of Results

A. Phase 1 - Selected Statistics on All Pinellas County Public Pools

Figures 4 - 6, Appendix F provide the results generated from the analysis (**PROC FREQ** technique) of the data on the 2207 public pools that the Pinellas County Public Health Unit monitored. The results in **Figure 4** showed that:

- 58.2 % of the pools were located in condominium complexes,
- 23.1 % in tourist facilities (motel, hotel, etc.),
- 18.4 % in apartment complexes,
- 4.6 % in municipal facilities and
- 1.2 % in health clubs.

The results in **Figure 5** showed that:

- 93.2 % of the pools were < 60,001 gallons,
- 95.9 % < 70,001 gallons and
- only 4.1 % > 70,000 gallons.

The **average volume of the pools was 33,063 gallons**.

The combination of the above results was very surprising in that it showed that the typical public swimming pool is located in condominium, apartment and motel facilities and not in large municipal complexes and has an average volume of < 35,000 gallons.

The results in **Figure 6** showed that:

- 58.1 % of the pools were treated with trichloroisocyanuric acid tablets,
- 23.3 % with sodium hypochlorite,
- 15.8 % with calcium hypochlorite,
- 1.2 % with bromine tablets and
- 1.5 % with other sanitizers (gaseous chlorine, sodium dichloroisocyanurate, ionizers, ozone, etc.)

These results obviously showed that trichloroisocyanuric acid tablets were, by far, the preferred sanitizer. They were not considered too surprising in view of the results of the facility pool and volume data analyses. Facilities of this type and volumes of this magnitude require a low cost, convenient sanitizer and trichloroisocyanuric acid tablets fulfill these requirements easily.

The results of the sanitizer data analysis also implied that the cyanuric acid concentrations in 58.2 % of the pools in Pinellas County probably exceeded 100 ppm sometime during the pool season. This is because 58.2 % of the pools are treated with chlorinated isocyanurates. Since the other 41.8 % pools were not treated with chlorinated isocyanurates, the results also inferred that the concentration of cyanuric acid probably remained below 100 ppm in these pools.

The results of the above data analyses also provided some insight on the characteristics of the public pool market in the United States. They implied that the typical public pool is < 35,000 gallons, located in condo/apartment type complexes and that trichloroisocyanuric acid tablets are the predominant product.

B. Phase 2 - General Statistics on All Test Pools

This phase of the data analyses involved the generation of the statistical characteristics of each variable for the 486 test pools. The results were achieved by subjecting the data to the **PROC FREQ** technique. The master dataset, which is labeled **ALL POOLS-486**, contained data on **38 variables** and has **18,468 individual data entries**. **Figures 7A and B through 39A and B in Appendices G - N** contain graphical illustrations of the frequency distribution patterns (histograms) for each variable in dataset **ALL POOLS-486**. The results for each variable are also summarized narratively and organized in variable categories shown below and in the appendices to facilitate the understanding of the results.

B.1. Bacteria

The results of the application of the **PROC FREQ** technique to the bacteria data are shown as frequency distribution patterns in the graphs labeled **ALL POOLS-486 in Figures 7A and B through 13A and B, Appendix G**.

The **frequency distribution for Heterotrophic bacteria (ALL POOLS-486, Figures 7A and B)** revealed that:

- **438 (90.12 %) of the 486 test pools had Heterotrophic plate counts (HPCs) of < 501 CFU/ml (colony forming units per milliliter). These preliminary results implied that these pools were sufficiently sanitized to meet the Maximum Contaminant Level of 500 CFU/ml for drinking water and, hence, would be satisfactory for swimming.**
- **48 (9.88 %) of the 486 test pools had HPCs > 500 CFU/ml and were deemed not sufficiently sanitized to meet the drinking water standard and, thus, would be unsatisfactory for swimming.**

The **frequency distribution of the Total Coliform bacteria (ALL POOLS-486, Figures 8A and B)** showed that:

- The **Total coliform bacteria count was 0 CFU/100 ml in 439 (90.33 %)** of the 486 test pools. These results indicated that **these pools were adequately sanitized for swimming from a bacteria contaminant standpoint.**
- **47 (9.67 %)** of the 486 test pools had > 0 CFU/100 ml. These results indicated that **these pools were not sanitized satisfactorily.** However, it is important to remember that Total coliform bacteria generally cannot live very long outside their natural environment -- the intestines of warm-blooded animals. Hence, they will die naturally in the swimming pool even if a disinfectant is not present. Thus, it is entirely possible that the Total coliform population would die off and these pools would become satisfactory for swimming in a few hours.

The **frequency distribution of the Non-coliform bacteria (ALL POOLS-486, Figures 9A and B)** showed that:

- 409 (84.16 %) of the 486 pools had < 201 CFU/100 ml,
- 77 (15.84 %) pools had > 200 CFU/100 ml.

These preliminary data indicated that **the results of the Total coliform analyses for 409 (84.16 %) of the test pools provided valid statistics and 77 (15.84 %) of the results would be inconclusive. As a result, 77 of the pools would have to be categorized as unsatisfactory for swimming.**

The **frequency distribution of the Fecal coliform bacteria (ALL POOLS-486, Figures 10A and B)** revealed that:

- 458 (94.24 %) of the 486 test pools had 0 CFU/100 ml of Fecal coliform bacteria,
- 28 (5.76 %) pools had > 0 CFU/100 ml.

These results showed that **458 (94.24 %)** of the 486 test pools had **no Fecal coliform bacteria** contamination and 28 **(5.76 %) of the pools were highly contaminated.**

The Non-coliform bacteria plate counts indicate the possible presence of such pathogenic bacteria as Pseudomonas aeruginosa.

The **Pseudomonas aeruginosa bacteria frequency distribution (ALL POOLS-486, Figure 11A and B)** revealed that:

- **21 (77.78 %) of the 27 test pools sampled had 0 CFU/100 ml**,
- 25 (92.6 %) had ≤ 1 CFU/100 ml and
- 2 (7.4 %) had 2 - 25 CFU/100 ml.

The **Total staphylococcus bacteria frequency distribution (ALL POOLS-486, Figures 12A and B)** showed that:

- **25 (92.6 %) of the 27 test pools sampled had** ≤ **5 CFU/100 ml** and

- 2 (7.4 %) had > 5 CFU/100 ml.

The **Fecal streptococci bacteria frequency distribution (ALL POOLS-486, Figures 13A and B)** revealed that:

- **24 (92.3 %) of the 26 pools analyzed for Fecal streptococci had 0 CFU/100 ml,**
- 2 (7.7 %) pools had 1 - 2 CFU/100 ml and
- there was no data on one pool sampled.

In summary, the above results of the Heterotrophic, Total coliform, Non-coliform and Fecal coliform bacteria analyses indicated that at the very least 84.16 % of the test pools were biologically satisfactory for swimming. However, these results don't tell the whole story. In fact, as will be shown later, the percentage of the test pools deemed satisfactory for swimming was much lower when other pertinent factors were considered. At any rate, the bacteria data did indicate that a significant percentage of the test pools were well managed.

B.2. Water Chemistry

The results of the water chemistry frequency distribution analyses are presented in **ALL POOLS-486, Figures 14A and B through 22A and B, Appendix H.**

The **free chlorine frequency distribution (ALL POOLS-486, Figures 14A and B)** indicated that the free chlorine residuals were:

- 0 ppm in 49 (10.08 %) of the 486 test pools,
- 0.1 to 0.9 ppm in 56 (11.52 %) pools,
- 1.0 to 3.0 in 152 (31.28 %),
- 3.1 to 5.0 in 183 (37.65 %),
- 5.1 to 10.0 in 33 (6.79 %) and
- 10.1 to 40.0 in 13 (2.67 %).

These results showed that the free chlorine was:

- **within the Florida code standard range of 1.0 - 5.0 in only 335 (68.93 %) of the 486 pools,**
- 105 (21.60 %) of the 486 test pools were below the minimum of 1.0 ppm and probably not sanitized satisfactorily for swimming and
- 46 (9.47 %) of the pools exceeded the maximum 5.0 ppm free chlorine standard of the Florida code and would have been deemed unsatisfactory for swimming.

The **total chlorine frequency distribution (ALL POOLS-486, Figures 15A and B)** showed that:

- 18 (3.70 %) of the 486 test pools had 0 ppm of total chlorine residual,
- 80 (16.46 %) had 0.1 to 0.9 ppm,
- 159 (32.72 %) had 1.0 to 3.0 ppm,
- 183 (37.65 %) had 3.1 to 5.0 ppm,
- 33 (6.79 %) had 5.1 to 10.0 ppm and
- 13 (2.67 %) had 10.1 to 40 ppm.

These results indicated that the total chlorine was:

- **> 0.9 ppm in 388 (79.8 %) of the 486 test pools, thus indicating bacteristatic conditions existed in these pools,** and
- < 1.0 ppm in 98 (20.2 %) of the pools indicating that disinfection conditions were not satisfactory.

The **pH frequency distribution (ALL POOLS-486, Figures 16A and B)** showed that the pH was:

- **within the recommended range of 7.2 to 7.8 in 404 (83.3 %) of the 486 test pools,**
- below the range in 18 (3.71 %) pools and
- above the range in 63 (12.99 %) pools.

Since good disinfection conditions can usually be supported by maintaining the free chlorine and pH within the recommended ranges continuously, the above free and total chlorine and pH results indicated that at best only 78.40 % of pools would probably be bacteriologically satisfactory for swimming. This is because 83.3 % of the pools were in the recommended pH range whereas only 78.40 % of pools had sufficient free chlorine (> 1.0 ppm) to maintain disinfection conditions. However, from a Florida swimming pool code standpoint, the percentage of satisfactory pools falls to 68.93 % because the free chlorine was > 5.0 ppm in 9.47 % of the pools. Thus, it was readily apparent at this point that on a free chlorine basis, the maximum percentage of satisfactory pools could be no more 68.93 % even though it is a well-known fact that it is safe to swim in pools with free chlorine concentrations > 5.0 and up to 10 - 15 ppm.

The **cyanuric acid frequency distribution (ALL POOLS-486, Figures 17A and B)** revealed that the cyanuric acid concentration was:

- **0 - 10 ppm in 109 (22.43 %) of the 486 test pools,**
- 11 - 20 ppm in 21 (4.32 %),
- **21 - 100 ppm in 234 (48.15 %)**,
- 101 - 200 ppm in 98 (20.16 %),
- 201 - 400 ppm in 22 (4.53 %) and

- 401 - 800 ppm in 2 (0.41 %).

These results indicated that **the cyanuric acid in 356 (73.2 %) of the 486 test pools was > 20 ppm.** Thus, **these pools were disinfected with stabilized free chlorine.** In addition, **130 (26.8 %) of the pools had < 21 ppm of cyanuric acid and the free chlorine in these pools was unstabilized.**

The Pinellas County sanitarians found that the cyanuric acid in 122 (25.1 %) of the 486 test pools exceeded the 100 ppm limit of the Florida code. In each case, the sanitarians ordered the pool operator to drain enough water from the pool and refill with fresh water to reduce the cyanuric acid below 100 ppm.

The **total dissolved solids (TDS) frequency distribution (ALL POOLS-486, Figures 18A and B)** showed that the TDS was:

- < 1,001 ppm in 184 (37.86 %) of the 486 test pools,
- 1,001 - 2,000 ppm in 159 (32.72 %),
- 2,001 - 3,000 ppm in 76 (15.64 %),
- 3,001 - 4,000 ppm in 30 (6.17 %),
- 4,001 - 5,000 ppm in 34 (7.0 %) and
- 5,001 - 6,000 ppm in 3 (0.62 %).

Thus, these results showed that:

- **only 159 (32.72 %) of the 486 test pools were within the recommended range of 1,000 - 2,000 ppm** and
- 67 (13.79 %) of the pools had excessively high (> 3,000 ppm) total dissolved solids and should have some water removed and replaced with fresh water.

The **hardness, total alkalinity, copper and nitrate** frequency distribution patterns are given in **ALL POOLS-486, Figures 19A and B, 20A and B, 21A and B, and 22A and B, respectively, in Appendix H.** The results showed that:

- The **total alkalinity** was within the recommended range of 80 - 125 ppm in **298 (61.6 %)** of the 486 test pools **(ALL POOLS-486, Figures 20A and B)**.
- The **hardness** was within the recommended range of 120 - 180 ppm in only **59 (13.2 %)** of the 447 pools tested for hardness **(ALL POOLS-486, Figures 19A and B)**.
- **Copper** was < 1.0 ppm (the Florida code limit) in all of the 440 pools tested for copper **(ALL POOLS-486, Figures 21A and B)**.
- **Nitrate** was > 10 ppm in 272 (61.4 %) of the 443 pools tested for nitrate **(ALL POOLS-486, Figures 22A and B)**.

Rarely do any of the above variables affect the disinfection conditions. However, they can affect the condition of the pool surfaces as will be shown by the results later in the report. But, these preliminary results provided no insight as to the effect on the pools.

B.3. Turbidity

The **turbidity frequency distribution (ALL POOLS-486, Figures 23A and B, Appendix I)** revealed that:

- **431 (94.31 %) of the 457 pools where turbidity data was recorded were judged to have no turbidity,**
- 13 (2.84 %) were low,
- 8 (1.75 %) were medium and
- 5 (1.1 %) were high or unsatisfactory for swimming with respect to turbidity.

These preliminary results indicated that in general the free chlorine concentrations had been maintained at the proper levels and the filtration systems were in good condition and had been operated sufficiently to maintain the turbidity levels adequately in almost all of the test pools.

B.4. Sanitizers

The **sanitizer frequency distribution (ALL POOLS-486, Figures 24A and B, Appendix J)** showed that:

- **227 (46.71 %) of the 486 test pools were treated with trichloroisocyanuric acid tablets,**
- 166 (34.16 %) with calcium hypochlorite,
- 71 (14.16 %) with sodium hypochlorite,
- 2 (0.41 %) with gaseous chlorine,
- 2 (0.41 %) with bromine tablets and
- 1 (0.21 %) with sodium dichloroisocyanurate granules.
- No data were available on 17 (3.58 %) pools.

B.5. Environmental

All graphical illustrations pertaining to this category are provided in **ALL POOLS-486, Figures 25A and B through 27A and B, Appendix K.**

The **water temperature frequency distribution (ALL POOLS-486, Figures 25A and B)** revealed that the temperature was:

- 63 to 75 °F in 27 (6.11 %) of the 442 pools for which the temperature was recorded,

- 76 to 80 °F in 121 (27.38 %),
- 81 to 85 °F in 148 (32.48 %),
- 86 to 91 °F in 145 (32.81 %) and
- 92 to 95 °F in 1 (0.23 %).

With regards to weather, the **rain frequency distribution (ALL POOLS-486, Figures 26A and B)** revealed the following information about the amount of rain that occurred within a 24 hour period prior to collection of the water samples:

- No rain occurred with 216 (44.44 %) of the 486 test pools,
- < 0.1 inch with 83 (17.08 %),
- > 0.1 but < 1 inch with 104 (21.40 %) and
- > 1 inch with 29 (5.97 %).
- There were no records on 54 (11.11 %) pools.

The **swimmer frequency distribution (ALL POOLS-486, Figures 27A and B)** showed that there were:

- **no swimmers in 318 (65.57 %) of the 486 test pools when water samples were collected, even though many persons were sunbathing in many instances,**
- 1 to 10 swimmers in 161 (33.20 %) of the pools during water sampling and
- 11 to 18 swimmers in 6 (1.24 %).

B.6. Swimming Pool Characteristics

Graphs illustrating the results of the frequency distribution analyses for the variables in this category are shown in **ALL POOLS-486, Figures 28A and B through 32A and B, Appendix L**.

The **facility frequency distribution (ALL POOLS-486, Figures 28A and B)** revealed that:

- 204 (42.15 %) of the 486 test pools were in apartment complexes,
- 168 (34.71 %) in condominium complexes,
- 102 (21.07 %) in tourist (hotels, motels, etc.) facilities,
- 6 (1.24 %) in municipal facilities and
- 4 (0.83 %) in health club pools.

The **pool volume frequency distribution (ALL POOLS-486, Figures 29A and B)** showed that the volumes ranged from:

- 12,000 to 20,000 gallons in 102 (20.99 %) pools,

- 20,001 to 40,000 gallons in 281 (57.82 %),
- 40,001 to 80,000 gallons in 91 (18.72 %),
- 80,001 to 100,000 gallons in 6 (1.23 %) and
- 100,001 to 148,000 gallons in 6 (1.23 %).

The **water return system frequency distribution (ALL POOLS-486, Figures 30A and B)** revealed that the pool water returned to the pool recirculation/filtration system via:

- gutters in 453 (93.98 %) of the pools and
- skimmers in 29 (6.02 %) of the pools.

The **type of pool surface frequency distribution (ALL POOLS-486, Figures 31A and B)** indicated that:

- 461 (94.9 %) of the 486 test pools had marcite surfaces and
- 25 (5.1 %) had Fiberglass surfaces.

Note: The term Fiberglass does not necessarily indicate that the pool walls are constructed of this material. In fact, these pools are probably marcite pools that have had their surfaces covered with Fiberglass resin.

The **surface finish condition distribution (ALL POOLS-486, Figures 32A and B)** showed that the surfaces in:

- 301 (62.19 %) of the 486 test pools were in satisfactory condition,
- 154 (31.82 %) were fair and
- 29 (5.99 %) were poor.

B.7. Time

The frequency distribution patterns for these variables are presented in **ALL POOLS-486, Figures 33A and B through 35A and B, Appendix M**.

The **sampling day frequency distribution (ALL POOLS-486, Figures 33A and B)** showed that the data were generated from:

- 100 (20.58 %) of the 486 test pools on Sunday,
- 146 (30.04 %) on Monday,
- 181 (37.24 %) on Tuesday,
- 56 (11.52 %) on Wednesday and
- 3 (0.62 %) on Thursday.

- No samples were collected on Friday or Saturday.

The **month frequency distribution (ALL POOLS-486, Figures 34A and B)** showed that water samples were collected from:

- 31 (6.38 %) of the 486 test pools in July,
- 125 (25.72 %) in August,
- 148 (30.45 %) in September,
- 122 (25.10 %) in October and
- 60 (12.35 %) in November.

The **time of day frequency distribution (ALL POOLS-486, Figures 35A and B)** showed that the water samples were collected from:

- 258 (53.08 %) of the 486 test pools between 7:00 AM and 12:59 PM and
- 228 (46.92 %) between 1:00 and 6:00 PM.

B.8. Algae

The results of the **algae** frequency distribution analyses are given in **Figures 36A and B through 39C and D, Appendix N.**

The **algae frequency distribution (NO ALGAE-297, Figures 36C and D)** indicated that:

- **297 (61.11 %) of the 486 pools did not have algae** whereas
- **189 (38.89 %) had some type of algae.**

The **black algae frequency distribution (ALL POOLS-486, Figures 36A and B)** indicated that:

- **304 (62.55 %) of the 486 test pools did not have black algae** whereas
- **182 (37.45 %) pools had black algae.**
- **Thus, 7 (1.44 %) of the 486 test pools had yellow, green or pink algae but not black algae.**

The frequency distribution **(ALGAE BLK-182, Figures 36C and B)** showed that the **extent of black algae growth** was:

- low in 140 (76.92 %) of the 182 black algae pools,
- medium in 32 (17.58 %) and
- high in 10 (5.49 %).

The **yellow algae frequency distribution (ALL POOLS-486, Figures 37A and B)** indicated that:

- **454 (93.42 %)** of the 486 test pools did not have yellow algae and
- **32 (6.58 %)** of the 486 pools had yellow algae.

The frequency distribution **(ALGAE YL-32, Figures 36C and D)** indicated that:

- 25 (78.13 %) of the 32 yellow algae pools **had yellow and black algae** and
- 7 (21.87 %) of the 32 yellow algae pools **did not have black algae.**

The extent of growth of yellow algae (ALGAE YL-32, Figures 37C and D) was:

- low in 23 (71.88 %) of the 32 pools,
- medium in 8 (25 %) and
- high in 1 (3.12 %).

The **green algae frequency distribution (ALL POOLS-486, Figures 38A and B)** indicated that:

- 482 (99.18 %) of the 486 test pools **did not have green algae** whereas
- 4 (0.82 %) **had green algae**.

Of the 4 green algae pools:

- 1 pool had low growth,
- 2 had medium and
- 1 had high.

The **pink algae frequency distribution (ALL POOLS-486, Figures 39A and B)** indicated that only 1 (0.2 %) had a low growth of pink algae.

The preliminary algae results did not indicate whether the pools would be biologically unsatisfactory for swimming. However, the results in **Figure 36A, ALL POOLS-486, Appendix N** did indicate that the extent of algae growth in **10 (2.06 %) of the 486 test pools** was high enough to be deemed unsatisfactory for swimming on the basis of the algae standard of the Florida swimming pool code.

C. Phase 3 - Identification of Statistically Significant Relationships of Variable Pairs

In this data analysis phase, the PROC CORR technique was used to determine if statistically significant relationships existed between pairs of variables. This technique measures the strength of linear association of one variable with another. A pair of variables are considered to have a positive association when increases in one variable correspond to increases in the other variable. On the other hand, a pair of variables is said to have a negative association when increases in one corresponded to decreases in the other. The associations are determined mathematically by calculating correlation coefficients. **The calculated values of the coefficients range from - 1, a perfect negative association, to + 1, a perfect positive association.** The significance of the magnitude of the correlation coefficient is tested by determining the probability that the actual coefficient is 0 (no correlation). **In this study, if the probability was 95 % or more that the coefficient was not 0, the variables were considered to be correlated**, and hence, associated.

The reader should remember that the associations are not ironclad guarantees of relationships. For instance, statistics show that there is a positive association between people's height and weight. However, this does not exclude cases of one person being taller than another, but weighing less. **Associations do not always represent cause and effect relationships either. On the other hand, this technique proved to be very useful in identifying the most important variable relationships. In addition, the authors want to point out that all of the results obtained in this study agreed with what knowledgeable experts would expect of the identified relationships.**

The results of the **correlation analyses for all variable pair combinations** from the **ALL POOLS-486** pool category are provided in **Appendix O.** The **data in bold face type** indicate that a **statistically significant relationship (95 % or more, i.e., 2nd number for each entry in Appendix O is < 0.05)** existed between that **variable pair combination.** An explanation of how to interpret the correlation analyses is also provided with the data.

The **results of the correlation analyses in Appendix O are summarized by variable categories (e.g., bacteria, water chemistry, etc.) in Tables 8 - 16, Appendices P - V.** The intent of this data reporting format was to provide a simple way to show which variables had statistically significant effects on other variables and which ones did not. The tables were constructed to highlight only those variables with statistically positive or negative relationships. In spite of this simplified format, it was impossible to avoid the incorporation of some variable pairs that did not have statistically significant relationships. For this reason, a 0 was entered in the field for these variable pairs, meaning no relationship.

Figures 40 - 49 in Appendix W are scatter plots for some of the statistically significant variable pairs that have an influence on the bacteria populations and, hence, the disinfection conditions of the pools. It is obviously very difficult to envision how the correlation analyses can determine whether there is a statistically significant relationship between these pairs of variables. For this reason, the pool study team devised a statistically valid graphing technique to illustrate the results of the correlation analyses more clearly. The technique is very simple and involved the following steps: 1) calculate the statistical average of the dependent variable at selected ranges for the independent variable; and 2) plot the resulting averages as a function of the independent variable. For example, **Figure 40, Appendix W** is a plot of all of the Heterotrophic bacteria population data points versus all of the corresponding free chlorine concentration data points. **Figure 50, Appendix X** is a plot generated from the same data with the special technique. This graph was generated by: a) calculating the statistical average of the Heterotrophic Plate Counts at free chlorine concentrations of 0, 0.1-0.9, 1.0-1.9, 2.0-2.9, 3.0-3.9, 4.0-4.9, 5.0-5.9, and >5.9 ppm; and b) then plotting the statistical averages as a function of the same (e.g., 0, 0.1-0.9, 1.0-1.9, etc.,) free chlorine concentrations. This simple technique obviously makes it easier to comprehend the correlation analyses results.

Figures 50 – 180 in Appendices X through DD are graphs generated by the special technique for the variables identified by the correlation analyses as having statistically significant relationships. Note, that the graphs are organized in the appendices by variable categories. In addition, the values of the dependent variable are always on the Y-axis and the independent variables on the X-axis.

C.1. Bacteria Variable Relationships

The **Heterotrophic bacteria correlation analyses (Appendix O; Table 8, Appendix P; and Figures 50 - 58, Appendix X)** clearly demonstrated that the following variables had an effect on the Heterotrophic population and/or were affected by the Heterotrophic bacteria population. All of the associations found are narratively summarized below:

- The Heterotrophic bacteria population **decreased with increases** in free and total chlorine and cyanuric acid. **(Figures 50, 51 and 52, respectively)**.
- The Heterotrophic bacteria population **increased with increases** in the Total coliform, Non-coliform and Fecal coliform bacteria populations, total dissolved solids and turbidity **(Figures 53, 54, 55, 56 and 57, respectively)**.
- The Heterotrophic bacteria population was higher in municipal swimming pools than in condo/apartment facility pools **(Figure 58)**.

The **Total coliform bacteria correlation analyses (Appendix O; Table 8, Appendix P; and Figures 59 - 70, Appendix X)** showed that the following relationships existed with Total coliform bacteria:

- Total coliform bacteria population **decreased with increases** in free and total chlorine **(Figures 59 and 60, respectively)**.
- Total coliform bacteria population **increased with increases** in Heterotrophic, Non-coliform, Fecal coliform and Fecal streptococcus bacteria populations, turbidity, bather load, water temperature and total dissolved solids **(Figures 61, 62, 63, 64, 65, 66, 67 and 68, respectively)**.
- Total coliform bacteria population was **higher** in tourist pools **(Figure 69)**.
- Total coliform bacteria population **decreased with increases** in cyanuric acid **(Figure 70)**.

The **Non-coliform bacteria correlation analyses (Appendix O; Table 8, Appendix P; and Figures 61, 62, 71 - 76, Appendix X)** showed that the following relationships existed with Non-coliform bacteria:

- **Decreases** in Non-coliform bacteria population correlated with **increases** in free and total chlorine and in the progression of the pool season from summer to fall **(Figures 71, 72 and 73, respectively)**.
- **Increases** in Non-coliform bacteria population correlated with **increases** in Heterotrophic, Total coliform, Fecal coliform and Fecal streptococcus bacteria populations and water temperature **(Figures 61, 62, 74, 75 and 76, respectively)**.

The **Fecal coliform bacteria correlation analyses (Appendix O; Table 8, Appendix P; and Figures 77 - 81, Appendix X)** demonstrated the following relationships with Fecal coliform bacteria:

- Fecal coliform bacteria population **increases correlated with increases** in the populations of Heterotrophic, Total coliform, Non-coliform and Fecal streptococcus bacteria **(Figures 77, 78, 79 and 80, respectively)**.
- The Fecal coliform bacteria population was higher in pools with skimmers than with gutters **(Figure 81)**.

The **Pseudomonas aeruginosa correlation analyses (Appendix O; and Table 9, Appendix P)** and the figure cited below indicated that:

- The Pseudomonas aeruginosa bacteria population was lower in pools equipped with gutters **(Figure 83, Appendix X)**.

The **Total staphylococcus bacteria correlation analyses (Appendix O; and Table 9, Appendix P)** and the figures cited below indicated that:

- The Total staphylococcus bacteria population increased with increases in pH and total dissolved solids **(Figures 84 and 85, Appendix X)**.

The **Fecal streptococcus bacteria correlation analyses (Appendix O; and Table 9, Appendix P)** and the figures cited below indicated that:

- Increases in Fecal streptococcus bacteria occurred with increases in Total coliform, Non-coliform and Fecal coliform bacteria, bather load and yellow algae **(Figures 64, 75, 80, 86 and 87, respectively, Appendix X)**.

In summary, the results of the bacteria variable correlation analyses and the special graphing technique clearly demonstrated, as expected, that the populations of the Heterotrophic, Total coliform and Non-coliform bacteria were strongly dependent on the free and total chlorine concentrations and they decreased with increases in the concentrations of these chlorine species. They also showed that the free chlorine concentration should be at least 1 ppm in order to control these bacteria at or below the

Maximum Contaminant Limits for drinking water and swimming pools. Thus, the correlation analyses clearly identified free and total chlorine as two of the most important variables in the study, especially from a disinfection standpoint.

The bacteria variable correlation analyses results also indicated that the population of the Heterotrophic bacteria was associated with the Total coliform, Non-coliform and Fecal coliform bacteria populations. These results were not really that surprising since the Heterotrophic bacteria is basically the sum of all types of bacteria. As a consequence, if the populations of the latter bacteria increased then one would expect the population of the Heterotrophic bacteria to increase proportionately. They also indicate that the populations of all types of bacteria tend to increase and decrease together, rather than one type growing at the expense of the another type.

The bacteria variable correlation analyses also indicated that the Heterotrophic and Total coliform bacteria populations decreased with increases in cyanuric acid concentrations. These results are due to the fact that the populations of these bacteria are strongly dependent on the free and total chlorine concentrations, decreasing with increases in the chlorine species concentrations, and the free chlorine concentration tends to be higher in pools containing enough (> 20 ppm) cyanuric acid to stabilize the free chlorine than in pools not having enough cyanuric acid to stabilize the free chlorine.

Free chlorine consists of two chlorine species (hypochlorous acid and hypochlorite ion) the relative concentrations of which are affected by the pH; the concentration of the hypochlorous acid decreases with increases in pH whereas the hypochlorite ion increases with increases in pH. Since the bactericidal properties of hypochlorous acid are vastly superior to the hypochlorite ion, the pH must be controlled so that the concentration of the hypochlorous acid, and hence, bactericidal properties, are maximized. Above a pH of 7.8, the concentration of hypochlorous acid is < 30 % of the concentration of the free chlorine species and the bactericidal properties are greatly reduced. In view of these factors, one would expect the results of the PROC CORR analyses to indicate statistically significant relationships between pH and bacteria populations, i.e., increases in pH would result in increases in bacteria populations as a result of the decreased efficacy of free chlorine. **But, they did not.** However, these results were not too surprising when the following results were considered. First, the pH PROC FREQ analyses indicated that the pH was > 7.8 in only 63 (12.99 %) of the 486 test pools. Second, a PROC FREQ analyses of free chlorine, pH and bacteria showed that the free chlorine concentrations were > 2.0 ppm in ~ 60 % (44) of the 63 high (> 7.8) pH pools. Thus, the effect of the high free chlorine probably provided enough hypochlorous acid to offset most of the possible deleterious effects that the high pH might have on efficacy of free chlorine.

The PROC CORR analyses indicated that there were statistically significant positive relationships between total dissolved solids and Heterotrophic, Total coliform and Total staphylococcus bacteria populations, i.e., the populations of these bacteria increased with increases in total dissolved solids. Since no statistically significant negative relationship was observed between total dissolved solids and free chlorine concentration, there does not appear to be any apparent explanation for these results.

The other significant bacteria variable relationship identified was the positive one between Total coliform bacteria and bather load, i.e., increases in bather load caused increases in the population of the Total coliform bacteria. These results were not surprising at all, because swimmers are a primary source of Total coliform bacteria.

The PROC CORR analyses also indicated there were positive relationships between water temperature and Total coliform and Non-coliform bacteria. These results were not unexpected and are attributed to the following factors: 1) increases in water temperature results in increases in bather load; 2) increases in bather load increases the rate of introduction of Total coliform bacteria to the pool; and 3) increases in water temperature increases the growth rates of bacteria.

C.2. Water Chemistry Variable Relationships

The **free chlorine correlation analyses (Appendix O; and Table 10, Appendix Q)** and the figures cited below indicated that:

- **Increases** in free chlorine correlated with **decreases** in Heterotrophic, Total coliform and Non-coliform bacteria, turbidity and black and yellow algae (**Figures 50, 59 and 71, Appendix X; Figure 138, Appendix Z; and Figures 168 and 177, Appendix DD; respectively)**.
- **Increases** in free chlorine correlated with **increases** of total chlorine **(Figure 93, Appendix Y)**.
- Free chlorine **increased** with **increases in cyanuric acid** concentrations **(Figure 88, Appendix Y)**.
- **Decreases** in free chlorine were observed with **increases** in **bather load (Figure 89, Appendix Y)**.
- Free chlorine was **higher** on weekdays and in the summer **(Figures 90 and 91, Appendix Y)**.
- Free and total chlorine decreased from morning to afternoon **(Figure 92 and 98, Appendix Y)**.

The relationships between free chlorine and the bacteria were discussed in section **B.1. Bacteria Variable Relationships** and, hence, will not be reviewed here.

The positive relationship between free and total chlorine was expected, since total chlorine is the sum of the free and combined chlorine values. Thus, one would expect the total chlorine values to be strongly dependent on the free chlorine values, increasing with increasing free chlorine concentrations.

The PROC CORR analyses indicated **a positive relationship between free chlorine and cyanuric acid concentrations**. These results were not surprising since the results of the 1971-83 Pinellas County studies demonstrated that this phenomenon existed.

The PROC CORR analyses indicated that **a negative relationship existed between free chlorine and bather load** which is the result one would expect since an increase in bather load increases the contaminant load in the pool. As a result, the consumption of free chlorine increases and the free chlorine concentration decreases. If a swimming pool is properly managed, this phenomenon will not occur to the extent that the pool becomes bacteriologically unsatisfactory for swimming. With a properly managed pool, the pool operator will know what days the bather loads will usually be greater and approximately what time of the day the increase in bather load will begin. Thus, management will also know that it should increase the feed rate of free chlorine to the pool prior to the increase in the bather load so that the concentration of the free chlorine will be adequate to offset the increased chlorine demand. If all of the pools in this study were well-managed, the PROC CORR analyses might not have indicated that such a relationship existed. However, since most pools are not well-managed, this relationship existed and was identified by the correlation analyses.

Negative relationships between free chlorine and turbidity and free chlorine and black algae were indicated. These results were expected and will be discussed in detail in sections **B.3. Turbidity and B.8. Algae,** respectively.

The **correlation analyses for total chlorine (Appendix O; Table 10, Appendix Q; Figures 51, 60 and 72, Appendix X; Figures 94 through 98, Appendix Y; and Figures 169 and 178, Appendix DD) indicated that the variable pair relationships for total chlorine were essentially the same as those observed for free chlorine.**

With regards to **pH, the correlation analyses (Appendix O; and Table 10, Appendix Q)** and the graphs cited below showed that:

- **Increases** in pH correlated with **increases** of Total staphylococcus bacteria and total alkalinity **(Figure 84, Appendix X; and Figure 99, Appendix Y; respectively)**.
- **Decreases** in pH correlated with **increases** in usage of trichloroisocyanuric acid tablets, cyanuric acid and water temperature **(Figures 100, 101 and 102, respectively, Appendix Y)**.
- **Decreases** in pH correlated with **deterioration** of pool surface finish condition **(Figure 159, Appendix BB)**.
- pH was **higher** in the fall than the summer and lower during the weekdays versus Sunday **(Figures 103 and 104, Appendix Y)**.
- pH was higher in municipal pools than in apartment and condo pools **(Figure 105, Appendix Y)**.

The results for the negative relationships between pH and cyanuric acid and pH and trichloroisocyanuric acid tablets were expected because the continuous use of trichlor tends to increase the acidity, i.e., lower the pH, of the pool. This phenomenon occurs in most pools because: 1) hydrochloric acid is formed from free chlorine during the killing of bacteria and other microorganisms and the chemical destruction of the contaminants; and 2) the cyanuric acid formed during the dissolution of the tablets in the pool water is so chemically stable that its concentration increases with time, unless controlled by some water discharge program which all pools should have. The combination of the above chemical events will tend to drive the pH toward the natural pH (3) of aqueous trichlor solutions. A well-managed pool will always maintain sufficient (80 - 125 ppm) total alkalinity in the pool so that the pH stays within the recommended range of 7.2 - 7.8. Also, a well-managed pool will have a practice for discarding the water from the pool periodically to control total dissolved solids. Such a practice will also prevent the cyanuric acid from reaching high concentrations. However, as is often the case, some pools are not managed well enough. As a result, this phenomenon will be easily observed in studies having valid statistical data.

The negative relationship between pH and water temperature was observed because increases in water temperature result in increased bather loads which in turn result in higher consumption rates of free chlorine, and hence, increased production of hydrochloric acid in the pool. Again, a well-managed pool will maintain the total alkalinity within the recommended range and not allow it to fall below the minimum level of 80 ppm.

The positive relationship observed between pH and the progression of the pool season was probably due to the fact that the bather loads declined from summer to fall and resulted in decreases in the chlorine usage. As a result, the pH of the pools did not decrease as much as in the fall and was therefore higher.

The most plausible explanation for the negative relationship indicated between pH and day of the week appears to be that the bather load was heavier on the weekend than during the week. This resulted in higher chlorine consumption rates and caused the pH to fall. The phenomenon probably occurred because the pools did not have enough total alkalinity to offset the increase in the hydrochloric acid that is generated during the disinfection and chemical cleaning of the pools with free chlorine during the weekend.

The pH/pool surface finish condition relationship will be discussed later in this section, in the C.6. Swimming Pool Variable Relationships section and in the D.2. Water Chemistry Variable Relationships section.

For cyanuric acid, the correlation analyses (Appendix O; and Table 10, Appendix Q) and the graphs cited below indicated that:

- **Increases** in cyanuric acid levels correlated with **increases** in the use of trichloroisocyanuric acid tablets, with skimmers, and the free and total chlorine concentrations **(Figures 106, 107, 88 and 97, respectively, Appendix Y)**.
- **Decreases** in cyanuric acid concentrations correlated with progression of the pool season from summer to fall **(Figure 108, Appendix Y)**.

- Cyanuric acid concentrations were higher in apartment pools than in municipal pools **(Figure 109, Appendix Y)**.
- **Increases** in cyanuric acid levels correlated with **decreases** in Heterotrophic bacteria population, pH, total dissolved solids, hardness and surface finish condition **(Figure 52, Appendix X; Figures 101, 113 and 120, Appendix Y; and Figure 157, Appendix BB; respectively)**.

The positive relationship between cyanuric acid and trichloroisocyanuric acid tablets is obvious and expected since trichlor contains cyanuric acid.

The positive relationship between the cyanuric acid and the water return simply indicates that trichlor tablets were used more often in pools equipped with skimmers that those equipped with gutters. This result should not be a surprise because the use of trichlor tablets in skimmers is a common practice employed by pool operators.

The positive relationships between cyanuric acid and free chlorine and cyanuric acid and total chlorine were discussed in previous sections and will not reviewed here.

The negative relationship between cyanuric acid and the pool facility code means that trichlor tablets were used more often in apartment and condominium complexes than in municipal and tourist pool facilities.

The negative relationship between cyanuric acid and month code value simply indicates that the amount of trichlor tablets fed to the pools declined as the season progressed from summer to fall. Obviously, this is an expected event since the bather load would naturally decline and less trichlor would be needed to meet the lower chlorine demand of the pools.

The negative relationships between cyanuric acid and Heterotrophic bacteria population, and cyanuric acid and pH were discussed in the **C.1. Bacteria Variable Relationships** section and the previous subsection of this section.

The negative relationships between cyanuric acid and hardness and cyanuric acid and pool surface condition will be discussed in the following subsections of this section and in the **C.6. Swimming Pool Variable Relationships** section, respectively.

The total dissolved solids correlation analyses (Appendix O; and Table 10, Appendix Q) and the figures cited below showed that:

- **Increases** in total dissolved solids correlated with **increases** in hardness and nitrate **(Figures 115 and 110, respectively, Appendix Y)**.
- **Increases** in total dissolved solids correlated with **increases** in Heterotrophic, Total coliform and Total staphylococcus bacteria **(Figures 56, 68 and 85, respectively, Appendix X)**.

- Total dissolved solids were **higher** in marcite and tourist pools **(Figures 111 and 112, Appendix Y)**.
- Total dissolved solids **decreased** with **increases** in cyanuric acid and were **lower** in pools treated with trichloroisocyanuric acid tablets **(Figures 113 and 114, Appendix Y)**.

A positive correlation between total dissolved solids and hardness and nitrate was not surprising. Hardness and nitrate measurements are specific tests for the amount of calcium and nitrate ions dissolved in the water, respectively. Since total dissolved solids measurements include all of the solids dissolved in the water, one would naturally expect the total dissolved solids to increase with hardness and nitrate.

A positive correlation between total dissolved solids and Heterotrophic and Total staphylococcus bacteria was surprising until it was realized that a part of the total dissolved solids values could be due to water insoluble colloidal particles not removed by the filtration systems. It is possible for bacteria to grow in the interstices of colloidal particles thereby making it very difficult for free chlorine to diffuse to and kill the bacteria. Thus, the colloidal particles act as havens for the bacteria. Hence, the bacteria population would tend to increase as the total dissolved solids increase.

The most plausible explanation for the positive correlation between total dissolved solids and marcite pools is that the leaching of the calcium ions from the walls of the marcite pools caused the increase in total dissolved solids.

The positive relationship between total dissolved solids and tourist pools is probably due to the fact that the bather loads are higher in these pools. As a result, the contaminant loads are higher and more chlorine is required to maintain good disinfection conditions and sparkling clear water. Hence, more solids are introduced into the pools and the total dissolved solids content naturally increases if some of the water is not discarded from the pool periodically.

The negative relationship between total dissolved solids and cyanuric acid and trichloroisocyanuric acid is related to the fact that trichlor tablets have at least 50 % more available chlorine than the other common chlorine sanitizers. Hence, less pounds of trichlor are required to maintain the same level of free chlorine in the pool than the other sanitizers. As a consequence, less solids are being dissolved in the pool. Hence, the total dissolved solids content of pools treated with trichlor tablets will be lower than pools treated with other sanitizers.

The **correlation analyses on hardness (Appendix O; and Table 11, Appendix Q)** and the figures cited below indicated that:

- Hardness **increased** with **increases** in total dissolved solids, the use of calcium hypochlorite and nitrate **(Figures 115, 116 and 117, respectively, Appendix Y)**.
- Hardness **increased** with **decreases** in pool volume and bather load **(Figures 118 and 119, respectively, Appendix Y)**.

- Hardness **decreased** with increases in cyanuric acid levels and use of trichloroisocyanuric acid tablets **(Figures 120 and 116, Appendix Y)**.
- Pool surface finish condition was **better** at higher hardness **(Figure 160, Appendix BB)**.
- Hardness tended to increase with the increase in facility pool code value **(Figure 122, Appendix Y)**.
- **Decreases** in black and yellow algae incidence correlated with **increases** in hardness **(Figures 171 and 182, Appendix DD)**.

The positive relationship between hardness and total dissolved solids was discussed above and will not be repeated. Please refer to the previous subsection.

The positive relationship between hardness and calcium hypochlorite is obviously due to the fact the use of calcium hypochlorite increases the concentration of calcium ions and hardness is a measure of the calcium ion concentration of water.

It was not clear why there was a positive relationship between hardness and nitrate. One possible explanation is that the nitric acid content of the marcite pools was high enough at times to cause leaching of calcium ions from surfaces of the pool. The facts supporting this conclusion are as follows: 1) Most of the pools in Pinellas County are marcite pools; 2) The correlation analyses indicated a positive relationship between nitrate and rain; 3) Pinellas County has the highest incidence of lightning storms in the United States; and 4) Lightning usually occurs with many rainstorms and is known to generate nitric oxide, NO_2, which will react with water to form nitric acid. Thus, during a very rainy period it is entirely possible to form enough nitric acid in the pool to leach sufficient calcium from the pool walls to increase hardness.

The negative relationship between hardness and pool volume was surprising in that more of the smaller volume pools are treated with trichlor tablets whereas more of the larger volume pools are treated with calcium hypochlorite and sodium hypochlorite. One possible explanation for this unexpected result is that the pH was not controlled as well in the smaller pools. As a result, the pH of the smaller pools fell below 7 more frequently and calcium ions were leached from the marcite pool walls, thereby increasing the hardness.

It was not clear why there was a negative relationship between hardness and bather load unless sodium hypochlorite and calcium hypochlorite were used in the large pools where the bather load would be higher.

The negative relationship between hardness and cyanuric acid was explained above in the cyanuric acid subsection.

The correlation analysis indicated that the condition of the pool surfaces improved with hardness. This positive relationship made sense because pools with higher hardness were usually treated with calcium hypochlorite. This practice increases the calcium ion concentration in the water and tends to make the water more alkaline. The combination of these two factors suppresses the tendency of the water to leach calcium from the marcite pool walls. As a consequence, the pool surfaces tend to be smoother and not as mottled as it would be if the water was deficient in calcium ions and/or more acidic (less alkaline).

It was not clear why there were negative relationships between hardness and incidence of black and yellow algae.

The **correlation analyses for total alkalinity (Appendix O; and Table 11, Appendix Q)** and the figures cited below showed that:

- Total alkalinity **increases** correlated with **increases** in pH and in the quality of the condition of the pool surfaces **(Figure 99, Appendix Y; and Figure 161, Appendix BB, respectively)**.
- Total alkalinity **increases** correlated with **increases** in bather load **(Figure 123, Appendix Y)**.
- Total alkalinity was **higher** in condo, municipal and tourist pools **(Figure 124, Appendix Y)**.

The positive correlation between total alkalinity and pH made sense since increases in pH will naturally increase the total alkalinity of water.

The positive relationship between total alkalinity and pool surface condition is due to the fact that if pool water has total alkalinity, the pH is usually > 7. As a result, there is less of a tendency for the water to leach calcium ions from the marcite pools. Hence, the surface condition of the marcite pools tends to be smoother and of better quality in pools where the total alkalinity is maintained high enough (80 ppm or more) to prevent leaching of calcium ions from the surfaces.

The correlation analyses indicated that the total alkalinity increased with increases in bather load. This result is related to the fact that bather load increased with increases in pool volume and the larger pools were usually treated with calcium hypochlorite, which is an alkaline product.

The total alkalinity/municipal pool positive relationship indicated that more of the pools in these types of facilities were treated with calcium hypochlorite. Since calcium hypochlorite is an alkaline product, the total alkalinity will tend to be higher in these pools as opposed to those treated with more acidic type products such as trichlor tablets.

The **correlation analyses on copper (Appendix O; and Table 11, Appendix Q)** and the figures cited below indicated that:

- Copper levels were **higher** in Fiberglass and municipal and health club pools **(Figures 125 and 126, respectively, Appendix Y)**.

- Copper levels **increases** correlated with **increases** in nitrate **(Figure 127, Appendix Y)**.

The positive relationship between copper and nitrate is probably due to the same factors involved in the positive relationship between nitrate and hardness. Very simply, this relationship indicated that during rainy periods the nitric acid content of the water became high enough to increase the corrosion of the copper recirculation pipes thereby increasing the concentration of copper in the water.

It was not clear why there were positive relationships between copper and Fiberglass pools and pools located in municipal and tourist facilities.

The **correlation analyses on nitrate (Appendix O; and Table 11, Appendix Q)** and the figures cited below indicated that:

- Increases in nitrate correlated with increases in total dissolved solids, hardness and copper **(Figures 110, 117 and 127, respectively, Appendix Y)**.
- Nitrate levels were higher in pools equipped with gutters **(Figure 128, Appendix Y)**.
- Nitrate increased from summer to fall **(Figure 129, Appendix Y)**.

All of these positive relationships have been discussed above; therefore refer to the above appropriate sections for details.

C.3. Turbidity Variable Relationships

The **turbidity correlation analyses (Appendix O; and Table 12, Appendix R)** and the figures cited below indicated that:

- Turbidity **increased** with **increases** in Heterotrophic bacteria, Total and Fecal coliform and Fecal streptococcus bacteria, bather load, water temperature, and black and yellow algae **(Figures 130 - 137, Appendix Z)**.
- Turbidity **decreased** with **increases** in **free chlorine (Figure 138, Appendix Z)**.
- Turbidity was **higher** on Sundays than weekdays **(Figure 139, Appendix Z)**.
- Turbidity increased with pool volume up to 80,000 gallons and then decreased with increases in pool volume **(Figure 140, Appendix Z)**.
- Turbidity **increases** correlated with **decreases** in pool surface condition **(Figure 142, Appendix Z)**.
- Turbidity increased from morning to afternoon **(Figure 142, Appendix Z)**.

The positive relationships between Heterotrophic, Total coliform, Fecal coliform and Fecal streptococcus bacteria made sense because if the populations of these bacteria increased it meant that the free chlorine concentration had decreased. It follows that, if the chorine is too low to control the growth of the bacteria population then it was probably too low to adequately oxidize the organic contaminants. Hence, the turbidity of the pools would be higher.

With regard to the positive relationship between turbidity and bather load, swimmers introduce contaminants which are often insoluble in the water and react with free chlorine. If the supply of the free chlorine to the pool is not adequate, the free chlorine will decrease. If this occurs, there is not enough free chlorine to oxidize the water insoluble organic matter. As a consequence, the turbidity of the pool will increase with bather load.

The positive relationship between turbidity and water temperature simply indicated that increases in water temperature will result in increases in bather loads which in turn increases the rate of introduction of contaminants and consumption of free chlorine. The combination of these events can result in free chlorine concentrations that are not adequate to chemically destroy the organic matter. Hence, turbidity tends to increase as the water temperature increases.

Free and total chlorine had negative relationships with turbidity for the reasons cited in the previous paragraphs.

The negative relationship between turbidity and the sampling day was attributed to the fact that the bather load was higher on Sundays than it was on the following (Monday, etc.) days (cf. correlation analysis results for bather load and sampling day). Thus, the higher bather loads on Sunday resulted in lower free chlorine levels which were inadequate to chemically oxidize the organic matter. This supposition is supported by the fact that free chlorine/sampling day relationship indicated that free chlorine was lower on Sunday than during the week days. Hence, the turbidity was higher on Sundays because of the higher bather loads and lower free chlorine levels.

It was not apparent why the turbidity decreased as the volume of the pool water increased. One possible explanation for this negative relationship is that the larger pools were managed better than the smaller ones. As a result, the free chlorine was higher in the larger pools. Since turbidity was shown to decrease with increasing free chlorine, the turbidity would tend to be lower in the larger pools.

C.4. Sanitizer Variable Relationships

The **correlation analyses on the type of sanitizer used (Appendix O; and Table 13, Appendix S)** and the figures cited below indicated that:

- The use of trichloroisocyanuric acid tablets increased the cyanuric acid concentration **(Figure 106, Appendix Y)**.
- The Pseudomonas aeruginosa bacteria population was lower in pools treated with trichlor tablets **(Figure 82, Appendix X)**.
- pH, total dissolved solids and hardness were lower with pools with trichlor tablets **(Figures 100, 114 and 121, Appendix Y)**.

- Black and yellow algae incidence was higher in pools treated with sodium hypochlorite and trichloroisocyanuric acid tablets **(Figures 174 and 180, Appendix DD)**.
- Trichlor was used more often in apartment pools versus municipal pools **(Figure 143, Appendix AA)**.
- The finish condition of pool surfaces was better in pools treated with calcium hypochlorite **(Figure 158, Appendix BB)**.

All of the sanitizer variable relationships cited in this section have been discussed previously. Therefore refer to the appropriate section for more details about the relationships.

C.5. Environmental Variable Relationships

The **correlation analyses on water temperature (Appendix O; and Table 13, Appendix S)** and the figures cited below indicated that:

- **Increases** in water temperature correlated with increases in black algae and bather load **(Figure 172, Appendix DD; and Figure 148, Appendix AA)**.
- **Increases** in water temperature correlated with **deterioration** of pool surface finish condition and **decreases** in pH **(Figure 156, Appendix BB; and Figure 102, Appendix Y)**.
- Water temperatures were **higher** in the summer time **(Figure 145, Appendix AA)**.

The positive relationship between the incidence of black and yellow algae and water temperature made sense. This is because increases in water temperatures increases the rate at which microorganisms such as algae and bacteria grow in water. Since the correlation analyses indicated that the water temperature was, as expected, higher in the summertime, then it follows that the incidents of algae would tend to be greater in the summertime when the water temperatures are higher.

The positive relationship between water temperature and deterioration of pool surfaces was plausible because the solubility of materials increase with water temperature. Thus, the surfaces of pools will tend to dissolve faster and deteriorate more rapidly with increases in water temperature. This relationship could also be caused by the fact that free chlorine is consumed faster in warmer water thereby increasing the rate at which hydrochloric acid is produced by the process. Acidic pool water will increase the deterioration of the pool surfaces.

The **correlation analyses on rain (Appendix O; and Table 13, Appendix S)** and the figures cited below indicated that:

- Rain occurred more frequently in August and September **(Figure 146, Appendix AA)**.

- **Increases** in rain correlated with **increases** in water temperature **(Figure 147, Appendix AA)**.

All of the above rain variable relationships are plausible. For example, rain occurs more frequently and water temperatures are higher in the summertime.

With regards to **bather load,** the **correlation analyses (Appendix O; and Table 13, Appendix S)** and the figures cited below indicated that:

- Increases in bather load correlated with increases in Total coliform and Fecal streptococcus bacteria, turbidity and total alkalinity **(Figures 66 and 86, Appendix X; Figure 134, Appendix Z; and Figure 123, Appendix Y)**.
- Increases in bather load correlated with decreases in free and total chlorine and water hardness **(Figures 89, 94, and 119, Appendix Y)**.
- Bather loads increased with water temperature and pool volume and were higher in health club pools and on Sundays than week days **(Figures 148, 149, 150 and 151, respectively, Appendix AA)**.
- Bather loads increased from morning to the afternoon **(Figure 152, Appendix AA)**.

All of these relationships were discussed previously. See the **Bacteria** and **Water Chemistry** sections for details.

C.6. Swimming Pool Variable Relationships

The **pool volume correlation analyses (Appendix O; and Table 14, Appendix T)** and the figures cited below indicated that:

- The larger volume pools had Fiberglass surfaces whereas the smaller had marcite surfaces **(Figure 153, Appendix BB)**.
- Increases in pool volume correlated with increases in bather loads **(Figure 149, Appendix AA)**.
- Skimmers were used in smaller volume pools as opposed to gutters **(Figure 154, Appendix BB)**.
- The extent of growth of black and yellow algae was greater in larger pools **(Figures 173 and 179, Appendix DD)**.
- Decreases in hardness correlated with increases in pool volume **(Figure 118, Appendix Y)**.

The positive correlation between pool volume and Fiberglass surfaces was a surprise because one would expect that the larger pools would have marcite surfaces and the smaller ones Fiberglass. In discussing this result with the Pinellas County Public Health Unit, they indicated that both the correlation analysis result and the expected result were correct. This result is related to the fact that most of the large marcite pools were very old and had poor surfaces. As a result, some of them had been resurfaced with

Fiberglass resin. Thus, many of the pools had newer surfaces which would naturally be in better condition than many of the older marcite pools that had not been resurfaced.

The positive correlation between pool volume and bather load made sense because, on the average, larger pools will naturally have more swimmers than smaller pools.

The skimmer/smaller pool volume relationship was due to the fact that the Florida swimming pool code prohibits skimmers in large volume pools.

It was not apparent why incidence of yellow and black algae were greater in larger pools.

The hardness/pool volume relationship is due to the fact that most of the smaller pools in Pinellas County were treated with trichlor tablets. Since trichlor doesn't contain calcium ions, the hardness of pool water will be lower than pools treated with calcium hypochlorite or sodium hypochlorite.

The **facility pool correlation analyses (Appendix O; and Table 14, Appendix T)** and the figures cited below indicated that:

- Trichloroisocyanuric acid tablets were used more often in apartment and condominium pools and less in municipal pools **(Figure 144, Appendix AA)**.
- Calcium hypochlorite and sodium hypochlorite were used more often in municipal pools **(Figure 144, Appendix AA)**.
- The Heterotrophic and Total coliform bacteria populations, total dissolved solids, total alkalinity, copper and pH were higher in municipal and tourist pools as opposed to apartment pools **(Figures 58 and 69, Appendix X; and Figures 112, 124, 126 and 105, Appendix Y)**.
- The bather loads were higher in health clubs and tourist pools **(Figure 150, Appendix AA)**.

The relationship between trichloroisocyanuric acid tablets and pools located in apartment, condos and tourist facilities is primarily due to the fact the volumes of these pools are significantly < 60,000 gallons. Thus, the pool operators in these facilities do not invest in complicated sanitizer feed equipment. As a result, trichlor tablets are preferred because simple feed devices can be used to maintain the free chlorine in the pools.

Larger pools can, and do, invest in more complex sanitizer feed equipment. Hence, calcium hypochlorite and sodium hypochlorite are used more frequently than trichlor tablets. Also, since bather loads are much higher in large volume pools, it is difficult to keep the cyanuric acid concentration in the large pools below the 100 ppm limit.

The positive relationships between bacteria, total dissolved solids, total alkalinity and pH with larger volume pools are logical. This is because larger volume pools have higher bather loads. Hence, more bacteria and contaminants are introduced than in smaller volume pools. In turn, more sanitizer is required to kill the bacteria and eliminate the contaminants. Also, the fact that calcium hypochlorite and sodium hypochlorite are used in larger pools will naturally increase the total dissolved solids of the pool faster than if the pools were treated with trichlor tablets. Hence, the total dissolved solids will tend to be higher in larger volume pools. In addition, the pools tend to have higher pHs because calcium hypochlorite and sodium hypochlorite are alkaline products and will increase the total alkalinity and pH of the pools.

It is not clear why copper was higher in municipal pools.

The **type of pool surface correlation analyses (Appendix O; and Table 14, Appendix T)** and the graphs cited below indicated that:

- The condition of the pool surfaces was better in Fiberglass pools than in marcite **(Figure 155, Appendix BB)**.
- The larger volume pools had Fiberglass surfaces **(Figure 153, Appendix BB)**.
- The copper levels were higher in the Fiberglass pools **(Figure 125, Appendix Y)**.
- The total dissolved solids were higher in marcite pools **(Figure 111, Appendix Y)**.
- Black algae was more prevalent in marcite pools **(Figure 175, Appendix DD)**.

The correlation analyses indicated that the surface condition of the pools was better with pools having Fiberglass surfaces. This correlation analysis result is not surprising since the deterioration of marcite pool surfaces is usually related to chemical reactions and Fiberglass surfaces are more resistant to chemical reactions.

The Fiberglass/volume relationship was explained previously.

It is not clear why copper levels were higher in Fiberglass pools.

The positive relationship between marcite pools and total dissolved solids was explained in the total dissolved solids section above.

The positive relationship between black algae and marcite pools was related to the fact that the surface finishes of some of the marcite pools were older and in poorer condition. As a result, there were more niches in the surfaces of the marcite pools where black algae can become established as a result of low free chlorine concentrations. Under these conditions, it is more difficult to eliminate the black algae by simply increasing the free chlorine because a significant portion of the algae mass is below the original surface and is not readily reached by the free chlorine. This phenomenon was not as prevalent in the Fiberglass pools because they were basically old marcite pools with deteriorated surfaces that had been resurfaced with Fiberglass resin in the last few years. Hence, the surfaces were in better condition.

The **pool surface condition correlation analyses (Appendix O; and Table 14, Appendix T)** and the figures cited below indicated that:

- The quality of the surface finish was poorer in marcite pools **(Figure 155, Appendix BB)**.
- The quality of the surface finish deteriorated with increases in water temperature, cyanuric acid and the use of trichloroisocyanuric acid tablets **(Figures 156, 157 and 158, Appendix BB)**.
- The quality of the pool surface condition deteriorated with decreases in pH, hardness and total alkalinity **(Figures 159, 160 and 161, Appendix BB)**.
- Increases in total dissolved solids and turbidity correlated with decreases in the quality of the pool surface condition **(Figure 162, Appendix BB; and Figure 142, Appendix Z)**.
- The extent of growth of black and yellow algae was greater in pools with poorer surface finishes **(Figures 170 and 181, Appendix DD)**.

The **water return correlation analyses (Appendix O; and Table 14, Appendix T)** and the figures cited below revealed that:

- Trichlor tablets were used more often in pools equipped with skimmers than pools with gutters **(Figure 163, Appendix BB)**.
- Cyanuric acid was higher in pools equipped with skimmers **(Figure 107, Appendix Y)**.
- Smaller volume pools were equipped with skimmers **(Figure 154, Appendix BB)**.
- Fecal coliform and Pseudomonas bacteria populations were higher in pools equipped with skimmers **(Figures 81 and 83, Appendix X)**.

All of the above relationships made sense and explanations, with the exception of yellow algae, were offered above.

The relationship with yellow algae is probably related to the same conditions provided above for the relationship between black algae and the type of surface finish.

C.7. Time Variable Relationships

The **sample day correlation analyses (Appendix O; and Table 15, Appendix U)** and the figures cited below indicated that:

- The free and total chlorine residuals and water temperatures were higher during the weekdays as opposed to Sunday **(Figures 90 and 95, Appendix Y and Figure 144, Appendix AA)**.

- More pools with yellow algae, larger volumes and higher bather loads were sampled on Sunday than during the weekdays **(Figure 183, Appendix DD; Figure 165, Appendix BB; and Figure 151, Appendix AA)**.
- Turbidity decreased from Sunday to Thursday **(Figure 140, Appendix Z)**.
- More pools were sampled on Monday and Tuesday than on Sunday. Fewer pools were sampled on Wednesday and Thursday, and no pools were sampled on Friday or Saturday **(Figure 164, Appendix CC)**.

The relationships between free and total chlorine and day of the week make sense because the bather loads were higher on Sunday than during the weekdays. As a result, the free and total chlorine concentrations tended to be lower since most pool operators don't manage the input of the free chlorine to the pools to offset the losses due to the increase in contaminant load.

The relationships with yellow algae and higher bather loads are due to the fact that the pools were used more on weekends than weekdays. As a result, the free chlorine concentrations are lower and it is easier for yellow algae to become established in the pools on Sunday. During the week days, there are fewer swimmers and the free chlorine is usually higher thereby making it more difficult for yellow algae to become established.

The **month frequency distribution analysis (Appendix O; and Table 15, Appendix U)** and the figures cited below indicated that:

- Free and total chlorine residuals were higher in the summer months **(Figures 91 and 96, Appendix Y)**.
- The Non-coliform bacteria population decreased from summer to fall **(Figure 73, Appendix X)**.
- The water temperature decreased from summer to fall **(Figure 145, Appendix AA)**.
- pH increased from summer to fall **(Figure 103, Appendix Y)**.
- Nitrate increased from summer to fall **(Figure 129, Appendix Y)**.
- Less rain occurred in the fall months than in the summer months **(Figure 146, Appendix AA)**.
- Cyanuric acid decreased from summer to fall **(Figure 108, Appendix Y)**.
- More pools were sampled in the fall than in the summer **(Figure 166, Appendix CC)**.

The **time of day frequency distribution analysis (Appendix O; and Table 15, Appendix U)** and the figures cited below revealed the following:

- Turbidity increased from morning to afternoon **(Figure 143, Appendix Z)**.

- The number of swimmers in the pool during the collection of the water samples increased from morning to afternoon **(Figure 152, Appendix AA)**.
- Free and total chlorine decreased from morning to afternoon **(Figures 92 and 98, Appendix Y)**.
- The Sunday water samples were collected in the afternoon hours whereas the weekday samples were collected earlier in the day **(Figure 167, Appendix CC)**.

The turbidity tended to increase from morning to afternoon because the free and total chlorine decreased as a result of the increase in bather load and the intensity of the sun's rays during this time period.

The weekday and time of day correlation simply indicated that sampling of pools on Sunday occurred in the afternoon hours whereas the sampling during the week days tended to be earlier in the day.

C.8. Algae Variable Relationships

The **black algae correlation analyses (Table 16, Appendix V)** and the graphs cited below revealed that:

- The incidence of black algae increased with decreases in free and total chlorine, condition of the pool surface finish and water hardness **(Figures 168, 169, 170 and 171, respectively, Appendix DD)**.
- The incidence of black algae increased with increases in water temperature and pool volume **(Figures 172 and 173, Appendix DD)**.
- Increases in turbidity correlated with increases in the incidence of black algae **(Figure 136, Appendix Z)**.
- Black algae was more prevalent in marcite pools **(Figure 175, Appendix DD)**.
- Increases in the incidence of black algae correlated with increases in the incidence of yellow algae **(Figure 176, Appendix DD)**.

All of the above relationships made sense. Explanations for all have been provided in previous sections.

The yellow algae/black algae correlation result indicated that if the conditions in the pool were such that black algae infestation would occur, then the conditions were also favorable for the establishment of yellow algae infestations.

The **yellow algae correlation analyses (Table 16, Appendix V)** and the graphs cited below revealed that:

- Although the correlation analysis did not indicate a relationship between yellow algae and free chlorine, the results of the special data analysis **(Figures 177 and 178,**

Appendix DD) showed that the incidence of **yellow algae decreased with increases in free and total chlorine**.

- **Increases** in the incidence of yellow algae correlated with **increases** in pool volume and pools treated with trichloroisocyanuric acid tablets **(Figures 179 and 180, Appendix DD)**.
- **Increases** in the incidence of yellow algae correlated with **decreases** in the condition of the pool surfaces and hardness **(Figure 181 and 182, Appendix DD)**.
- **Increases** in **turbidity and Fecal streptococcus bacteria** correlated with **increases** in the **incidence** of yellow algae **(Figure 137, Appendix Z; and Figure 87, Appendix X)**.
- Incidence of yellow algae decreased from Sunday to Thursday **(Figure 183, Appendix DD)**.

D. Summary of Correlation Analyses Results

D.1. Bacteria Variable Relationships

The primary purpose of conducting correlation analyses on the bacteria variables was to determine what variables had statistically significant influences on the populations of the bacteria (Heterotrophic, Total coliform and Non-coliform) used as indicators of disinfection efficacy. The results of the bacteria correlation analyses showed that the following variables had the most statistically significant relationships with the populations of these bacteria:

1. free chlorine
2. total chlorine
3. bather load
4. total dissolved solids
5. water temperature
6. cyanuric acid
7. turbidity

Free chorine was considered as the variable having the greatest influence on the populations of these bacteria. This is because it is well-known that these bacteria can be killed quickly and controlled below their maximum contamination limits by maintaining the proper concentration of free chlorine continuously.

The correlation analyses indicated that total chlorine had statistically significant relationships with the bacteria populations. Total chlorine should never be used to judge whether the pool has sufficient chlorine to sanitize the pool. This is because total chlorine is a measure of free and combined chlorine. Since it is well-known that the bactericidal properties of free chlorine are vastly superior to those of combined chlorine, it follows that if combined chlorine is a significant part of any total chlorine measurement, the pool may not have enough free chlorine to control the bacteria populations. Hence, total chlorine measurements can be misleading. However, total chlorine measurements can be useful if used in conjunction with free chlorine. This is because if the results indicate that the combined chlorine is significant (> 0.2 ppm), the free chlorine is not eliminating the contaminants very well and should be increased. For these reasons, total chlorine was considered to be less significant than free chlorine.

It was not surprising that Total coliform and Fecal streptococcus bacteria populations correlated with bather load since swimmers are a source of these bacteria. However, the pool study team felt that this was not as an important variable as free chlorine because if the free chlorine is being maintained at the proper levels continuously, the bacteria populations will be controlled well below their maximum contamination levels regardless of the number of swimmers in the water. Besides, the pool operator has no control over the number of swimmers, but he can control the free chlorine.

Although bacteria populations correlated with total dissolved solids, the influence of total dissolved solids was considered to be significantly less than free chlorine because free chorine will readily reduce the total dissolved solids, especially the organic portion, if it is maintained at the appropriate concentrations. Besides, there will always be some pools in which the total dissolved solids will be primarily inorganic materials which do not provide a haven for bacteria like the insoluble organic colloidal particulates because of the lack of nutrients in the inorganic materials.

Water temperature would naturally have a statistically significant effect on bacteria populations because bacteria growth rates increase with water temperature. However, this variable was still considered to be less important than free chlorine, because again if free chorine is being maintained continuously at the proper levels the bacteria can be controlled at the proper populations regardless of the water temperature.

The relationships between bacteria and cyanuric acid were not considered to be as important as the free chlorine/bacteria relationships. This is because cyanuric acid does not have any bactericidal properties. For this reason, the bacteria populations can be controlled satisfactorily by maintaining the free chlorine at the proper levels, regardless of the cyanuric acid concentration. However, cyanuric acid is an important variable because it helps maintain the free chlorine at the proper levels.

Although turbidity correlated with bacteria populations, it was not considered to be as important as free chlorine. This is because turbidity simply indicates that the pool did not have enough free chlorine to control the bacteria and eliminate the contaminants. Besides, the turbidity/free chlorine correlation demonstrated that turbidity would decrease if the free chlorine was maintained at the proper levels. Thus, the presence of turbidity simply indicated that the pool was out of control and the bacteria populations may be above their maximum contamination levels.

The correlation analyses also clearly demonstrated that none of the following variables had a statistically significant influence on the disinfection conditions of the test pools:

1. filtration
2. pH
3. alkalinity
4. copper
5. nitrate
6. hardness
7. rain
8. day of the week
9. month
10. type of pool surface
11. condition of pool surface
12. volume
13. water return system
14. algae

Although filtration can affect the disinfection conditions of pools, the correlation analyses did not indicate that filtration had a statistically significant influence on the disinfection conditions of the test pools. This result is attributed to the fact that the turbidity in practically all of the pools was very low and did not vary enough to have an effect. This result indicated that the filtration systems were in good working condition and had been operated for the appropriate period of time each day. Hence, filtration was not found to be a statistically significant factor.

pH can certainly have an effect on disinfection conditions of pools, especially when the pH is > 7.8. However, the correlation analyses indicated that pH did not have a statistically significant influence on disinfection conditions in this study. At first, this result seemed surprising. However, the pH frequency distribution analysis revealed that the pH in most of the test pools was < 7.8. Thus, there were not enough pools with pH > 7.8 to demonstrate that pH had a statistically significant effect on the disinfection conditions.

D.2. Water Chemistry Variable Relationships

The primary purpose for conducting the water chemistry correlation analyses was to determine what variables had statistically significant influences on the disinfection, chemical and physical conditions of the test pools. Such results would be useful in helping the Pinellas County Public Health Unit expand their knowledge on what influenced the conditions of the swimming pools in their district. The most salient results are summarized below.

The most important water chemistry variables in any pool management program are: 1) free chlorine; 2) total chlorine; 3) pH; 4) total alkalinity; 5) hardness; and 6) cyanuric acid. The results of this study certainly indicated that these variables had statistically significant influences on water chemistry which in turn can affect not only the disinfection but other conditions of swimming pools.

The results of the free and total chlorine correlation analyses showed that the most significant influences of these variables were on the bacteria populations and algae. They did not indicate that they had any statistically significant influences on the physical conditions of the swimming pool structures.

The results of the pH correlation showed that the most significant influence of this variable was with the quality of the surface finish of the pools. The results showed that the quality of the finishes of the marcite pools deteriorated as the pH decreased. These results were not surprising since low pHs increase the rate at which calcium ions are leached from marcite surfaces. The results also showed that the sanitizer, cyanuric acid and total alkalinity variables had statistically significant influences on pH.

The use of trichloroisocyanuric acid and the increase of cyanuric acid concentration caused the pH to decrease. The pH increased with increases with total alkalinity. The combination of these results indicated that the pools treated with trichlor did not control the total alkalinity very well. This is because trichlor is an acidic material and will cause the pH to decrease if nothing is done to control the pH within the proper range. Controlling total alkalinity within the proper range will permit better control of the pH.

The total alkalinity correlation analyses showed that the most statistically significant relationships were with pH and pool surface condition. The influence of this variable was discussed in the previous paragraph and obviously should be controlled.

The most statistically significant relationship for hardness was that the condition of the pool surfaces improved with increases in hardness. This is not a surprising result since pools with high hardness will have high calcium ion concentrations. As a result, the pool water will leach the calcium ions from the marcite surfaces considerably more slowly or not at all.

The most significant relationships for the cyanuric acid were with free chlorine and pool surface conditions. Free chlorine concentrations in pools with cyanuric acid were significantly higher than in pools with low (< 20 ppm) cyanuric acid concentrations.

The cyanuric acid/pH results clearly demonstrated that increases in cyanuric acid will decrease pH. It follows that if the pool operators do not control pH very well the pool surface conditions will deteriorate at a higher rate in pools treated with trichlor.

D.3. Algae Variable Relationships

The results of the algae correlation analyses demonstrated that free chlorine was by far the most important parameter. They clearly indicated that incidence of algae in pools increased as the free chlorine concentration decreased.

The results also indicated a statistically significant relationship with turbidity. However, this should not be any surprise because turbidity in pools will increase naturally if the free chlorine is not sufficient to control bacteria and algae and eliminate organic contaminants.

Statistically significant relationships were indicated between marcite pools, pool surface conditions and black algae. The most plausible reason for these results is that surface condition of marcite pools tend to deteriorate readily if the pH of the pools is not controlled in the proper range. As a result, when the free chlorine becomes insufficient to control black algae, the etched areas of the pools become excellent havens for the black algae. This is because these areas are usually recessed below the pool surfaces thereby making it very difficult for the free chlorine to reach the underlying layers of the black algae colonies.

E. Phase 4 - Development of A Reference Model for Assessing the Effectiveness of Pool Judgment Methods and the Importance of Variables Used as Criteria

Since the results of the correlation analyses and the special data analysis technique demonstrated that free chlorine had by far the greatest influence on the bacteria populations and, hence, disinfection conditions, this phase of the data analyses involved the use of bacteria and free chlorine to develop a reference model that enabled the pool study team to assess:

- the effectiveness of the procedures typically used by pool operators and public health units to judge whether pools are satisfactory for swimming and
- the relative importance of the variables commonly used in pool judgment procedures.

The development of the reference model was achieved in the following manner. The first step involved defining two categories of pools so that it was possible to determine the number and the relative percentage of pools that were:

- bacteriologically satisfactory for swimming and had sufficient free chlorine to maintain these desired bacteriological conditions and
- not bacteriologically satisfactory for swimming or did not have sufficient free chlorine to maintain satisfactory biological conditions.

The categories were labeled as shown below:

- **SAT Pools:** pools satisfactory for swimming
- **UNSAT Pools:** pools unsatisfactory for swimming

and sorted on the basis of the following criteria.

A swimming pool was placed in the **SAT** pool category if it **met every one** of the following criteria:

- Free chlorine: 1.0 - 5.0 ppm;
- Heterotrophic bacteria: < 501 CFU/ml;
- Total coliform bacteria: 0 CFU/100 ml; and
- Non-coliform bacteria: < 201 CFU/100 ml.

A swimming pool was placed in the **UNSAT** pool category if the pool **failed to meet one or more** of the criteria for the **SAT** pool. Thus, a pool was identified as an **UNSAT** pool if:

- Free chlorine: < 1.0 ppm or > 5.0 ppm; or
- Heterotrophic bacteria: > 500 CFU/ml; or
- Total coliform bacteria: > 0 CFU/100 ml; or
- Non-coliform bacteria: > 200 CFU/100 ml.

The results in **Figure 187, Appendix EE** showed that by the criteria of this reference model:

- **290 (59.7 %) of the 486** test pools were judged to be **satisfactory for swimming** whereas
- **196 (40.3 %) were not.**

These statistics were somewhat surprising in view of the fact that the results in **ALL POOLS-486, Figures 7A, 8A and 9A, Appendix G** indicated that the bacteria populations were at satisfactory levels in about 84.16 % of the pools. For this reason, the **SAT** and **UNSAT** pool datasets were subjected to more rigorous data analyses to determine why so many pools failed to meet the **SAT** pool criteria.

In these data analyses, the SAT pools dataset was labeled as **SAT 1-5CL2-290**. The **UNSAT** pools dataset was not labeled at first because the pools in this category did not seem to have any statistically valid relationships whereas the pools in the **SAT 1-5CL2-290** category did. However, after several data analyses, it became readily apparent that statistically valid relationships could be obtained for groups of pools by using a specific set of criteria for each subgroup. The most statistical valid relationships could best be developed by subdividing the **UNSAT** pool category into 6 subcategories. **These subcategories were designated as UNSAT A - F - X, where A - F designates the UNSAT pool subcategory and X is the number of pools in the subcategory.**

The statistical characteristics of both the **SAT 1-5CL2-290** pool category and the **UNSAT A - F** pool subcategories are presented and compared in the following sections.

F. Phase 5 - Statistical Characteristics of Pools (SAT 1-5CL2-290) Judged to be Satisfactory for Swimming by the Reference Model

The statistical characteristics for these pools are given in **SAT 1-5CL2-290, Figures 7A and B through 39A and B, Appendices G - N** and are summarized narratively below.

F.1. Bacteria

The **bacteria frequency distribution analysis on the 290 pools (SAT 1-5CL2-290, Figures 7A and B through 13A and B, Appendix G)** generated the following results.

The **Heterotrophic bacteria population** was < 501 CFU/ml in all of these pools **(SAT 1-5CL2-290, Figures 7A and B)** with a frequency distribution of:

- 0 - 250 CFU/ml in 99.66 % (289) of the 290 pools and
- 251 - 500 CFU/ml in 0.34 % (1 pool).

The **Total coliform bacteria population** was 0 CFU/100 ml in all 290 pools **(SAT 1-5CL2-290, Figures 8A and B).**

The **Non-coliform bacteria population** was < 201 CFU/100 ml in all of the 290 pools **(SAT 1-5CL2-290, Figures 9A and B)** and the distribution pattern was:

- 0 - 100 CFU/100 ml in 96.21 % (279) of the 290 pools and
- 101 - 200 CFU/100 ml in 3.79 % (11) of these pools.

The **Fecal coliform bacteria population** was 0 CFU/100 ml in 99.3 % (288) of the 290 pools **(SAT 1-5CL2-290, Figures 10A and B).** One pool had 1 and the other had 12 CFU/100 ml, respectively.

As was indicated previously, Fecal coliform do not live long outside their natural environment -- intestines of warm-blooded animals -- and are easily killed with free chlorine and/or will die without a sanitizer in the water.

The **Pseudomonas aeruginosa bacteria frequency distribution (SAT 1-5CL2-290, Figures 11A and B)** revealed that the bacteria population was:

- 0 CFU/100 ml in 91.67 % (11) of the 12 test pools sampled and
- > 0 CFU/100 ml in 8.33 % (1).

The **Total staphylococcus bacteria frequency distribution (SAT 1-5CL2-290, Figures 12A and B)** revealed that the population of this bacteria was:

- 0 - 1 CFU/100 ml in 8.33 % (1) of the 12 test pools sampled in this category,
- between 1 and 5 CFU/100 ml in 83.33 % (10) and

- > 5 CFU/100 ml in 8.33 % (1).

The Fecal streptococcus bacteria (SAT 1-5CL2-290, Figures 13A and B) showed that 100 % of the 12 pools sampled had 0 CFU/100 ml.

F.2. Water Chemistry

The statistical characteristics for the variables in this category are given in **SAT 1-5CL2-290, Figures 14A and B through 22A and B, Appendix H**.

The **free chlorine frequency distribution (SAT 1-5CL2-290, Figures 14A and B)** showed that the free chlorine residuals were:

- 1.0 - 5.0 ppm in 100 % of the 290 pools,
- 1.0 - 3.0 ppm in 46.6 % (135) and
- 3.1 - 5.0 ppm in 53.4 % (155).

The **total chlorine frequency distribution (SAT 1-5CL2-290, Figures 15A and B)** revealed that the total chlorine was:

- 0.1 - 0.9 ppm in 0.34 % (1) of the 290 pools,
- 1.0 - 5.0 ppm in 99.31 % (288) and
- 5.1 - 10.0 ppm in 0.34 % (1).

The **pH frequency distribution (SAT 1-5CL2-290, Figures 16A and B)** revealed that the pH was:

- within the recommended range of 7.2 - 7.8 in 84.48 % (245) of the 290 pools,
- 7.9 - 8.4 in 12.76 % (37) and
- 6.7 - 7.1 in 2.76 % (8).

The **cyanuric acid frequency distribution (SAT 1-5CL2-290, Figures 17A and B)** showed that the cyanuric acid was:

- 0 - 10 ppm in 20.00 % (58) of the pools,
- 11- 20 ppm in 3.45 % (10),
- 21 - 100 ppm in 50.34 % (146),
- 101 - 200 ppm in 20.69% (60),
- 201 - 400 ppm in 4.83 % (14) and
- 401 - 800 ppm in 0.69 % (2).

These results indicated that:

- **76.55 % (222) of the pools were disinfected with stabilized chlorine (> 20 ppm of cyanuric acid).**
- **The cyanuric acid was > 100 ppm in 26.21% (76) of the pools.**
- **23.45 % (68) of the 290 pools were sanitized with unstabilized chlorine (cyanuric acid < 21 ppm).**

The **total dissolved solids frequency distribution (SAT 1-5CL2-290, Figures 18A and B)** revealed that:

- only 32.41 % (94) of the 290 pools were within the recommended range of 1, 000 - 2, 000 ppm;
- 37.59 % (109) were below the recommended range;
- 15.86 % (46) were moderately (2,001 - 3,000 ppm) above the range and
- 14.41 % (41) were excessively (3,001 - 5,000 ppm) above.

The **hardness, total alkalinity, copper and nitrate frequency distributions** are provided in **SAT 1-5CL2-290, Figures 19A and B, 20A and B, 21A and B and 22A and B,** respectively.

The results did not indicate that any of the values of these variables were unusual.

F.3. Turbidity

The **frequency distribution (SAT 1-5CL2-290, Figures 23A and B, Appendix I)** showed that:

- 96.0 % (264) of the pools had no turbidity,
- 3.27 % (9) had low to medium turbidity and
- only 0.72 % (2) had high turbidity.

F.4. Sanitizers

The **sanitizer frequency distribution (SAT 1-5CL2-290, Figures 24A and B, Appendix J)** showed that:

- 46.21 % (134) of the 290 pools were sanitized with trichloroisocyanuric acid tablets,
- 37.59 % (109) with calcium hypochlorite,
- 13.79 % (40) with sodium hypochlorite and
- 0.34 % (1) with sodium dichloroisocyanurate.
- None were treated with bromine tablets or gaseous chlorine.
- No data were obtained on 2.07 % (6) of the pools.

F.5. Environmental

Refer to **SAT 1-5CL2-290, Figures 25A and B through 27A and B, Appendix K** for the frequency distribution patterns in this variable category.

The **water temperature frequency distribution (SAT 1-5CL2-290, Figures 25A and B)** revealed that the pool temperature was:

- 76 - 91 °F in 91.35 % (243) of the 266 pools for which the temperature was measured and
- < 76 °F in 8.27 % (22) of these pools.

The **rain frequency distribution (SAT 1-5CL2-290, Figures 26A and B)** showed that:

- No rain occurred within 24 hours prior to the collection of the water samples with 46.21 % (134) of the 290 pools and
- < 0.1" occurred with 15.86 % (46),
- > 0.1 - < 1.0" with 20.69 % (60) and
- > 1.0" with 5.17 % (15).
- No data were obtained on 12.07 % (35).

The **bather load frequency distribution (SAT 1-5CL2-290, Figures 27A and B)** revealed that:

- There were no swimmers in 66.78 % (193) of the pools during collection of the water samples and
- 1 - 10 swimmers in 33.22 % (96).

It should be noted that in many cases there were several people sunbathing, but it was not determined if they had been swimming prior to collection of the water samples. Hence, these pools were categorized as not having any swimmers.

F.6. Swimming Pool Characteristics

See **SAT 1-5CL2-290, Figures 28A and B through 32A and B, Appendix L** for the distribution patterns of these variables.

The **facility pool frequency distribution (SAT 1-5CL2-290, Figures 28A and B)** showed that:

- 46.71% (135) of the pools were in apartment complexes,
- 33.22 % (96) in condominium complexes,
- 18.69 % (54) in tourist facilities,
- 0.69 % (2) in health clubs and

- 0.69 % (2) in municipal facilities.

These results indicated that 98.45 % of the SAT pools were located in condos, apartments and tourist facilities.

The **pool volume frequency distribution (SAT 1-5CL2-290, Figures 29A and B)** revealed that:

- 19.31 % (56) of the pools were < 20,001 gallons,
- 58.28 % (169) were > 20,000 and < 40,001 gallons,
- 20.34 % (59) were > 40,000 and < 80,001 gallons,
- 1.03 % (3) were > 80,000 and < 100,001 gallons and
- 1.03 % (3) were > 100,000 and < 148,001 gallons.

Therefore, 97.93 % of the SAT pools were < 80,000 gallons.

The **water return system frequency distribution (SAT 1-5CL2-290, Figures 30A and B)** revealed that:

- 94.43 % (271) of the pools had gutters and
- 5.57 % (16) had skimmers.
- Data were missing on 3 pools.

The **pool surface type frequency distribution (SAT 1-5CL2-290, Figures 31A and B)** indicated that:

- 94.83 % (275) of the pools were marcite and
- 5.17 % (15) were Fiberglass.

The **pool surface condition frequency distribution (SAT 1-5CL2-290, Figures 32A and B)** indicated that:

- 94.12 % (272) of the pool surfaces were in fair to good condition and
- 5.88 % (17) were poor.

F.7. Time

Refer to **SAT 1-5CL2-290, Figures 33A and B through 35A and B, Appendix M** for the statistics on these variables.

The **sampling day frequency distribution (SAT 1-5CL2-290, Figures 33A and B)** showed that water samples were collected from:

- 38.28 % (111) of the pools on Tuesday,

- 28.97 % (84) on Monday,
- 20.69 % (60) on Sunday,
- 11.72 % (34) on Wednesday and
- 0.34 % (1) on Thursday.
- No samples were collected on Friday and Saturday.

The **month frequency distribution (SAT 1-5CL2-290, Figures 34A and B)** showed that:

- 3.45 % (10) of the pools were sampled in July,
- 24.14 % (70) in August,
- 29.66 % (86) in September,
- 29.31 % (85) in October and
- 13.45 % (39) in November.

The **time of day frequency distribution (SAT 1-5CL2-290, Figures 35A and B)** revealed that:

- Water samples were collected between 7 AM and 12:59 PM for 47.58 % (138) of the pools and
- between 1 and 6 PM for 52.42 % (152).

F.8. Algae

SAT 1-5CL2-290, Figures 36A and B through 39A and B in Appendix N show the frequency distribution patterns for this variable category.

The **black algae frequency distribution (SAT 1-5CL2-290, Figures 36A and B)** showed that:

- 61.72 % (179) of the 290 pools had no black algae,
- 29.66 % (86) had low growth and
- 8.62 % (25) had medium to heavy growth.

The **yellow algae frequency distribution (SAT 1-5CL2-290, Figures 37A and B)** showed that:

- 94.48 % (274) of the pools had no yellow algae,
- 4.14 % (12) had low growth and
- 1.34 % (4) had medium to heavy growth.
- 15.39 % (16) of the 104 black algae pools also had yellow algae.

G. Phase 6 - Statistical Characteristics of Pools Judged to be Unsatisfactory for Swimming by the Reference Model

As indicated in Section E. above, **the SAT/UNSAT pool frequency distribution (Figure 187, Appendix EE)** indicated that 40.36 % (196) of the 486 test pools were characterized as being unsatisfactory for swimming.

The **free chlorine frequency distribution** for the **196 UNSAT pools (UNSAT A-42 through F-14, Figures 14C and D, Appendix H)** showed that the free chlorine ranged from 0 - 40 ppm and was:

- **> 5.0 ppm in 46 (23.47 %) of the 196 pools (UNSAT A-42 and UNSAT B-4),**
- **< 1.0 ppm in 105 (53.57 %) of the pools (UNSAT C-58 and UNSAT D-47) and**
- **1.0 – 5.0 ppm in 45 (22.96%) of the pools (UNSAT E-31 and UNSAT F-14).**

Each of these three groups of pools were divided into two datasets, as described below.

The Heterotrophic, Total Coliform and Non-coliform bacteria frequency distributions on the 46 UNSAT pools with > 5.0 ppm of free chlorine (UNSAT A-42 and UNSAT B-4, Figures 7C and D through 9C and D, Appendix G) showed that:

- **42** pools met all of the bacteriological criteria for SAT pools and
- **4** pools did not.

On this basis, these **46 UNSAT pools** were divided into two datasets: 1) **UNSAT A-42** with 42 pools; and 2) **UNSAT B-4** with 4 pools.

The Heterotrophic, Total Coliform and Non-coliform bacteria frequency distributions for the 105 UNSAT pools with < 1.0 ppm of free chlorine (UNSAT C-58 and UNSAT D-47, Figures 7C and D through 9C and D, Appendix G) showed that:

- **58** of the 105 pools met all of the bacteriological criteria for SAT pools and
- **47** pools did not.

On this basis, these **105 UNSAT pools** were divided into two datasets: 1) **UNSAT C-58** with 58 pools, and 2) **UNSAT D-47** with 47 pools.

The remaining 45 UNSAT pools had free chlorine in the 1.0 - 5.0 ppm range, but were UNSAT because they failed at least one of the bacteriological criteria for SAT pools (UNSAT E-31 and UNSAT F-14 in Figure 14C, Appendix H; and Figures 7C through 9C, Appendix G). These pools were reviewed from a bacteria standpoint. The results revealed that:

- **31** of the 45 pools failed either the Heterotrophic or Total coliform bacteria criteria.

- **14** pools had Heterotrophic bacteria populations significantly < 501 CFU/ml thereby indicating that the pools were adequately disinfected. These were designated UNSAT because the Non-coliform bacteria population were > 200 CFU/100 ml.

As a consequence, these **45 UNSAT pools** were divided into two datasets: 1) **UNSAT E-31** with 31 pools, and 2) **UNSAT F-14** with 14 pools.

The above analyses therefore resulted in the generation of 6 UNSAT pool datasets, which are summarized in the following table.

Summary of UNSAT Pool Datasets (Categories)
Definitions and Criteria

UNSAT Pool Definition: **Pool conditions fail to meet one or more of the SAT Pool criteria.**

POOL CATEGORY	**CRITERIA**
UNSAT A-42	**1) Free chlorine > 5.0 ppm (exceeds SAT pool standard)** **2) Meet all of the following SAT pool category bacteria criteria:** • **Heterotrophic bacteria (HPC) < 501 CFU/ml** • **Total Coliform bacteria (TCOLI) = 0 CFU/100 ml** • **Non-coliform bacteria (NCOLI) < 201 CFU/100 ml**
UNSAT B-4	**1) Free chlorine > 5.0 ppm (exceeds SAT pool standard)** **2) HPC, TCOLI or NCOLI fail to meet one or more of SAT pool bacteria criteria (cf. bacteria criteria in UNSAT A-42 pool category above)**
UNSAT C-58	**1) Free chlorine < 1.0 ppm (below SAT pool minimum standard)** **2) HPC, TCOLI and NCOLI meet SAT Pool bacteria criteria (cf. bacteria criteria in UNSAT A-42 pool category above)**
UNSAT D-47	**1) Free chlorine < 1.0 ppm (below SAT pool minimum standard)** **2) HPC, TCOLI or NCOLI fail to meet one or more SAT pool bacteria criteria (cf. bacteria standards in UNSAT A-42 Pool category above)**
UNSAT E-31	**1) Free chlorine was 1.0 - 5.0 ppm (SAT Pool standard)** **2) HPC, TCOLI or NCOLI fail to meet one or more of SAT Pool bacteria standards (cf., bacteria standards in UNSAT A-42 pool category above)**
UNSAT F-14	**1) Free chlorine was 1.0 - 5.0 ppm (SAT Pool standard)** **2) HPC < 501 CFU/ml (SAT Pool standard)** **3) NCOLI > 200 CFU/100 ml (exceeds SAT Pool standard)** **4) TCOLI inconclusive since NCOLI > 200 CFU/100 ml**

These 6 datasets are distinct subsets of the 196 UNSAT pools with very specific criteria. Hence, each of the 196 pools falls into one, and only one, of these datasets (categories) and cannot fit into any other dataset.

Each of these **UNSAT** pool datasets were then subjected to further data analyses to generate statistical characteristics about each variable in each pool dataset. In addition, analyses of variances were conducted on combinations of **SAT** and **UNSAT** pools to determine if there was any evidence that particular variables caused a particular pool to fall into one of the **UNSAT** categories. The results of the data analyses are presented below.

G.1. UNSAT A-42 Pools Statistical Characteristics

The results of the **frequency distribution analyses** for all of the variables in this category of pools are provided in **UNSAT A-42, Figures 7C and D through 39C and D, Appendices G - N.** The most salient characteristics are summarized below.

- As expected, the free chlorine in all 42 pools exceeded the Florida code limit of 5.0 ppm for free chlorine **(UNSAT A-42, Figures 14C and D, Appendix H)** with 30 pools having 5.1 to 10.0 ppm and 12 pools with 10.1 to 40.0 ppm.
- As expected, all of the bacteriological criteria were satisfied **(UNSAT A-42, Figures 7C and D through 9C and D, Appendix G)**.
- The **cyanuric acid concentration distribution (UNSAT A-42, Figures 17C and D, Appendix H)** was:
    - 0 - 20 ppm in 8 (19.04 %) of the 42 pools,
    - 21 - 100 ppm in 23 (54.76 %),
    - > 100 ppm in 11 (26.2 %) and
    - only 1 pool (2.38 %) had > 200 ppm.
- 26 (61.9 %) of the 42 pools were treated with trichlor tablets, 13 (30.95 %) with calcium hypochlorite and 2 (4.76 %) with sodium hypochlorite **(UNSAT A-42, Figures 24C and D, Appendix J)**.
- 8.1 % of the pools were located in condominium and apartment complexes **(UNSAT A-42, Figures 28C and D, Appendix L)**.
- 97.22 % of the pools were judged to have no turbidity **(UNSAT A-42, Figures 23C and D, Appendix I)**.
- 73.8 % of the pools had no swimmers in the water at the time the water samples were taken **(UNSAT A-42, Figures 27C and D, Appendix K).** However, several pools had many sunbathers.
- 78.6 % of the water samples were collected on Tuesdays and Wednesdays **(UNSAT A-42, Figures 33C and D, Appendix M)**.

- 83.33 % of the pools were < 40,001 gallons **(UNSAT A-42, Figures 29C and D, Appendix L)**.

G.2. UNSAT B-4 Pools Statistical Characteristics

Since there are only 4 pools in this category, no frequency distributions were generated. Instead, a simple printout of the raw data is provided in **Table 17, Appendix GG.** The most notable characteristics were:

- **All of the pools failed the Total coliform bacteria criteria (UNSAT B-4, Figures 8C and D, Appendix G)**. The Total coliform bacteria population was 1 – 8 CFU/100 ml in these 4 pools **(Table 17, Appendix GG)**.
- **All of the pools met the Heterotrophic and Non-coliform bacteria criteria (UNSAT B-4, Figures 7C and D and 9C and D, Appendix G). In fact, the Heterotrophic bacteria was < 20 CFU/ml in 3 of the 4 pools**.
- The free chlorine was significantly > 5.0 ppm in all 4 pools.
- One pool, a municipal facility, may have been out of compliance because it had been shock-chlorinated a few hours prior to the sanitarian's visit. **(Table 17, Appendix GG)**.
- Of the other 3 pools (one tourist and two condos), 2 had swimmers and the other (one condo) did not **(Table 17, Appendix GG)**.
- Rain had occurred in 3 of the 4 pools within 24 hours.
- 2 pools were treated with stabilized chlorine and the other 2 with unstabilized chlorine **(Table 17, Appendix GG)**.
- 1 of the 4 pools had a pH = 8.2 **(Table 17, Appendix GG)**.

G.3. UNSAT C-58 Pools Statistical Characteristics

The characteristics of these 58 pools are summarized under the dataset **UNSAT C-58** in **Figures 7C and D through 39C and D, Appendices G - N.** The most significant results were:

- The **free chlorine** was 0 ppm in 31.03 % (18) of the 58 pools and 0.1 - 0.9 ppm in the other 68.97 % (40) pools **(UNSAT C-58, Figures 14C and D, Appendix H)**.
- The **total chlorine** was 0 ppm in 6 (10.34 %) pools, 0.1 - 0.9 ppm in 45 (77.59 %) pools and 1.0 - 5.0 in 7 (12.07 %) pools **(UNSAT C-58, Figures 15C and D, Appendix H)**.
- As expected, all of the pools met the Heterotrophic, Total coliform and Non-coliform bacteria criteria **(UNSAT C-58, Figures 7C and D through 9C and D, Appendix G)** indicating that bacteria regrowth had not occurred enough to make the pools bacteriologically unacceptable for swimming.

- **56.89 %** (33) of the 58 pools were **treated with stabilized chlorine** (> 20 ppm of cyanuric acid) and **43.11 % (25) with unstabilized chlorine** (< 21 ppm of cyanuric acid) **(UNSAT C-58, Figures 17C and D, Appendix H)**.
- 44.83 % of the pools were treated with calcium hypochlorite, 27.6 % with trichloroisocyanuric acid tablets and 18.97 % with sodium hypochlorite **(UNSAT C-58, Figures 24C and D, Appendix J).**
- Rain had occurred within 24 hours before water sample collection with 48 % of the pools **(UNSAT C-58, Figures 26C and D, Appendix K)**.
- 43.86 % of pools were located in apartment complexes **(UNSAT C-58, Figures 28C and D, Appendix L)**.
- 65.52 % of the pools had no swimmers in the water during the collection of the water samples **(UNSAT C-58, Figures 27C and D, Appendix K)**.

G.4. UNSAT D-47 Pools Statistical Characteristics

This category of pools contains 47 pools which had **significantly < 1.0 ppm of free chlorine and failed to meet the bacteriological criteria.** The frequency distributions shown under the category **UNSAT D-47** in **Figures 7C and D through 39C and D, Appendices G - N** provide a graphical summary of the characteristics of the variables. The most salient characteristics are summarized below.

- **Free chlorine** was **0 ppm** in **65.96 %** of the pools **(UNSAT D-47, Figures 14C and D, Appendix H)**.
- **Total chlorine** was **< 1.0 ppm in 97.87 %** of the pools **(UNSAT D-47, Figures 15C and D, Appendix H)**.
- The **Heterotrophic, Total coliform and Non-coliform bacteria** were > 500 CFU/ml, > 0 CFU/100 ml and > 200 CFU/100, respectively, in 63.83, 51.07 and 25.54 % of the pools **(UNSAT D-47, Figures 7C and D through 9C and D, Appendix G)**.
- 57.45 % of the pools were treated with trichloroisocyanuric acid tablets, 14.89 % with calcium hypochlorite and 12.77 % with sodium hypochlorite **(UNSAT D-47, Figures 24C and D, Appendix J)**.
- **63.84 % of the pools had > 20 ppm of cyanuric acid (UNSAT D-47, Figures 17C and D, Appendix H)**.
- 65.96 % of the pools were located in apartment and condominium facilities **(UNSAT D-47, Figures 28C and D, Appendix L)**.
- 65.95 % of the water chemistry and bacteriological water samples were collected on Mondays and Tuesdays **(UNSAT D-47, Figures 33C and D, Appendix M)**.
- 61.7 % of the pools had no swimmers in the water during water sample collection **(UNSAT D-47, Figures 27C and D, Appendix K)**.

- Rain had occurred within 24 hours prior to collection of the water samples from 63.84 % of the pools **(UNSAT D-47, Figures 26C and D, Appendix K)**.

G.5. UNSAT E-31 Pools Statistical Characteristics

This particular category of pools contained 31 pools which had **1.0 - 5.0 ppm of free chlorine and failed one or more of the bacteria criteria.** The statistical characteristics of these pools are summarized graphically under the category **UNSAT E-31** in **Figures 7C and D through 39 C and D, Appendices G - N.** The more salient characteristics are highlighted below.

- **Free chlorine** was 1.0 - 5.0 ppm in 100 % of the pools **(UNSAT E-31, Figures 14C and D, Appendix H)**.
- **Total chlorine** was 1.0 - 5.0 ppm in 100 % of the pools **(UNSAT E-31, Figures 15C and D, Appendix H)**.
- **Heterotrophic bacteria** was > 500 CFU/ml in 58.06 % of the pools **(UNSAT E-31, Figures 7C and D, Appendix G)**.
- **Total coliform bacteria** was > 0 CFU/100 ml in 61.29 % of the pools **(UNSAT E-31, Figures 8C and D, Appendix G)**.
- **Non-coliform bacteria was** > 200 CFU/100 ml in 70.97 % of the pools **(UNSAT E-31, Figures 9C and D, Appendix G)**.
- **Fecal coliform bacteria was** > 0 CFU/100 ml in 32.3 % of the pools **(UNSAT E-31, Figures 10C and D, Appendix G)**.
- **pH** was 6.7 - 7.8 in 90.32 % of the pools **(UNSAT E-31, Figures 16C and D, Appendix H).**
- **Cyanuric acid (UNSAT E-31, Figures 17C and D, Appendix H)** was:
  - 0 - 20 ppm in 25.81 % of the pools,
  - > 20 - 100 in 41.9 % and
  - > 100 in 32.26 %.
- 54.84 % of the pools had **swimmers** in the pools during collection of the water samples **(UNSAT E-31, Figures 27C and D, Appendix K)**.
- 74.19 % of the water samples were collected on Mondays and Tuesdays **(UNSAT E-31, Figures 33C and D, Appendix M)**.
- 41.94 % of the pools were in condos, 32.26 % in apartments and 25.81 % in tourist facilities **(UNSAT E-31, Figures 28C and D, Appendix L)**.

G.6. UNSAT F-14 Pools Statistical Characteristics

As discussed previously, the 14 pools in this dataset had 1.0 - 5.0 ppm of free chlorine, Heterotrophic bacteria populations < 500 and Non-coliform bacteria populations > 200. **On the basis of the authors' definitions of SAT and UNSAT pools, these pools were labeled UNSAT F-14 because the results of the Total coliform bacteria analyses were declared inconclusive as a result of the Non-coliform bacteria populations being > 200 CFU/100 ml.** However, on the basis of the water chemistry standard in the Florida code, the sanitarian would have probably deemed these satisfactory for swimming. The characteristics of these pools are summarized in **Figures 7C and D through 39C and D in Appendices G - N** under the **UNSAT F-14** pool category. The more important characteristics are noted below.

- As expected, **free chlorine** was 1.0 - 5.0 ppm **(UNSAT F-14, Figures 14C and D, Appendix H)** in 100 % of the pools.
- **Total chlorine** was 1.0 - 5.0 ppm **(UNSAT F-14, Figures 15C and D, Appendix H)** in all of the pools.
- **pH** was 7.2 - 7.8 in 85.71 % of the pools **(UNSAT F-14, Figures 16C and D, Appendix H)**.
- **Heterotrophic bacteria** was considerably < 501 CFU/ml in 100 % of the pools **(UNSAT F-14, Figures 7C and D, Appendix G)**.
- As expected, **Non-coliform bacteria** was > 200 CFU/100 ml in 100 % of the pools **(UNSAT F-14, Figures 9C and D, Appendix G)**.
- There were no **swimmers** in 78.57 % of the pools during the collection of the water samples **(UNSAT F-14, Figures 27C and D, Appendix K)**.
- 71.43 % of the pools were treated with trichloroisocyanuric acid tablets **(UNSAT F-14, Figures 24C and D, Appendix J).**
- Water samples were collected from 50 % of the pools on Monday **(UNSAT F-14, Figures 33C and D, Appendix M)**.

H. Phase 7 - Comparison of SAT and UNSAT Pools Statistics

SAS T Test statistical analyses were conducted on all corresponding pairs of variables for various combinations of **SAT** and **UNSAT** pool datasets presented in the following subsections. The **T Test** statistical analysis program determines if the variances of the variables in the two datasets are equal or unequal. It also determined the probability that the data for a given variable in one dataset was significantly different or the same as the data for the same variable in the other dataset. The technique involves the comparison of the statistical averages and the standard deviations of a particular variable in a given dataset with those in another dataset. The basic assumption is that the data for one variable are considered significantly different if the calculations indicate that there is less than a 5 % chance that the difference in the means (statistical averages) is due to the random generation of any numbers. The results of this data analysis phase are summarized below.

In reviewing these results, the reader should remember that if a variable is not cited this indicates that there was not sufficient evidence to say that the particular variable had any influence on the status of the pools.

H.1. SAT 1-5CL2-290 Pools vs UNSAT A-42 Pools

Both categories of pools met all of the bacteria criteria. However, the **SAT 1-5CL2-290** pools had 1.0 - 5.0 ppm of free chlorine whereas the **UNSAT A-42** pools had > 5.0 ppm. The results of the **T Tests of means and analyses of variances (Appendix FF)** on the variables in each dataset revealed that:

- The average **free and total chlorine** concentrations were, as expected, higher in the UNSAT A-42 pools.
- Even though the average Heterotrophic and Non-coliform bacteria populations were significantly < 501 CFU/ml and < 201 CFU/100 ml, respectively, in both pool categories, the average **Heterotrophic and Non-coliform bacteria** populations were significantly lower in the UNSAT A-42 pools where the free chlorine was significantly higher.
- The average **water temperature** was about 2 °F higher in the UNSAT A-42 pools.
- The extent of **black algae** was lower in the UNSAT A-42 pools which had higher free chlorine.
- The correlation analyses provided no evidence that the remaining variables were significantly different and had an influence on whether a particular pool fell into these categories.

Thus, these results clearly demonstrated that the only reason that these 42 pools were designated as UNSAT pools is that the free chlorine concentration was > 5.0 ppm.

H.2. SAT 1-5CL2-290 Pools vs UNSAT B-4 Pools

There are only 4 pools in the **UNSAT B-4** pools dataset **(Appendix GG).** Therefore, there were not enough pools to make valid T Tests and analyses of variances.

H.3. SAT 1-5CL2-290 Pools vs UNSAT C-58 Pools

The **UNSAT C-58** pools met all of the bacteria criteria even though the free chlorine was found to be < 1.0 ppm. The results of the **T Tests (Appendix HH)** on the variables indicated that there was sufficient evidence to say that:

- As expected, the average **free and total chlorine** residuals were lower in the UNSAT C-58 pools.

- The average **cyanuric acid** concentration was higher in the SAT 1-5CL2-290 pools and could have had an influence on why these pools were found to be safe.
- Although the **Heterotrophic and Non-coliform bacteria** populations were < 501 CFU/ml and < 201 CFU/100 ml, respectively, in both pool categories, the average population of both bacteria were significantly higher in the UNSAT C-58 pools.
- A greater number of SAT 1-5CL2-290 pools were observed during the weekdays whereas a greater number of UNSAT C-58 pools were sampled on Sundays.
- The averages of the other variables were not significantly different and thus probably did not have any influence on the results.

These results clearly showed that the only reason that the UNSAT C-58 pools, which were bacteriologically satisfactory for swimming, fell into the UNSAT pool category was that the free chlorine was < 1.0 ppm. Thus, these results indicated that the pools did have sufficient free chlorine prior to the time water samples were taken. These results in turn indicated that the free chlorine concentrations had fallen just prior to water sampling but had not been at this level long enough for the bacteria populations to grow to the unsatisfactory levels where the pools would be bacteriologically unsatisfactory for swimming. The most likely cause was a sudden increase in bather load and the failure of the pool management to supply free chlorine to the pools fast enough to cope with the contaminants introduced by the swimmers.

This conclusion is supported by the following facts:

- The results of the correlation analyses indicated that free chlorine decreased as the bather loads increased.
- The T Test of the means indicated that more of the pools in the UNSAT C-58 category were observed on Sunday than during the week.
- Bather loads were typically higher on Sundays.

H.4. SAT 1-5CL2-290 Pools vs UNSAT D-47 Pools

The **UNSAT D-47** pools had considerably < 1.0 ppm of free chlorine and failed to meet the bacteria criteria. The results of the **T Tests and analyses of variances (Appendix II)** on all of the variables indicated the following:

- As expected, the average free and total chlorine residuals were significantly lower in the UNSAT D-47 pools.
- The average population of the **Heterotrophic, Total conform and Non-coliform bacteria** were significantly higher in UNSAT D-47 pools.
- The average **water temperature** was higher in UNSAT D-47 pools by 2.5 °F.
- The average number of **swimmers** in the water during water sample collection was significantly higher in UNSAT D-47 pools.
- The averages of the other variables were not significantly different.

- Thus, it was quite clear why these pools fell into the UNSAT D-47 category. The free chlorine was too low and the bather loads and water temperature were higher than the SAT 1-5CL2-290 pool category. These results clearly indicated that the free chlorine concentrations in the UNSAT D-47 had not been maintained sufficiently to cope with the contaminants. Therefore, these pools had not been properly managed.

H.5. SAT 1-5CL2-290 Pools vs UNSAT E-31 Pools

The **UNSAT E-31** pools had 1.0 - 5.0 ppm of free chlorine but failed to meet all of the bacteriological standards, especially Heterotrophic and Total coliform bacteria. The results of the T Tests on the variables in the SAT and UNSAT pools datasets are provided in **Appendix JJ** and highlighted below.

- The average **Heterotrophic, Total coliform and Non-coliform bacteria** populations were significantly higher in the UNSAT E-31 pools.
- The average **free and total chlorine and pH** were not significantly different.
- The average **cyanuric acid** concentrations were not significantly different.
- The average number of **swimmers** in the water during the collection of the water samples were significantly higher in the UNSAT E-31 pools.
- The **turbidity** averages were not significantly different.
- There was no evidence that the rest of variables were significantly different and had influences on the bacteriological conditions of the pools.

The bacteria populations were higher in the UNSAT E-31 pools than expected for pool having the proper levels of free chlorine. The results of the T Test of the means indicated that the UNSAT E-31 pools had higher bather loads than the SAT 1-5CL2-290 pools. Thus, the most probable explanation appears to be that the higher bather loads at the time water samples were taken caused the bacteria populations to exceed the MCLs. It is entirely possible that the bacteria populations would have been found to be lower if the pools had been resampled a few minutes later. This assumes that the free chlorine remained within the 1 - 5 ppm range.

H.6. SAT 1-5CL2-290 Pools vs UNSAT F-14 Pools

The **UNSAT F-14** pools dataset consisted of 14 pools having 1.0 - 5.0 ppm of free chlorine and Heterotrophic bacteria populations significantly < 501 CFU/ml. These pools were deemed unsatisfactory for swimming because the Non-coliform bacteria population exceeded 200 CFU/100 ml. **However, on the basis of the Florida swimming pool code, the sanitarian would have probably deemed the pools satisfactory for swimming.**

The results of the T Tests and Analyses of Variances are provided in **Appendix KK** with the most important findings summarized below.

- The average **free and total chlorine** were significantly greater in the UNSAT F-14 pools.
- The average **Heterotrophic bacteria** population was significantly greater in UNSAT F-14 pools but still considerably < 501 CFU/ml.
- As expected, the average **Non-coliform bacteria** population was significantly higher in UNSAT F-14 pools.
- As expected, the average **Fecal coliform bacteria** population was lower in UNSAT F-14 pools.
- The average **total dissolved solids** content was significantly lower in UNSAT F-14 pools.
- The average **turbidity** was significantly lower in UNSAT F-14 pools.
- A greater percentage of UNSAT F-14 pools were treated with trichlor tablets.
- There was no evidence that any of the remaining variables had any influence on the results.

These results indicated that the reason these pools fell into the UNSAT F-14 category was due to the rigid Non-coliform bacteria standard of the authors' model for judging pools. Although the results indicated that a greater percentage of the pools were treated with trichlor tablets, the T Test of the means indicated that the average of the cyanuric acid concentrations in both pools categories were essentially the same. Hence, cyanuric acid did not cause the pools to fall into the UNSAT F-14 category. Without the knowledge of the bacteria analysis, the sanitarian and the pool operator would have judged these pools satisfactory for swimming.

H.7. UNSAT E-31 Pools vs UNSAT F-14 Pools

As indicated in the previous section, **UNSAT F-14** pools dataset consisted of 14 pools which the authors believe could be categorized as SAT pools on the basis of the water chemistry standard of the Florida swimming pool code. The **UNSAT E-31** pools failed to meet the bacteriological criteria even though the free chlorine was 1.0 - 5.0 ppm. T Tests and Analyses of Variances were conducted on these two categories to determine if there was sufficient evidence to say what variables were significantly different. The results are summarized in **Appendix LL** and highlighted below.

- The average **free and total chlorine** were significantly lower in UNSAT E-31 pools.
- All of the following variables were significantly greater in UNSAT E-31 pools.
- Heterotrophic, Total coliform and Fecal coliform bacteria populations,
- Swimmers, pool volume and water temperature and
- Total dissolved solids and hardness.
- The percentage of the pools treated with trichloroisocyanuric acid tablets was lower in UNSAT E-31 pools.

I. Phase 8 - Use of Reference Model to Assess Methods and Importance of Variables Typically Used to Determine Whether Pools Are Satisfactory for Swimming

In this phase, statistical analyses were conducted to assess the methods typically used by public pool sanitarians and pool operators to determine whether pools are satisfactory or unsatisfactory for swimming. As pointed out above, pool operators and public health units do not rely on bacteria analyses to determine whether pools are satisfactory or unsatisfactory for swimming. Instead, they rely on the common water chemistry variables of free chlorine and pH. Although cyanuric acid is not typically measured by most pool operators, it is included as a standard for public swimming pool codes. The data analyses were therefore carried out so that the relative effect of each water chemistry variable could be assessed. This was accomplished by developing a series of pool judgment models that used free chlorine, pH and cyanuric acid as criteria but did not rely on the bacteria analyses data. The data analyses were carried out in the following manner.

With the first model **(Model A),** the number and percentage of pools that had bacteria populations at or below the maximum contamination levels deemed necessary to meet the bacteria standards for swimming pool and drinking water were determined. Note, this data analysis model did not take into consideration free chlorine, pH or cyanuric acid measurements. Thus, this model does not indicate whether the pools have sufficient free chlorine to control the bacteria populations at or below the standards for swimming pools and drinking water. The results **(Figure 185, Appendix EE)** of this model analysis indicated that:

- **390 (80.2 %)** of the 486 test pools were bacteriologically satisfactory for swimming and drinking water and
- **96 (19.8 %)** were not bacteriologically satisfactory for swimming.

In the next model **(Model B),** the number and percentage of pools that would have sufficient (1.0 - 5.0 ppm) free chlorine to control the bacteria populations at or below the maximum contamination levels for pools and drinking water were determined. Note, this data analysis model did not take into consideration the bacteria, pH and cyanuric acid data. Thus, this model only indicates that the pools have adequate free chlorine to control the bacteria populations satisfactorily but does not indicate whether the bacteria populations are at satisfactory levels. The results of this model analysis **(Figure 186, Appendix EE)** showed that:

- **336 (69.1 %)** of the 486 test pools had 1.0 - 5.0 ppm of free chlorine and
- **150 (30.9 %)** of the test pools had free chlorine concentrations of < 1.0 or > 5.0 ppm.

The next model **(Model C)** combined the criteria of Models A and B. Thus, this model was capable of indicating that: a) the bacteria populations in the pools were at satisfactory levels, and b) the pools had sufficient free chlorine to control the bacteria populations at satisfactory levels. **Model C is therefore the reference model**

developed in section E. The results of the Model C data analysis **(Figure 187, Appendix EE)** showed that:

- **290 (59.7 %)** of the 486 test pools satisfied the criteria and hence were judged to be satisfactory for swimming and
- **196 (40.3 %)** did not.

Model D was used to determine the effect of pH. This was achieved by taking Model B, adding pH (7.2 - 7.8) as an additional criterion and then conducting the data analysis. The results of this model data analysis **(Figure 188, Appendix EE)** showed that:

- **285 (58.6 %)** of 486 test pools would be deemed satisfactory for swimming and
- **201 (41.4 %)** would not be.

Obviously, the percentage of satisfactory pools with Model D was less than with Model B and the decrease in percentage was due to the addition of pH to the judgment model.

The effect of cyanuric acid was determined with **Model E.** This was achieved by taking Model D, adding cyanuric acid (100 ppm) as an additional criterion and then conducting the data analysis. Thus, the criteria for Model E were: 1) free chlorine (1.0 - 5.0 ppm); 2) pH (7.2 - 7.8); and 3) cyanuric acid (100 ppm). **Model E is basically the Florida Swimming Pool Code.** The results of the Model E data analysis **(Figure 189, Appendix EE)** showed that by this model:

- **201 (41.4 %)** of the 486 test pools would have been deemed satisfactory for swimming and
- **285 (60.6 %)** would not.

This significantly lower percentage of satisfactory pools is due to one factor--the 100 ppm cyanuric acid limit.

With the final model, **Model F**, the effect of using a 1.0 - 3.0 ppm free chlorine standard instead of the 1.0 - 5.0 ppm standard in Model E was evaluated. This data analysis was achieved by changing the free chlorine standard of the Model E (Florida code) from 1.0 - 5.0 to 1.0 - 3.0 ppm and then carrying out the data analysis. Thus, Model F is basically the swimming pool code used by state regulatory agencies other than Florida. The results **(Figure 190, Appendix EE)** for Model F revealed that:

- **only 101 (20.8 %)** of the 486 test pools would be satisfactory for swimming and
- **285 (79.2 %)** would not.

This very low percentage of satisfactory pools is due to a combination of two factors: 1) the 100 ppm cyanuric acid limit; and 2) the narrower free chlorine range of 1.0 - 3.0 ppm.

These results were not surprising since Model E includes pools with 3.1 - 5.0 ppm of free chlorine whereas Model F does not. However, what is really significant is the fact the average bacteria populations for the Model E satisfactory pools are lower than the corresponding ones in the Model F satisfactory pools **(cf., T Test of the means for Heterotrophic, Total coliform and Fecal Coliform bacteria, Appendix MM).** These results should not be surprising because one would expect the average bacteria population to be lower in the 3.1 - 5.0 ppm range than in the 1.0 - 3.0 ppm since increases in free chlorine concentrations accelerate the killing of bacteria. And, this was exactly what the results of the T Test of the means in these two ranges showed **(T Test of means for the above cited bacteria, Appendix NN)**.

These results obviously demonstrated that more pools are likely to be properly sanitized if the swimming pool operator is allowed to let the free chlorine concentration range from 1.0 - 5.0 ppm than if the operator is restricted to 1.0 - 3.0 ppm. **It follows that the Florida code makes more sense because it allows for higher levels of free chlorine which provide a greater safety margin for coping with sudden influxes of contaminants.**

Some state agencies will argue that 5.0 ppm of free chlorine exposes the swimmers to undue risk. However, Mood has shown that 10 ppm of free chlorine is not detrimental to swimmers.[16] Also, it should be pointed out that EPA does not have a limit on free chlorine in drinking water. Even though it is considering setting one, 10 ppm of free chlorine are recommended for disinfecting raw water so that it satisfactory for drinking. In view of these results, the accidental ingestion of swimming pool water with 5.0 ppm of free chlorine apparently does not expose the swimmers to undue toxicological risk.

J. Summary of the Models A - F Analyses

Figure 191, Appendix EE summarizes the results of all of the model analyses. They obviously demonstrate that the number of the test pools that were deemed satisfactory for swimming decreased significantly as the complexity (use of more judgment criteria) of the pool judgment model increased from the simplest models **(Models A and B)** to the more complex models **(Models E and F). Thus, using a more complex pool judgment method simply increases the number of pools that will not be deemed satisfactory for swimming.**

K. Phase 9 - Relationships Between Bacteriologically Satisfactory Pools and Pools Deemed to be Satisfactory for Swimming by Pool Judgment Models A - F

Many will argue that using more complex judgment models is a sound approach because the more variables (or criteria) that are monitored the greater the probability that the pools will be bacteriologically satisfactory for swimming. This would be true if the criteria were surrogates of the bacteria indicators. **However, Models B, D, E and F do not utilize bacteriological data as judgment criteria. Therefore, the results for these models do not indicate how many of the pools deemed satisfactory for swimming by the models were actually bacteriologically satisfactory for swimming.**

For this reason, data analyses were conducted to determine how many of the pools judged to be satisfactory for swimming by **Models B, D, E and F** were actually bacteriologically satisfactory for swimming. This objective was achieved utilizing the bacteria criteria from Model C to conduct the data analysis on each model. The results of this data analysis, which are presented in **Table 18 and Figures 192 and 193, Appendix QQ,** showed that:

- By **Model A, 390 (100 %) of the 390** pools in this category were **bacteriologically satisfactory** for swimming.
- By **Model B, 290 (86.6 %) of the 335** pools in this category were bacteriologically satisfactory for swimming and **45 (13.4 %) were not**.
- With the reference model **(Model C), 290 (100 %) of the 290** pools in this category were bacteriologically satisfactory for swimming.
- With **Model D, 245 (86 %) of the 285 pools** in this category were bacteriologically satisfactory for swimming and **40 (14 %) were not**.
- With **Model E (Florida swimming pool code), 173 (86.1 %) of the 201** pools in this category were bacteriologically satisfactory for swimming and **28 (13.9 %) were not**.
- With **Model F, 86 (85.1 %) of the 101 pools** in this category were bacteriologically satisfactory for swimming and **14 (14.9 %) were not**.

The combination of these results was very surprising indeed. This is because they indicated that regardless of what judgment model was used outside of the bacteriologically rigidly perfect Models A and C, the relative proportion of bacteriologically satisfactory and unsatisfactory pools remained about 86 and 14 %, respectively. Thus, the addition of each additional judgment criterion only served to reduce the number of pools judged to be satisfactory for swimming but did not change the relative percentage of bacteriologically satisfactory and unsatisfactory pools. These results clearly indicated that free chlorine is the most important criterion that can be used to judge whether a swimming pool is satisfactory and/or unsatisfactory for swimming and that cyanuric acid is an unnecessary restriction from a disinfection standpoint.

L. Phase 10 - Algae Statistics

Because algae infestations can make pool surfaces slippery, algae infestations can be a safety hazard. For this reason, public swimming pool codes have algae standards.

As shown by the language in the algae standard of Florida's swimming pool code in section V. Experimental, F. Algae, the standards are based on visual observations. While they are very subjective, it is obvious that good attempts were made to make them as quantitative as possible.

Algae was not used as a criterion in any of the models used to judge whether the 486 test pools were bacteriologically satisfactory for swimming. However, the pool study team felt that it was important to determine if there were statistically significant relationships between bacteria populations and the incidence and extent of growth of algae species. In addition, the team wanted to determine what conditions would most likely minimize the incidence of algae species. In order to gain a better understanding about these questions, the pool study team conducted several additional statistical analyses on the data in the master data base. The results are presented in the following subsections.

L.1. Statistics on All Algae Species

The frequency distribution **(ALL POOLS-486, Figures 36 through 39 A and B and NO ALGAE-297, Figures 36 through 39C and D, Appendix N)** indicated that:

- 61.11 % (297) of the 486 test pools did not have any type of algae.
- 38.89 % (189) had algae species -- black, yellow, green and/or pink.

The black algae frequency distribution **(ALL POOLS-486, Figures 36A and B, Appendix N)** revealed that:

- 62.55 % (304) of the 486 test pools did not have black algae.
- 37.45 % (182) of pools had black algae.
- Thus, 7 of the 189 algae pools did not have black algae but had yellow, green or pink algae.

The yellow algae frequency distribution **(ALL POOLS-486, Figures 37A and B, Appendix N)** revealed that:

- 93.42 % (454) of the 486 pools did not have yellow algae.
- Only 6.58 % (32) of the 486 test pools had yellow algae.

The frequency distribution analysis **(ALGAE YL-32, Figures 36C and D, Appendix N)** also revealed that:

- 25 of the 32 yellow algae pools also had black algae.
- 7 of the 32 yellow algae pools had yellow algae only and not black algae.

The green and pink algae frequency distributions **(ALL POOLS-486, Figures 38 and 39A and B, Appendix N)** revealed that:

- Only 0.82 % (4) of 486 test pools had green algae.
- Only 0.21 % (1) of 486 pools had pink algae.

Thus, there were not enough incidence of green and pink algae to conduct valid statistical analyses. Therefore, the data analyses were focused only on the black and yellow algae pools, The results for these two species are provided in the following subsections.

L.2. Black Algae Pool Statistics

The frequency distribution analysis **(ALGAE BLK-182, Figures 36C and D, Appendix N)** revealed that the extent of growth for black algae was:

- low in 140 (76.92 %) of the 182 black algae pools,
- medium in 32 (17.58 %) and
- high in only 10 (5.49 %).

The statistical characteristics for pools with and without black algae are provided for all variables in **Figures 7 through 39A - D, Appendices G - N** and are discussed below.

L.2a. Bacteria

The frequency distribution analysis **(ALL POOLS-486, Figures 7A and B, Appendix G)** showed that 90.12 % of the 486 test pools had Heterotrophic bacteria populations of < 501 CFU/ml. The results in **ALGAE BLK-182, Figures 7C and D, Appendix G** indicated that the Heterotrophic bacteria populations were < 501 CFU/ml in 88.46 % of the 182 black algae pools. These results obviously indicated that the percentage of pools with Heterotrophic bacteria populations below the maximum contaminant levels were probably essentially the same for pools with and without black algae. Thus, it was no surprise that: a) the Heterotrophic bacteria correlation analysis indicated there was no statistically significant association between black algae and Heterotrophic bacteria **(Appendix O)**, and b) the T Test of the means of the Heterotrophic bacteria populations **(Appendix RR)** showed that there was no statistically significant difference between the averages of the Heterotrophic bacteria populations in both pool categories. It follows then, that the combination of the above results clearly indicated that **the presence or absence of black algae was not influenced by the Heterotrophic bacteria population or vice versa.**

The Total coliform frequency distribution **(ALL POOLS-486, Figures 8A and B, Appendix G)** showed that the population of these bacteria was 0 CFU/100 ml in 90.33 % of 486 test pools. The results in **ALGAE BLK-182, Figures 8C and D, Appendix G** indicated that the Total coliform bacteria population was 0 CFU/100 ml in 88.46 % of the 182 black algae pools. These results implied that **the Total coliform bacteria population of most of the pools in both categories were similar and at satisfactory levels.** Thus, it was not surprising that the correlation analysis **(Appendix**

O) indicated there was no statistically significant relationship between black algae and Total coliform bacteria. However, the T Test of the means of the Total coliform bacteria populations **(Appendix RR)** showed that the average Total coliform bacteria population was significantly higher in the pools with black algae. Hence, the results of these analyses simply indicated that **it was entirely possible for the Total coliform bacteria to be higher in pools with black algae.** On the other hand, this result may indicate that there was another variable that influenced both black algae and Total coliform, but the data was not sufficiently valid for the correlation analysis to demonstrate that there was a positive relationship between black algae and Total coliform bacteria. It is highly probable that this mystery variable is free chlorine since this variable has been demonstrated to have a strong influence on the presence or absence of algae and Total coliform bacteria. This inconsistency in this particular data analysis is probably due to the fact that the algae data are not sufficiently quantitative. In any case, the overall results of the Total coliform/black algae data analyses indicated that **there was no evidence that the presence of black algae had an influence on the Total coliform bacteria population.**

The Non-coliform bacteria frequency distribution **(ALL POOLS-486, Figure 9A and B, Appendix G)** revealed that the Non-coliform bacteria population was < 201 CFU/100 ml in 84.16 % of the 486 test pools. The frequency distribution analysis **(ALGAE BLK-182, Figures 9C and D, Appendix G)** indicated that the Non-coliform bacteria population was < 201 CFU/100 ml in 83.52 % of the 182 black algae pools. These results indicated that the Non-coliform bacteria population was below 201 CFU/100 ml in most of the pools with or without black algae. Thus, it was no surprise that a) the Non-coliform bacteria correlation analysis **(Appendix O)** indicated there was not a statistically significant relationship between black algae and Non-coliform bacteria, and b) the T Test of the means of the Non-coliform bacteria populations **(Appendix RR)** indicated that the averages of the Non-coliform populations were not significantly different. Thus, there was **no evidence that black algae had an influence on the Non-coliform bacteria population.**

Thus, the above results showed that there were no statistically significant relationship between bacteria and black algae. These results reinforce the conclusion that it is entirely possible for pools with black algae to be bacteriologically satisfactory for swimming.

L.2b. Water Chemistry

The frequency distribution **(ALL POOLS-486, Figures 14A and B, Appendix H)** showed that the free chlorine was at least 1.0 ppm in 78.40 % of the 486 test pools versus 75.27 % of the 182 black algae pools **(ALGAE BLK-182, Figures 14C and D, Appendix H).** The correlation analysis **(Appendix O; Table 16, Appendix V; and Figure 168, Appendix DD)** indicated that there was a negative relationship between black algae and free chlorine. In other words, the incidence of black algae decreased as the free chlorine increased. Thus, it was no surprise that the T Test of the means for free chlorine **(Appendix RR)** showed that the average free chlorine was significantly lower in pools with black algae. Thus, these results clearly indicated that **free chlorine had an influence on the presence or absence of black algae**.

The Total chlorine frequency distribution for all 486 test pools and the 182 black algae pools are given in **ALL POOLS-486, Figures 15A and B** and **ALGAE BLK-182, Figures 15C and D, respectively (Appendix H).** These results showed that the total chlorine was at least 1.0 ppm in 79.84 % of the 486 test pools and 78.02 % of the black algae pools. Also, the correlation analysis demonstrated that there was a negative relationship **(Appendix O; Table 16, Appendix V; and Figure 169, Appendix DD)** between the incidence of black algae and total chlorine. Thus, it was not a surprise that the T Test of the means for total chlorine **(Appendix RR)** showed that the total chlorine average was significantly lower in the black algae pools. Therefore, the above results demonstrated that **total chlorine had an influence on the presence or absence of black algae**.

The pH frequency distribution **(ALL POOLS-486, Figures 16A and B, Appendix H)** showed that the pH was < 7.9 in 87.01 % of the 486 test pools. The results in **ALGAE BLK-182, Figures 16C and D, Appendix H** indicated that it was < 7.9 in 88.46 % of the 182 black algae pools. Even though the correlation analysis **(Appendix O)** indicated that there was no statistically significant relationship between black algae and pH, the T Test of the means for pH **(Appendix RR)** did indicate that the pH average was significantly greater in the pools with no black algae. Therefore, the combination of the correlation and T Test of the means only indicated that the average pH was greater in the pools without black algae. Thus, **the results did not indicate that pH had an influence on the incidence of black algae.**

The cyanuric acid frequency distribution **(ALL POOLS-486, Figures 17A and B, Appendix H)** revealed that the cyanuric acid was > 20 ppm in 73.25 % of the 486 test pools versus 71.42 % in the 182 black algae pools **(ALGAE BLK-182, Figures 17C and D, Appendix H).** Also, the correlation analyses **(Appendix O)** indicated that there was not a statistically significant relationship between black algae and cyanuric acid. In addition, the T Test of the means for cyanuric acid **(Appendix RR)** showed that there was no significant difference in the average cyanuric acid concentration in either category of pool. Thus, there was **no evidence that the cyanuric acid concentration had an influence on the presence or absence of black algae.**

The frequency distribution analyses for total dissolved solids, calcium hardness, total alkalinity, copper and nitrate for the 486 test pools and the 182 black algae pools are given in **ALL POOLS-486, Figures 18 to 22A and B and ALGAE BLK-182, Figures 18 to 22C and D, respectively (Appendix H).** The correlation analyses for these variables **(Appendix O; Table 16, Appendix V; and Figure 171, Appendix DD)** indicated that the only statistically significant relationship was the negative one between black algae and hardness. However, the T Tests of the means of the variables for both pool categories (**Appendix RR)** indicated that there were no significant differences in the means of each of these variables. Thus, these results only indicated that **there was**

a relationship between black algae and hardness, but there was no evidence that averages of the hardnesses in both pool categories were significantly different.

L.2c. Turbidity

The turbidity frequency distribution **(ALL POOLS-486, Figures 23A and B, Appendix I)** showed that 94.31 % of the 486 test pools were judged to have no turbidity versus 89.88 % of the 182 black algae pools **(ALGAE BLK-182, Figures 23C and D, Appendix I).** The correlation analysis **(Appendix O; Table 12, Appendix R; and Figure 136, Appendix Z)** indicated that there was a positive relationship between black algae and turbidity. But, the T Test of the means for turbidity **(Appendix RR)** showed there was no significant difference in the turbidity averages of these two pool categories. Thus, these results probably indicated that **pools with black algae tended to be more turbid, but it was possible for pools to have black algae and low turbidity**.

L.2d. Sanitizers

The sanitizer frequency distribution **(ALL POOLS-486, Figures 24A and B, Appendix J)** indicated that 46.71 % of the 486 test pools were treated with trichloroisocyanuric acid, 34.16 % with calcium hypochlorite and 14.61 % with sodium hypochlorite. The correlation analysis **(Appendix O; and Table 16, Appendix V; and Figure 174, Appendix DD)** showed that **there was a positive correlation between black algae and the type of sanitizer used.**

The results in **ALGAE BLK-182, Figures 24C and D, Appendix J** showed that 51.10 % of the 182 black algae pools were treated with trichloroisocyanuric acid, 26.92 % with calcium hypochlorite and 19.23 % with sodium hypochlorite. The T Test of the means **(Appendix RR)** indicated that **the incidence of black algae was less in pools treated with calcium hypochlorite.**

However, if the **ALGAE BLK-182** and **NO ALGAE-297** (excluding the bromine, sodium dichloroisocyanurate and gaseous chlorine sanitizers) pool category data are subjected to frequency distribution analysis using the statistical average of free chlorine as a function of the three main sanitizers -- trichloroisocyanuric acid tablets, calcium hypochlorite and sodium hypochlorite -- the results **(Table 19 and Figure 194, Appendix SS)** showed that:

- The average free chlorine for pools having black algae was 2.35 ppm for pools treated with sodium hypochlorite, 2.93 with calcium hypochlorite and 2.98 with trichloroisocyanuric acid tablets.
- The average free chlorine for pools without black algae was 3.33 ppm for pools treated with sodium hypochlorite, 3.36 for calcium hypochlorite and 4.53 for trichloroisocyanuric acid tablets.

- The combination of the first two results indicated that the minimum free chlorine in a pool should be at least 3.4 ppm, regardless of the sanitizer, in order to have the best chance of minimizing black algae infestations.

The fact that the average free chlorine for the **NO ALGAE-297** pools treated with trichlor tablets was approximately 1 ppm higher does not necessarily mean that the minimum average free chlorine needs to be higher for trichlor treated pools. In fact, the data **(Table 20 and Figure 195, Appendix SS)** showed that of the pools with more than 5.0 ppm of free chlorine:

- 62 % were trichlor treated pools and had an average free chlorine of 11.9 ppm;
- 33 % were calcium hypochlorite treated pools with an average free chlorine of 8.8 ppm;
- 4.4 % were sodium hypochlorite treated pools with an average free chlorine of 12 ppm.

Thus, the data simply indicated that **the average free chlorine concentration in pools treated with trichlor is typically higher than in pools treated with other sanitizers.**

Since many of the pools had free chlorine concentrations significantly > 5.0 ppm, an average free chlorine frequency distribution analysis as a function of the sanitizer was conducted on pools having free chlorine of 5.0 ppm or less. The results **(Table 21 and Figure 196, Appendix SS)** showed that:

- The average free chlorine for pools with black algae was 2.15 ppm for the sodium hypochlorite treated pools, 2.80 for calcium hypochlorite pools and 2.39 for trichlor pools.
- The average free chlorine for pools without black algae was 2.99 ppm for the sodium hypochlorite treated pools, 2.63 for calcium hypochlorite pools and 3.09 ppm for trichlor pools.

Thus, these results indicated that controlling the free chlorine at the appropriate concentration had more influence on the presence or absence of black algae than the sanitizer. They also indicated that an average free chlorine of at least 3.4 ppm was probably required to minimize the incidence of black algae, regardless of the sanitizer.

L.2e. Environmental

The bather load frequency distribution **(ALL POOLS-486, Figures 27A and B, Appendix K)** indicated that only 34.44 % of the 486 test pools had swimmers versus 42.31 % in the 182 black algae pools **(ALGAE BLK-182, Figures 27C and D, Appendix K).** However, the correlation analyses indicated that there was not a statistically significant relationship between bather load and black algae **(Appendix O).** In addition, the results of the T Test of the means for bather load **(Appendix RR)** indicated that the bather load averages were not significantly different. Hence, **there is no evidence that this variable had any influence on the incidence of black algae.**

The water temperature frequency distribution **(ALL POOLS-486, Figures 25A and B, Appendix K)** showed that the water temperature was > 80 °F in 66.52 % of the 486 test pools versus 68.97 % in the 182 black algae pools **(ALGAE BLK-182, Figures 25C and D, Appendix K).** However, the correlation analyses indicated that there was a positive relationship between black algae and water temperature **(Appendix O; Table 16, Appendix V; and Figure 172, Appendix DD).** Although the T Test of the means for water temperature **(Appendix RR)** indicated that the average water temperature was essentially the same in both types of pools, the correlation analyses demonstrated that **water temperature had an influence on the incidence of black algae.**

L.2f. Swimming Pool Characteristics

The facility pool frequency distribution **(ALGAE BLK-182, Figures 28C and D, Appendix L)** clearly showed that most of the 182 black algae pools were observed with apartment complexes followed by condominiums, tourist and municipal pools. However, the results of the correlation analyses showed **there was no statistically significant relationship between black algae and pool facility (Appendix O).**

The type of pool surface frequency distribution **(ALGAE BLK-182, Figures 31C and D, Appendix L)** showed that 97.8% of the black algae pools had marcite surfaces. Also, the correlation analysis showed that **there was a positive relationship between black algae and marcite pools (Appendix O; Table 16, Appendix V; and Figure 175, Appendix DD).** In addition, the T Test of the means **(Appendix RR)** indicated that incidence of black algae was more prevalent in marcite pools. This result was probably influenced by the fact that marcite pools are older and Fiberglass surface coatings are newer.

The pool surface condition frequency distribution **(ALGAE BLK-182, Figures 32C and D, Appendix L)** indicated that 51.1 % of the black algae pools had fair-to-poor surface finishes. The correlation analysis also indicated a positive correlation between black algae and the poor condition of the pool surfaces **(Appendix O; Table 16, Appendix V; and Figure 170, Appendix DD).** The T Test of the means of the surface condition for both pool categories **(Appendix RR)** confirmed that the incidence of black algae was greater in pools with poorer surface finishes. Thus, the results indicated that **surface condition had an influence of the presence or absence of black algae.**

The water return system frequency distribution **(ALGAE BLK-182, Figures 30C and D, Appendix L)** implied that black algae was more prevalent in pools with gutters. However, the correlation analysis indicated that there was not a statistically significant relationship between black algae and the water return system **(Appendix O).** Also, the T Test of the means **(Appendix RR)** indicated that **the incidence of black algae was not significantly different in either type of pool.**

The correlation analysis **(Appendix O; Table 16, Appendix V; and Figure 173, Appendix DD)** and the T Test of the means **(Appendix RR)** indicated that there was a positive relationship between pool volume and black algae and that **the incidence of black algae was significantly higher in the larger volume pools.**

L.3. Summary of the Black Algae Statistics

The above results for black algae dealt with only those variables that the correlation analyses and/or the T Test of the means indicated there was a statistically significant relationship and/or difference in the averages of a given variable, respectively. Although several variables had statistically significant relationships with the incidence of black algae, the results clearly demonstrated that free chlorine was the most important variable. In other words, this particular variable probably had a greater influence on the incidence of black algae than any of the other variables.

These results should not be a surprise to anyone knowledgeable in swimming pool technology since it is a well-known fact that the population of microorganisms like algae, bacteria and fungi can be controlled very well by maintaining the appropriate concentration of free chlorine in pools continuously. It follows that whenever black algae is observed in swimming pools, it is an indication that the pool operator allowed the free chlorine to fall below the concentrations needed to prevent the growth of the algae to the population levels where the black algae colonies are visible. This is because pools are always being inoculated with algae colonies which are invisible. If there is sufficient free chlorine to kill these micro colonies of algae, they will never reach the population levels that are visible to the eye. However, if there is not enough free chlorine, the algae colonies become established and are often difficult to eliminate.

The above results also clearly indicated there was no evidence that cyanuric acid had any influence on the presence of black algae.

L.4. Yellow Algae Pool Statistics

As indicated above in subsection L.1., only 32 of the 486 test pools had yellow algae. In addition, 25 of the 32 yellow algae pools had black and yellow algae. The other 7 pools had yellow algae only and not black algae.

Although the pool study team thought that 32 pools may not be enough to obtain statistically valid comparisons, several statistical analyses were conducted on the data. The results derived from the frequency distribution analyses for all of the variables in the 32 yellow algae pools and the 297 pools without algae are summarized in the **ALGAE YL-32 and NO ALGAE-297, respectively, Figures 7 through 37C and D, Appendices G - N.** The results of the correlation analyses for the yellow algae variable are provided in **Appendix O; Table 16, Appendix V;** and the figures cited below. The T Test of the means for each of the variables identified by the correlation analyses as having a statistically significant relationships with yellow algae for the **NO ALGAE-297** and **ALGAE YL-32** pool categories are provided in **Appendix TT.** The statistically significant results for these data analyses techniques are summarized below.

The free chlorine frequency distribution for the 32 yellow algae pools **(ALGAE YL-32, Figures 14C and D, Appendix H)** revealed that the free chlorine was

- < 1.0 ppm in 10 (31.25 %) of the 32 pools,
- 1.0 to 3.0 ppm in 11 (34.38 %),
- 3.1 to 5.0 ppm in 9 (28.12 %) and
- > 5.0 ppm in 2 (6.24 %).

Thus, the free chlorine was significantly < 1.0 ppm in 1/3 of the yellow algae pools. The results in **Table 22, Appendix UU** showed that the free chlorine was actually < 0.5 ppm in these 10 pools. This was obviously not enough free chlorine to prevent the growth of yellow algae. These results also indicated that the number of incidences increased as the free chlorine decreased. Thus, it was no surprise that the T Test of the free chlorine means **(Appendix TT)** showed that the average free chlorine concentration was significantly lower in the ALGAE YL-32 pools than in the NO ALGAE-297 pools. Hence, these results clearly indicated that **free chlorine had an influence on the presence of yellow algae and that the incidence increased with decreases in free chlorine (Figure 177, Appendix DD).**

Similar results were obtained for total chlorine (cf. ALGAE YL-32 and NO ALGAE-297, Figures 15C and D, Appendix H; Appendix O; Table 16, Appendix V; Figure 178, Appendix DD; and the T Test results in Appendix TT).

Although pH can have an influence on the algicidal effectiveness of free chlorine, the results of: a) the frequency distribution analysis **(ALGAE YL-32, Figures 16C and D, Appendix H)**, b) the correlation analyses **(Appendix O)**, and c) the T Test of the pH means for the NO ALGAE-297 and ALGAE YL-32 pools **(Appendix TT)** showed that there was no statistically significant relationship between pH and yellow algae and that the pH averages were not significantly different in the two pool categories. Thus, the overall results indicated that **pH did not have an influence on the presence or absence of yellow algae in this study**.

The frequency distribution for cyanuric acid **(ALGAE YL-32, Figures 17C and D, Appendix H)** indicated that the cyanuric acid concentrations were > 20 ppm in 27 (84.37 %) of the 32 pools and < 21 ppm in 5 (15.63 %). Although these results could imply that cyanuric acid concentrations > 20 ppm were related to the higher incidence of yellow algae, the correlation analyses **(Appendix O)** indicated that **there was not a statistically significant relationship between yellow algae and cyanuric acid concentration.** In addition, the results of the T Test of the means for cyanuric acid **(Appendix TT)** showed that **cyanuric acid concentrations were not significantly different in the two pool categories. As a result, there was no evidence that cyanuric acid had an influence of the presence or absence of yellow algae.**

With regards to turbidity, the frequency distribution **(ALGAE YL-32 and NO ALGAE-297, Figures 23C and D, Appendix I)** showed that 25 (80.65 %) of the 32 yellow algae pools were judged to have no turbidity. However, the correlation analyses **(Appendix O; Table 12, Appendix R; and Figure 137, Appendix Z)** showed that **there was a positive relationship between yellow algae and turbidity**. In addition, the T Test of the means for turbidity in the respective pool categories **(Appendix TT)** demonstrated that the **turbidity was significantly higher in the ALGAE YL-32 pools than in the NO ALGAE-297 pools**. Again, these results were not surprising since a pool infested with yellow algae will have a significant amount of yellow algae colonies floating in the water. As a result, the turbidity will be significantly higher in a pool with yellow algae.

The sanitizer frequency distribution **(NO ALGAE-297 and ALGAE YL-32, Figures 24C and D, Appendix J)** showed that:

- 22 (68.8 %) of the 32 yellow algae pools were treated with trichlor tablets,
- 5 (15.6 %) were treated with sodium hypochlorite and
- 4 (12.5 %) were treated with calcium hypochlorite.
- The sanitizer for 1 pool was unknown but was not trichlor tablets since the cyanuric concentration was 0 ppm.

For the 22 trichlor treated pools, the free chlorine frequency distribution **(Table 22, Appendix UU)** revealed that the free chlorine concentration was:

- significantly < 0.5 ppm in 8 pools,
- 1.0 - 2.0 ppm in 4,
- 2.1 - 3.0 ppm in 4,
- 3.1 - 5.0 ppm in 5 and
- 12 ppm in 1.

The free chlorine for the 4 calcium hypochlorite treated pools were 2.0, 2.8, 4.0 and 6.0 ppm. In addition, the free chlorine for the 5 sodium hypochlorite treated pools was 0.3,1.4, 4.0, 4.0 and 5.0 ppm.

From a black and yellow algae aspect, both species were present in 16 of the 22 trichlor treated pools. Interestingly, the free chlorine was 1.4 ppm or less in 11 of the 16 pools and 2.5 ppm or more in the other 5 pools. The data also showed that 6 of the 22 yellow algae pools did not have black algae. It is also noteworthy that all but 1 of these 6 pools had < 2.5 ppm of free chlorine. Since the results of the black algae data analyses above showed that the average free chlorine in pools without algae was > 3.0 ppm, **it is entirely possible that 3.0 ppm or more of free chlorine is required to minimize the incidence of yellow algae.**

From an extent of growth standpoint, this analyses showed that the yellow algae growth in 15 of the 22 trichlor treated pools were rated as low. This means that the sanitarian had to kneel by the pool side to detect the algae. Thus, the yellow algae growths were barely VISIBLE in the pools.

Although the correlation analyses indicated a positive relationship existed between yellow algae and the type of sanitizer (Appendix O; Table 16, Appendix V; and Figure 180, Appendix DD), the above results did not verify this conclusion. In fact, the combination of these results implied that most of the pools did not have enough free chlorine to prevent the formation of yellow algae.

The hardness frequency distribution **(NO ALGAE-297 and ALGAE YL-32, Figures 19C and D, Appendix H)** indicated that the percentage of pools with hardness > 180 ppm was higher in the NO ALGAE-297 category than in the ALGAE YL-32 category (87.26 vs 70.97 %). In addition, the correlation analyses **(Appendix O; Table 16, Appendix V; and Figure 182, Appendix DD)** indicated a negative relationship between hardness and yellow algae. Furthermore, the T Test of means for hardness **(Appendix TT)** indicated that the pools with yellow algae had lower hardnesses than those without yellow algae. Thus, these results indicated that **hardness influenced the incidence of yellow algae and yellow algae decreased with increases in hardness.**

The pool volume frequency distribution **(ALGAE YL-32 and NO ALGAE-297, Figures 29C and D, Appendix L)** indicated that the percentage of incidence of yellow algae was higher in pools with > 40,000 gallons. The correlation analyses **(Appendix O; Table 16, Appendix V; and Figure 179, Appendix DD)** indicated that there was indeed a positive relationship between yellow algae and pool volume. In addition, the T Test of the means of the pool volumes for both pool categories showed that the average number of yellow algae incidence was higher in larger volume pools than in smaller volume ones **(Appendix TT).** These results obviously indicated that **there was a relationship between incidence of yellow algae and pool volume and yellow algae incidence tended to be higher in larger volume pools.**

The T Test analyses **(Appendix TT)** for the variables not cited above showed that **none of the other variables had influences on the incidence of yellow algae.**

L.5. Summary of the Yellow Algae Statistics

Although the extent of yellow algae growth was very low (inspectors had to get on their hands and knees to detect the algae) in most of the pools, the results of the yellow algae statistical analyses indicated that **free chlorine probably had more influence on the presence or absence of yellow algae than any other variable.** This conclusion was supported by the following facts: 1) The correlation analysis indicated that there was a statistically significant negative relationship between free chlorine and yellow algae; 2)The T Test of the means for free chlorine indicated that the average free chlorine was significantly lower in the pools with yellow algae than in pools without yellow algae. In fact, the free chlorine frequency distribution analysis of the yellow algae pools showed that the free chlorine was < 0.5 ppm in ~ 1/3 of the pools. Moreover, the free chlorine in 2/3 of the pools was < 3.0 ppm, a concentration below which the frequency of black algae incidence were found to be greater; and 3) No other variable produced such strong statistically significant results.

The statistical analysis results also indicated that cyanuric acid had no statistically significant influence on the incidence of yellow algae. Similar results were obtained for the type of sanitizer.

It was not clear why increases in pool volume had an influence on yellow algae. One possible explanation is that the free chlorine tended to decrease more readily in larger volume pools thereby creating conditions favorable to the growth of yellow algae. This supposition is supported by the results of this study which indicated that bather loads increased with pool volume and free chlorine decreased with increases in bather load.

It was not clear why there was a negative relationship between hardness and yellow algae. The results implied that the use of calcium hypochlorite was involved. However, there was not enough data to prove this point.

L.6. Summary of the Algae Statistics

The combination of the black and yellow algae statistics clearly demonstrated that free chlorine had the greatest influence on the incidence of these two species. In fact, the data, especially the black algae data, indicated very strongly that the **free chlorine probably had to be maintained above 3.0 ppm continuously in order to minimize the incidence of black algae, and probably yellow algae.**

M. Phase 11 - Frequency of Algae Incidences in Pools Deemed Satisfactory for Swimming by Judgment Models A - F

It was obvious from the results of the statistical analyses of the algae and bacteria data that a considerable number of the pools that were bacteriologically satisfactory for swimming had black and yellow algae. As a consequence, a statistical analysis was conducted to determine the relative incidence of algae in pools deemed to be satisfactory for swimming by the pool judgment **Models A - F** which were reviewed above in sections **E, H, I, J and K.** This was achieved by using the PROC FREQ technique to determine the relative percentage of pools with and without algae (black plus yellow algae only) for each category of pools. The results of these analyses (summarized in **Table 23 and Figures 197 and 198, Appendix VV**) showed that the relative percentages of pools without algae were between 60.0 and 63.4 % for all of the categories. The relative percentages for pools with algae ranged between 36.6 and 40.0 %. Thus, the results clearly demonstrated that **the relative percentages of pools with and without algae were essentially the same for all of the pool categories.**

These results were very surprising and interesting because they indicated that it **was possible for a pool with algae to be bacteriologically satisfactory for swimming. In addition, the results indicated that it easier to maintain bacteriologically satisfactory conditions than it is to keep a pool free of algae.** This conclusion is supported by the fact that the results of this study demonstrated that most pools with free chlorine concentrations > 1.0 ppm were bacteriologically satisfactory for swimming whereas the algae analyses indicated free chlorine concentrations of 3.0 ppm or more were required to minimize algae incidence, especially black algae. **Thus, it is harder to get rid of the algae than it is the bacteria.**

N. Comparison of the Results of This Study with Those of the 1973-81 Pinellas County Study

The results of this study clearly reinforced the results of the 1973-81 Pinellas County Pool Test Program. The evidence that lends strong support to this conclusion is:

- Free chlorine has the greatest effect on the bacteria contamination levels.
- The swimming pools were well sanitized as long as the free chlorine was at least 1.0 ppm.
- There was no evidence in either study that cyanuric acid, even > 100 ppm, had any influence on whether swimming pools were bacteriologically satisfactory for swimming.
- There was no evidence in either study that cyanuric acid had an influence on the incidence and extent of growth of black and yellow algae.

O. Cyanuric Acid Limits In Public Swimming Pools

The results of this study and those of the 1973-81 Pinellas County study clearly demonstrated that limiting the cyanuric acid levels in swimming pools did not have any bearing on whether swimming pools were bacteriological satisfactory for swimming. Thus, the results of this study clearly indicated it is feasible to raise the cyanuric acid above the current 100 ppm limit in public swimming pools without exposing the swimmers to bacteriological risks.

P. Summary of the Study

The results of this study were generated from one-time observations and grab samples of water. Since the conditions of pools are very dynamic, the data only represented snapshots of the pool conditions at the time the water samples were taken and the conditions were recorded. For this reason, the data did not always provide a clear and accurate picture of the conditions of the pools. However, with the aid of several statistical analysis techniques, the pool study team was able to obtain a good understanding of what variables should be controlled to maintain good disinfection conditions and minimize the incidence of algae in pools treated with stabilized or unstabilized chlorine.

Good pool management requires a properly filtered pool and a good chemical treatment program. This means that the filtration system must be of adequate design, in satisfactory operating condition and operated for the appropriate length of time every day. **Note, the Florida swimming pool code permits the recirculation system to be turned off 3 hours after pool closing time and turned on again 3 hours before the posted pool opening time.** If these filtration conditions are satisfied, the chemical treatment program will be more effective, provided the appropriate free chlorine, pH and water balance conditions are maintained continuously. If the filtration system is not operated properly, the chemical treatment program will be ineffective. As a result, the water will be cloudy, not properly disinfected and may have algae.

The results of this study showed that the filtration systems of the test pools were basically in good working condition as evidenced by the following facts: 1) the turbidity of practically all of the pools were judged to be very low; and 2) turbidity did not have any statistically significant influence on the bacteria populations and, hence, the disinfection conditions. Hence, the results indicated that the test pools were fulfilling one of the two major requirements of a good pool management program.

A good chemical treatment program will control the free chlorine, pH, total alkalinity and cyanuric acid in the recommended ranges. Cyanuric acid is commonly recommended because it reduces the loss of free chlorine from pools. As a result, the free chlorine concentrations tend to be higher in pools treated with stabilized chlorine. The results of this study clearly demonstrated the latter point, and also indicated that cyanuric acid had an influence on the bacteria populations. However, since it is well-known that cyanuric acid does not have any microbicidal properties, the results simply indicated that pools treated with stabilized chlorine had higher free chlorine concentrations and therefore lower bacteria populations. **As a consequence, the results of this study clearly demonstrated that free chlorine had the greatest influence on the disinfection conditions and growth of algae in the test pools.** This conclusion is supported by the statistical results which indicated that: 1) free chlorine had the strongest statistically significant influence on the bacteria populations and algae incidence; and 2) pH, total alkalinity and turbidity (an indicator of filtration) did not have any statistically significant influences on bacteria populations and incidence of algae in this study.

The conclusion that free chlorine was by far the most important variable was reinforced by the results of the statistical analyses that compared the relative percentages of bacteriological satisfactory and unsatisfactory pools that would be deemed satisfactory and/or unsatisfactory for swimming by the hypothetical pool judgment techniques. Basically, the results showed that: 1) the relative percentage of the bacteriological satisfactory and unsatisfactory for swimming were essentially 85 and 15 %, respectively, regardless of the number of criteria used to judge the pools; and 2) each time an additional standard (e.g., pH, cyanuric acid, etc.) was added to the basic free chlorine model **(Model B)**, the step only served to reduce the number of pools that would be deemed satisfactory for swimming. **Thus, the addition of another criteria resulted in deeming more bacteriologically satisfactory pools unsatisfactory for swimming, but did nothing to reduce the number of bacteriologically unsatisfactory pools.**

Only 20 to 40 % of the test pools were deemed satisfactory for swimming by the swimming pool code judgment models (Models E and F) as opposed to up to 80 % by the other models (Models A - D). The large differences between Models A - D and Models E and F were due to the fact that Models E and F contained a 100 ppm cyanuric acid limit criterion whereas Models A - D did not. These results and those cited in the previous paragraph clearly demonstrated that **the cyanuric acid limit is not a necessary disinfection criterion and serves no purpose from this aspect.**

Similar results were obtained from the statistical analyses of the algae. That is, free chlorine was the variable having the greatest influence on the incidence of black and yellow algae and none of the other variables were found to be statistically significant. **Most importantly, the results indicated that algae was more difficult to control and get rid of than bacteria.** As a consequence, it was possible to have bacteriologically satisfactory pools with algae. **Even more important was the fact the results indicated that it was possible to have a bacteriologically satisfactory pool free of algae if the free chlorine was continuously maintained at 3.0 ppm or more.**

The results of the statistical analyses on the effect of other chemical and physical variables on the conditions of the pools indicated that the condition of the pool surface, especially in marcite pools, decreased with pH, total alkalinity and cyanuric acid. These results indicated that the pool operators were not controlling the total alkalinity and pH very well. In fact, the results indicated that the pool operators had let the pH and total alkalinity fall below 7.2 and 80 ppm, respectively, several times during the history of the pool.

Overall, the results of this study point out that many of the problems observed with the pools could be minimized with good pool management programs. One way to get pool operators to have good pool management programs is to show that poor management results in higher costs.

VII. Acknowledgments

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IX. Appendices

Paper copies of the Appendices are collected in three binders as follows:

Binder 1: Appendices A – N
Binder 2: Appendices O – EE
Binder 3: Appendices FF – VV

Electronic copies of the Appendices are collected in three files as follows:

Pinellas_App_Binder1.doc: Appendices A – N
Pinellas_App_Binder2.doc: Appendices O – EE
Pinellas_App_Binder3.doc: Appendices FF – VV