Algae Computer Simulation:

Growth Forecasting Within A

Swimming Pool Environment

by

Roderick Ballard

A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Science in Technology

Approved November 2012 by the
Graduate Supervisory Committee:

Narciso Macia, Chair
Brentt Narveson
Albert McHenry
Thomas Dempster

ARIZONA STATE UNIVERSITY

December 2012

ABSTRACT

An issue with the utilization of swimming pools is that pumps are operated an excessive number of hours to keep the pool free of debris and algae. Case in point, according to the pool industry, a pump should operate one hour for every ten degrees of ambient temperature. A dynamic model and a control strategy have been developed using Matlab/Simulink that uses environmental conditions together with chemicals that hinder or aid algae growth in order to determine algae population. This model suggests ways to function the pump on shorter time intervals to reduce energy consumption, while simultaneously maintaining algae populations at acceptable levels. Other factors included in the model are pool thermal dynamics and pool pump/filter performance characteristics, since they also have an effect algae growth. This thesis presents the first step for an alternative way of operating a swimming pool by minimizing operating costs while eliminating algae.

DEDICATION

This thesis I want to dedicate to the following: My Lord and Savior Jesus Christ, my wife, family, friends, and all others that gave encouraging words.

ACKNOWLEDGMENTS

The author wishes to thank my chair Dr. Macia and the rest of my committee members for taking time to assist in making this thesis a reality. Dr. McHenry thank you for laying the ground work for future Southern University System Alumni here at A.S.U.. Dr. Dempster thanks for your countless advice about algae from the AZCATI Algae Lab Tour of Fall 2010 and on up to now. Mr. Brentt Narveson, I was totally clueless about maintaining a pool and you and the staff had patience with me. Lastly, all other faculty, staff, students, and other professionals that provided advice along the way.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Overview

Algae (i.e. bio-matter) have been an ongoing problem for swimming pool owners. Pool filtration systems are frequently over-utilized in hopes to stop future algae growth. This domino effect leads to time and financial losses for the pool's owner, since typical operational guidelines for keeping the algae under acceptable limits require over-use of the pool circulation equipment. There must be a way to take existing information to help detect more accurately when algae begin to exceed acceptable limits. This thesis addresses one of the major components of the solution to this problem. The thesis presents a general model that predicts the algae population in a pool, based on an assumed weather profile and application of chemicals that hinder algae growth. Eventually, in a continuation of this research effort, this model will be used by a device that will address this problem in the pool. The model will measure actual weather and pool conditions; compare it to the pool water temperature predicted by the model. Then, it will use the difference to adjust pool pump operating conditions (frequency and duration) to keep the algae under control.

Characteristics of Model

The weather variables that will be included in the model include: wind speed, temperature, and solar irradiation cloud cover, and its impact on pool water temperature. In addition, the pool's filtration system is modeled in terms of its ability to remove algae and the nutrients that aid its growth. Thirdly, the model also captures the effect of added chemicals that stop the growth of algae.

Lastly, input factors have been gathered from a pool specialist and a local biologist to make sure the model is performing appropriately. This model developed can simulate different test conditions based on the kind of algae present in the pool. The results of this research constitute the first step to help consumers in reducing their misuse of money and energy.

This model has been implemented in Matlab/Simulink, and addresses algae population, concentration of chemicals that aid algae growth, as well as those that hinder it. The model also incorporates components of a previously-developed model that predicts solar heating and pool water temperature. The model is simulated for a period of seven days, under the assumption that such a period is representative of pool dynamics.

Scope

This thesis incorporates different phases:

1. Develop a model which predicts algae concentration in a generic pool. Selection of parameters for the model that produce a reasonable behavior.
2. Selection of a specific pool and estimation of the parameters in the model. Test accuracy of the model and alter it if needed.

3. Develop a control strategy that uses estimated weather conditions in the model, together with actual weather data, to modify the pump frequency of the operation. Test effectiveness of control strategy through simulation.
4. Develop an actual controller (microcontroller-based) and place it in a specific swimming pool. Then analyze its performance.

This thesis addresses Phase 1. The rest of the phases will be developed in the future, by other graduate students.

Possible Eventual Implementation

This section suggests a possible hardware implementation strategy, even though that aspect is not part of this thesis' goals. Figure 1.1 shows a possible hardware realization of the concept, implemented in a microcontroller, which has a simplified version of the model presented here. This hardware realization is a complex one since it requires the measurement of multiple pool variables. In this realization, the following variables are measured: ambient temperature, (Tamb), pool water temperature (*Twater*), solar irradiation (*Irad*), and concentration of chemicals that aid (*Ca*) and hinder algae growth (*Ch*). These variables are processed by the microcontroller, taking into consideration the predictions and assumptions made by the model, and as a result determine when the pump should be operating.

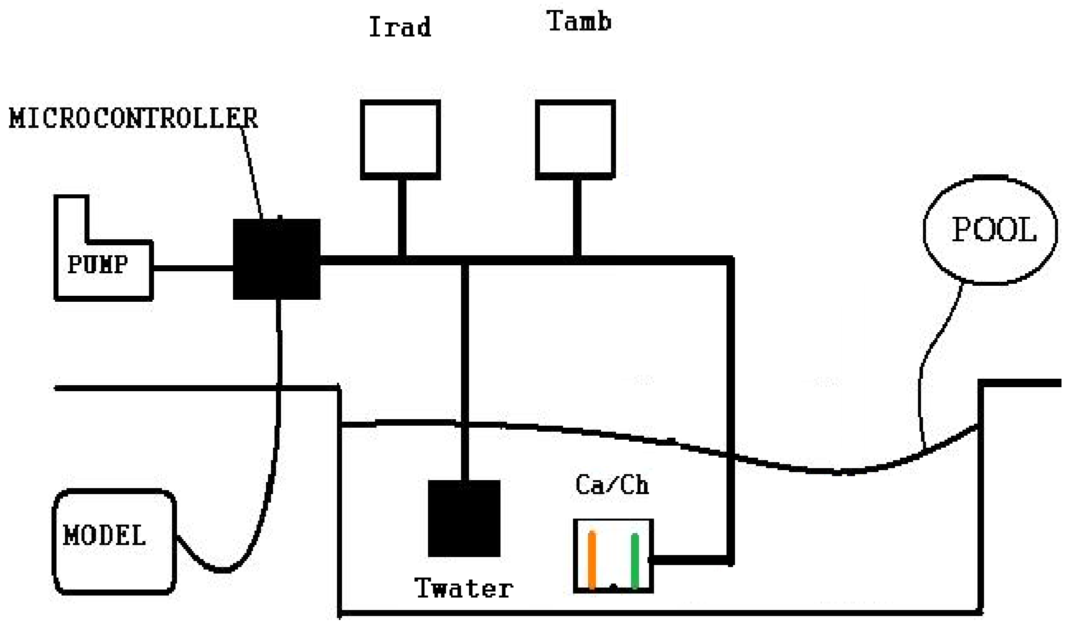


Figure 1.1 Possible hardware implementation.

CHAPTER 2

LITERATURE REVIEW

This chapter summarizes information about the following: algae growth rates, minimal pool operating time, minimal amount of chemicals needed, dynamic behavior of alga. Algae (i.e. phytoplankton) have been an ongoing problem within the pool industry. Countless dollars are spent by the consumers insuring that their pools do not become green lakes. The research for this endeavor has proven to be painstaking because information has to be gathered for three separate topics then merged together for this thesis. One of the topics is algae. According to Venkataraman, algae can be broken down into ecological communities [49]. Planktons are a type of algae that are found in water whereas; saphophytes are on soil algae [49]. Some algae can exist in different temperature climates. Thermophytes thrive in high temperatures but cryophytes prefers the opposite [49]. Then there are kinds of algae that dwell on or within plants or animals [49]. Some are found at the bottom of lakes; however, there are those that exist in salty environments 2 -17 times stronger than sea water. Lastly, there are lithophytes which exist on rocks. Other things to take into consideration are the following: how does it get around, nutrients needed and sunlight. In regards to transportation, Goyal and Smith make some suggestions. Goyal mentions that some algae have flagella which allow them to move from one location to another while in water. On the other hand, Smith [reference] states that wind can play a role in the transport of cells. A side note, dust clouds starting on the west coast or the Great

Plains have traveled east of the Mississippi before hitting ground [42]. Algae are considered to be a rootless plant but it still needs sunlight. Case in point, algae in freshwater can receive light in water do to three conditions: water color, turbidity, and dissolved salts [42]. Depending on the type of light (i.e. red, blue or violet) and depth determines how far light travels in the pool [42]. Phototaxis deal with how phytoplankton responds to light [49]. Green algae have a positive phototaxis whereas stoneworts (i.e. black algae) have a negative one [49]. Continuing on about the importance of light, there is a concept called the Emerson effect. Robert Emerson observed in 1957 that exposing plants to two wavelengths of light short and long increased the rate of photosynthesis [49]. Shifting to nutrients, inorganic compounds are essential for the growth of algae [42]. An example of a nutrient would be something with nitrogen in the compound [42]. The University of Texas has an algae culture collection which can be viewed online [18, 34]. This website provides information on green and yellow algae along with suggested medium to grow it. Some concerns came up in regards to where can these nutrients are found in nature. Fertilizers typically have a good amount of the compounds needed to grow phytoplankton. Other ways to find where nutrients exist is provided at www.mindat.org [21].

As stated above, this thesis had to combine three parts. Now, the attention is shifted to the swimming pools, recognizing that swimming pools are similar to freshwater environments. According to B&B Pools there are three kinds of algae which give the most problems with pool upkeep [30]. Green algae are free floating and/or wall clinging. Next, there are black algae which majority of the time dwells in the shaded areas where there are cracks, crevices and plastered pools [30]. Lastly, there is a mustard alga which normally dwells on the bottoms or sides of the walls of pools [30]. The store has different chemicals to help eliminate the algae. Chlorine comes in three basic forms: tablets, powder, and liquid. Typically, tablets are about 90% strength whereas liquid chlorine is 12%. Some other items used to combat phytoplankton are listed: algaecides, clarifiers, and phosphate removers. The Myron L. Company has a solids checker device that checks what is in pool water [36]. Pool industry standard indicate that the water in a pool should be turned at least once a day. B&B Pools states that green algae become visible when there are 10x106 cells per ounce of water. Algae mainly occur due to the following factors: sunlight, nitrate, high pH, low chlorine, and poor filtration. For the average pool owner these are pools terms that may not be known. The following website provides guidance assistance in this area: www.havauz.org/glossary/pool-a-b.htm.

What is the importance of models? With models a mathematical description of the process to be controlled or analyzed is created [25]. For example, quantitative models permit the investigator to do the following: predict future behaviors, observe patterns, and synthesize data [5]. From “Models in the Ecosystem Science”, models can be put into two categories: complex with more room for error, and simple with less chance for error [5]. The next chapter will get into more detail on the model used, and the parameters used in the model.

CHAPTER 3

METHODOLOGY AND MODEL

This chapter presents the method used to develop the mathematical model for swimming pools. In this project, only simulation data will be generated and analyzed. The overall objective is to obtain a model that could be used as a template, regardless of the following: type of algae, amount of chemicals present, amount of nutrients present, size of pool, type of pump or frequency of use, type of filter, and weather conditions. The model is governed by the following three differential equations:

$$\frac{dN_p}{dt} = -q_o n_o + q_i n_i + k_a C_a N_p - k_h C_h N_p - k_p A_{pool} V_{wind}$$

$$\frac{dCh}{dt} = \frac{m_{dot\_h}}{V} - k_{sun} A_{pool} I_t - k_{hinder} N_p - k_{temp} decay(T_{water})$$

$$\frac{dC_a}{dt} = k_{wind} A_{pool} V_{wind} - k_{aid} N_p$$

The first differential equation is a first order equation with five terms, and it captures the time rate of change of N_p, the number of algae cells. The concentration of chemicals that hinder algae growth is C_h. The concentration of chemicals that aid algae growth is C_a. The water flow out and into the pool are represented as q_o and q_i. For this model, it is assumed that flow rate into the pool is the same flow out of the pool. n_o is the concentration of cells (i.e. cell/unit volume) leaving the pool and n_i is the concentration of cells entering the pool.

A_{pool} represents the area water-air interface of the pool and k_p presents a proportionality value.

The rate of change of algae is also proportional to the concentration of chemical that hinder or aid its growth (C_a , C_h) and the number of algae. k_h and k_a are the proportionality constants associated with these terms. The second differential equation is a first order equation with four terms, and it captures the time rate of change of C_h, the concentration of chemical that hinders algae growth. m_{dot_h} is the rate at which chemical (i.e. chlorine) is put into the pool. For example, it could represent the rate at which chlorine tablets dissolve. V equals the volume of the pool. I_t is the solar irradiation or light intensity of sun which facilitates photosynthesis in the algae. k_{sun} is the proportionality constant (related to cloud cover) which mediates the impact of solar radiation. k_{hinder} is indicative of the rate at which algae (i.e. N_p) is consumed by the pool chemicals. k_{temp} connects the rate of decay of chemical that hinders algae growth to the pool's water temperature. Specifically, it connects the effects of water temperature to the decay of chlorine in the pool [8, 14, and 43].

The third differential equation is a first order equation with two terms and it captures the rate of increase of nutrients into the pool that feed the algae. k_{wind} is a proportionality constant that relates the influx of nutrients to the wind velocity and the pool area A_{pool}. k_{aid} addresses the rate in which the nutrients are consumed by the algae. Additional information, together with initial values of these parameters, is included in Appendix A.

The typical simulation explored in this thesis, consist of a pool in which two chlorine tables are dissolved in the pool over a period of two days. When the pump is on, the chlorine tablets dissolve at a faster rate than when the pump is off, since the water velocity passing past the chlorine tablets is greater when the pump is on. The pump is initially scheduled to run four times a day, at 30 minute intervals. This on time (30 min) is the control variable that is used to mitigate the effect of factors that increase algae growth.

The model's differential equations are captured in Simulink, shown in Figure 3.1. It consists of five main blocks: output, filter/pump timer, $k_pA_{pool}V_{wind}$, $k_aC_aN_p$, and $k_hC_hN_p$. The output is a scope which shows C_h, C_a, N_p, and n_p. The filter/pump timer block takes the pool water and its content and cleans it at rate based on the pump. For the simulation performed here, the filter is modeled as having 90% efficiency, and the pump runs 30 minutes intervals, four times a day. The $k_pA_{pool}V_{wind}$ block utilizes wind data from a file produced by the National Oceanic and Atmospheric Administration (NOAA) corresponding to the month of July 1990. The wind data is stored in knots but and then converted to meters per day since the independent variable(time) is in days $k_aC_aN_p$ takes the total nutrients and the amount algae along with a proportionality value. This block causes the cell counts to increase whereas $k_hC_hN_p$ does the opposite .

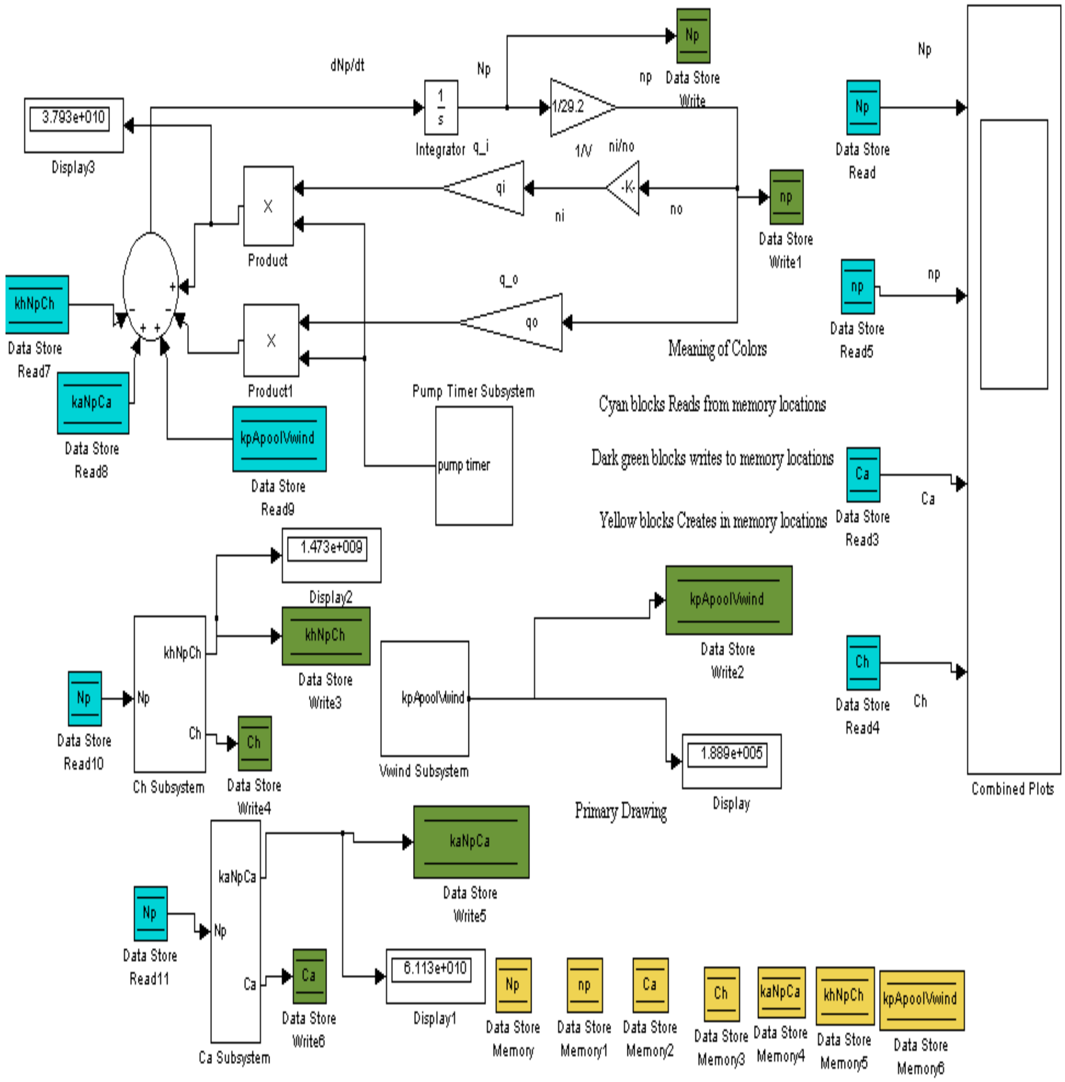


Figure 3.1 Primary Simulink model.

Figure 3.2 deals with the pump timer for the pool. In this model it is a generic pump with, no actual horsepower. It only turns on four times a day, for a 30 minute interval each.

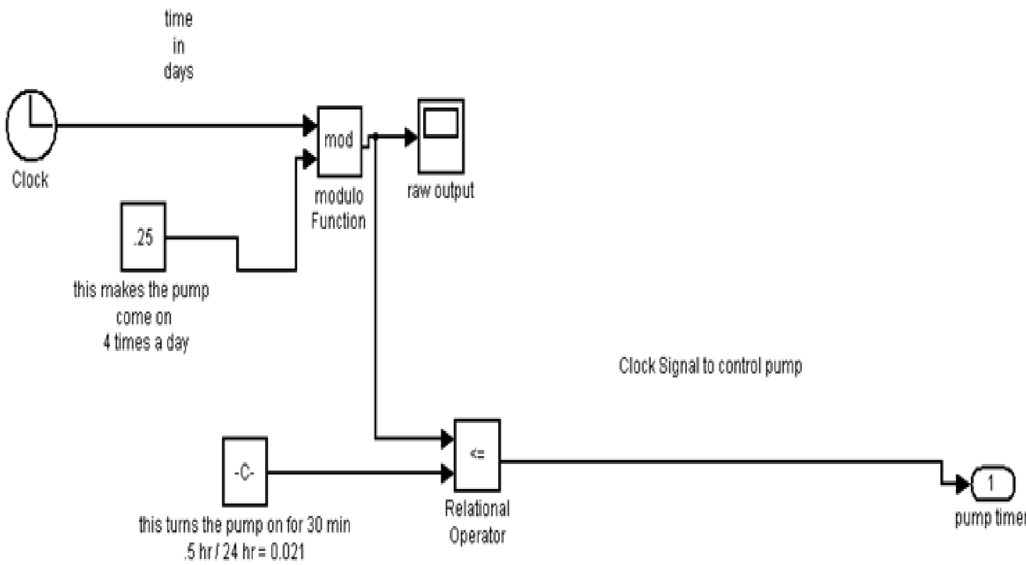


Figure 3.2 Pool pump timer.

Figure 3.3 shows the internal content of block $k_pA_{pool}V_{wind}$, as stated above. It takes July's wind data knots and then converts it to meters per day.

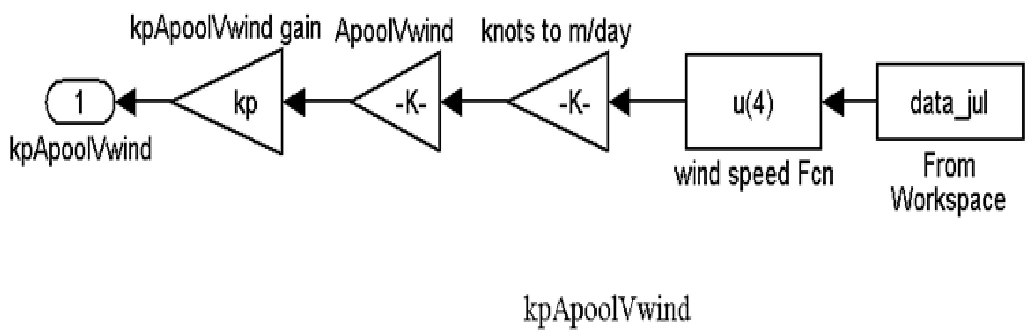


Figure 3.3 Block that introduces Vwind into the model.

Figure 3.4 is the internal content of $k_h C_h N_p$ block. It also calculates other terms such m_{dot_h}, which is show detail in Figure 3.5, dealing with the dispersions of chemicals in the pool. Another function performed by the blocks of Figure 3.4 is to decrease the cell count of algae in the pool.

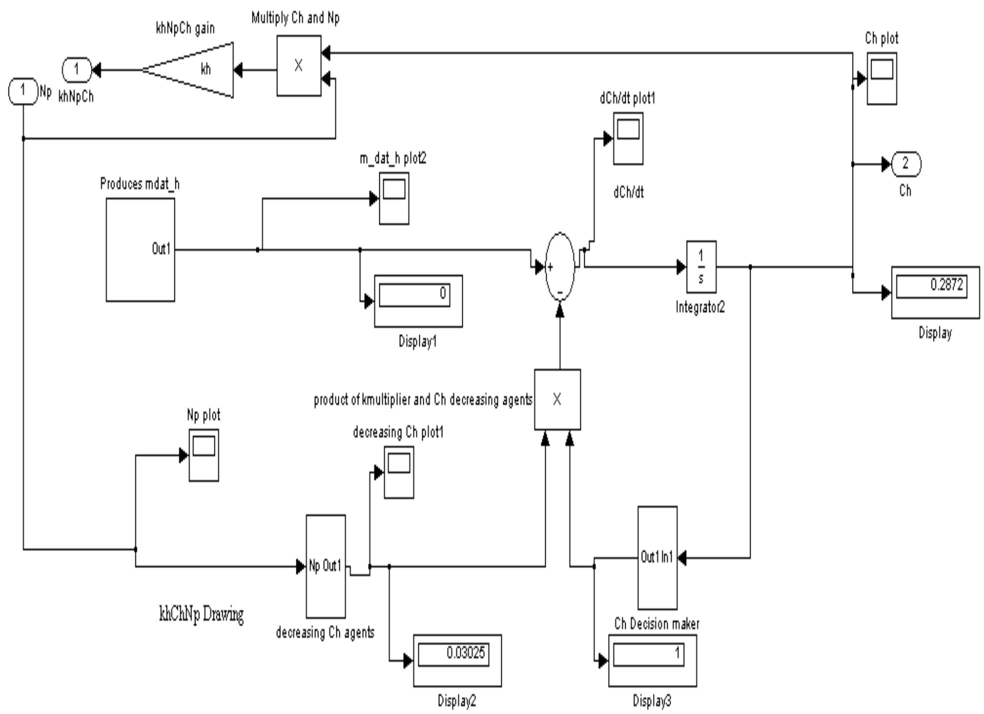


Figure 3.4 Factors that decreases algae cells.

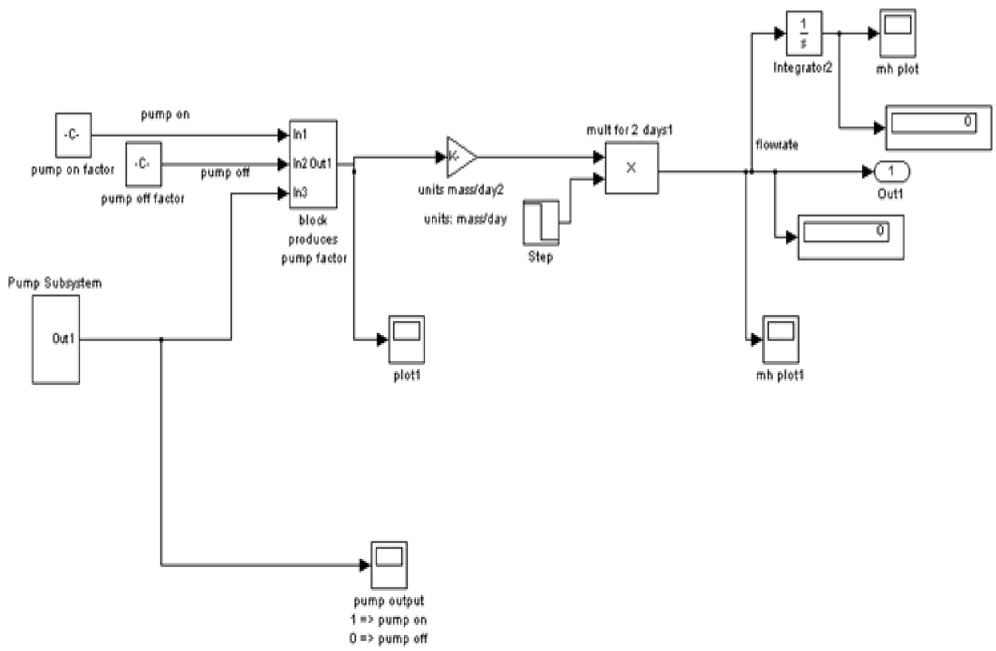


Figure 3.5 Chemical dispersion.

$\int_0^7 m_{dot\_h} dt = m_{dot\_h}$ represents the total quantity of chlorine dissolved into the pool during the overall simulation time, seven days. Chemicals are put in the pool during the first two days. The figure above has an expression that relates chemical dispersion and the state of the pump. $m_{dot\_h} = m_{dot\_h_0}(1 + PUMPFACTOR)$.

PUMPFACTOR deals with the state of the pump being on 2.8 when the pump is on, and 1 when the pump is off. When the pump is on, the water velocity passing the chlorine tablets is greater, causing a faster dispersion.

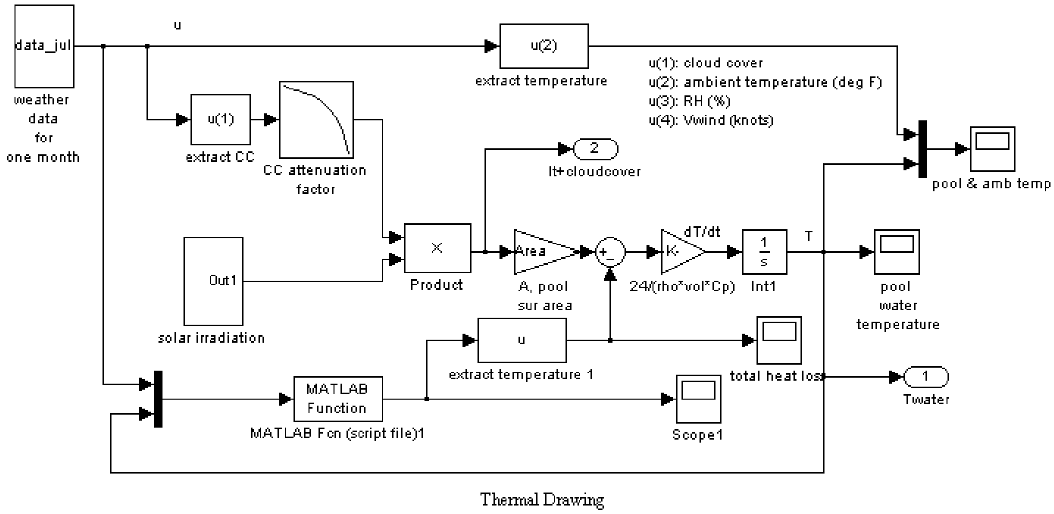


Figure 3.6 Thermal model.

Pool water temperature is an important variable in this problem, since it impacts the decay of chemicals that hinder algae growth *decay* term in of the $\frac{dC_h}{dt}$ differential equation. Pool water temperature is estimated in a thermal model, Figure 3.6. This model takes in the weather data from NOAA to calculate the pool water temperature. The model takes into consideration conduction (to the side of the pool), evaporation, and irradiation, radiation heat transfer mechanisms. The results are fed it into (Figure 3.7) below. Figure 3.7 captures the factors that decrease the value of C_h in the pool.

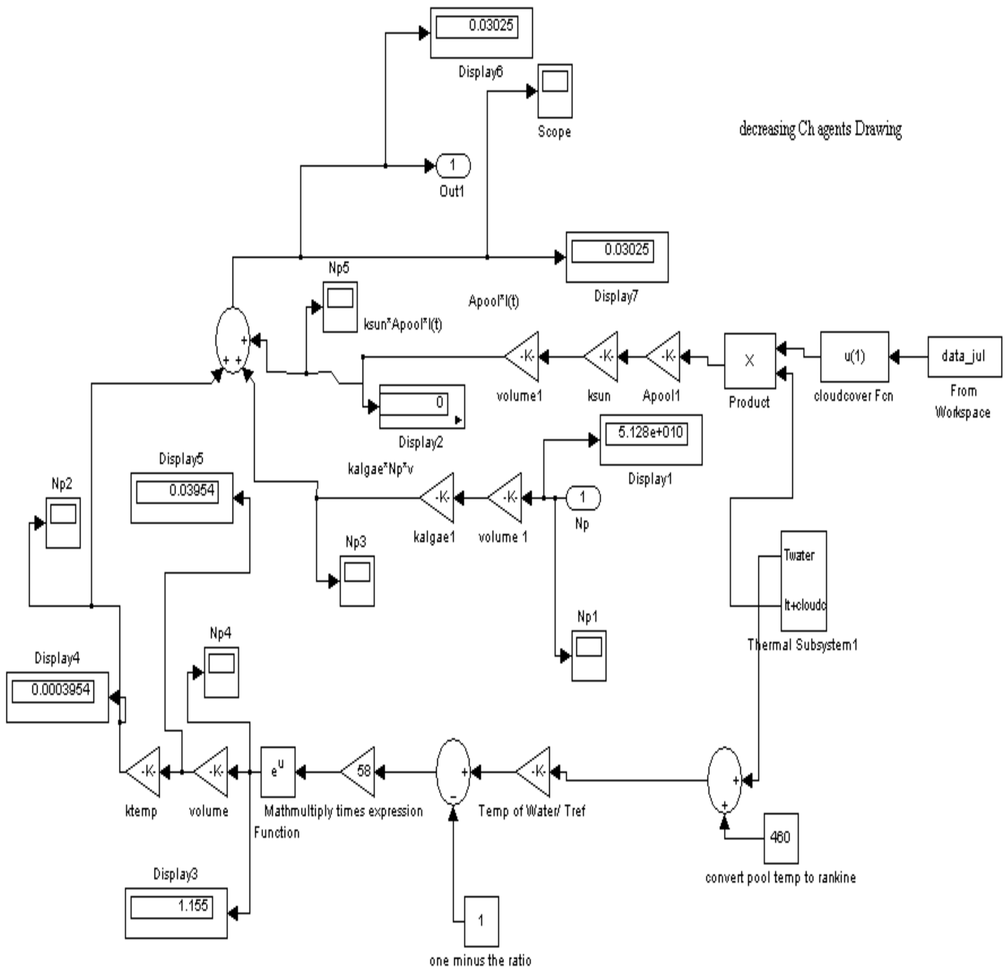


Figure 3.7 Submodel capturing factors that decrease pool chemicals that hinder algae growth.

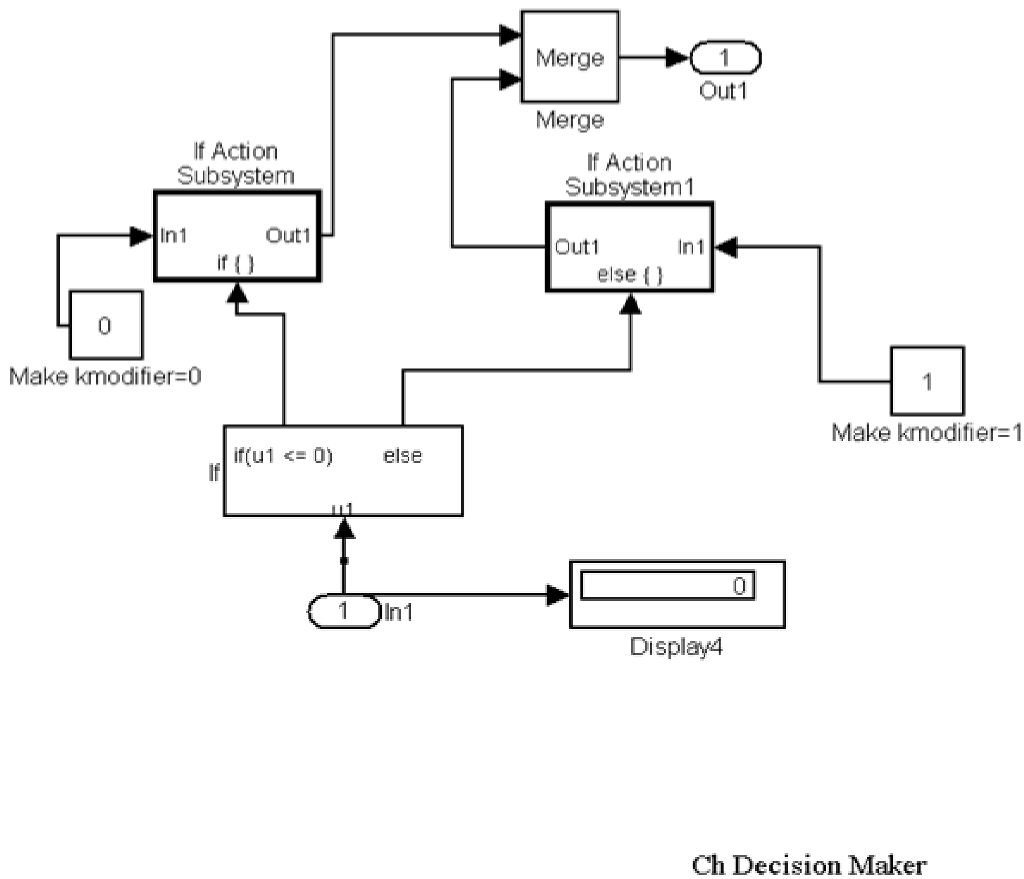
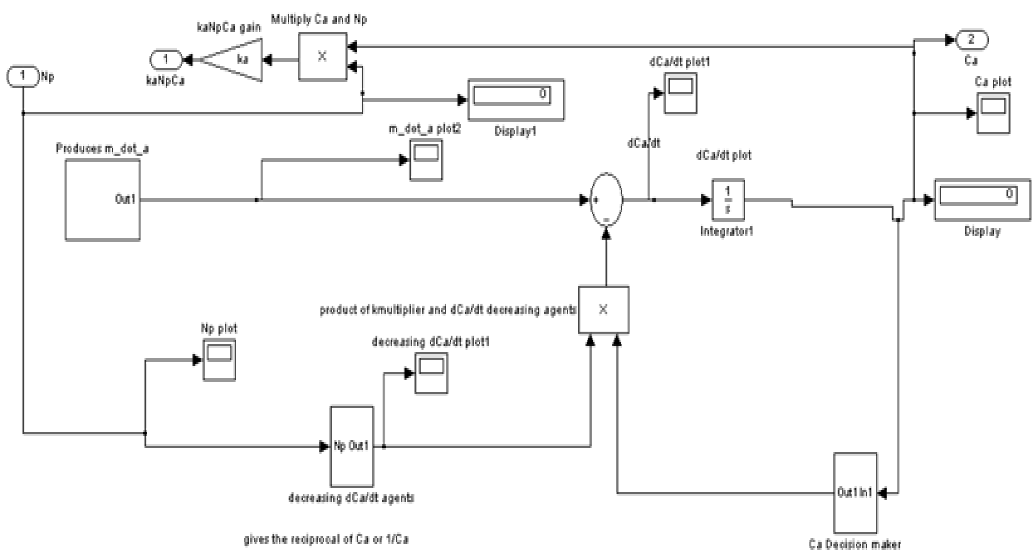


Figure 3.8 Submodel for keeping concentration chemicals above zero.

Figures 3.8 and 3.12 keep C_h and C_a from going below zero. These logical sub-blocks are essential because there is no such thing as a negative concentration of chemicals or nutrients. Figure 3.8 reads the value of C_h via In1 and if it is less than 0 then it force it to zero. C_h values greater than zero are forced to 1. These output values(Out1) are multiplied with the output results of the decreasing C_h agents in Figure 3.4. This is called *kmodifier*. *kmodifier* works in conjunction with the decision block of Figure 3.8.to help $\frac{dC_h}{dt}$ or chemical concentration stay at the right level with change in time. Shifting attention to Figure 3.12, the diagram mirrors the overall behavior of Figure 3.8. The main difference is that Figure 3.12 shows the aid or nutrients for algae within the pool. It takes $\frac{dC_a}{dt}$ or nutrient concentration and integrates it to C_a



kaCaNp Drawing

Figure 3.9 Submodel that makes algae cells increase.

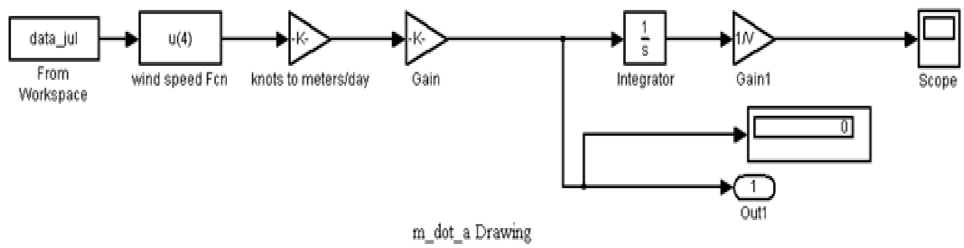


Figure 3.10 Submodel that impacts the influx of nutrients blown by the wind.

Figures 3.9, 3.10, and 3.11 show the various functions that work together to model algae growth. In Figure 3.10, nutrients come at the rate proportional to Vwind,and these values are fed into the submodel shown in Figure 3.9. The nutrients are consumed by the algae, a relationship which is shown in Figure 3.11.

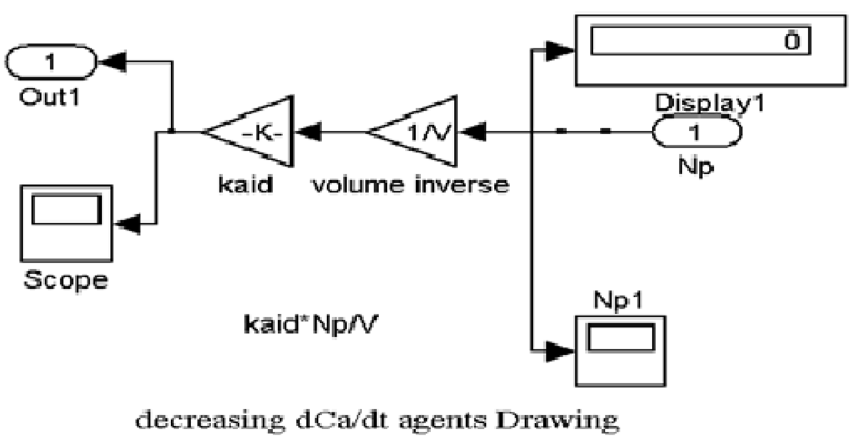


Figure 3.11 Submodel that captures factors that decrease nutrients.

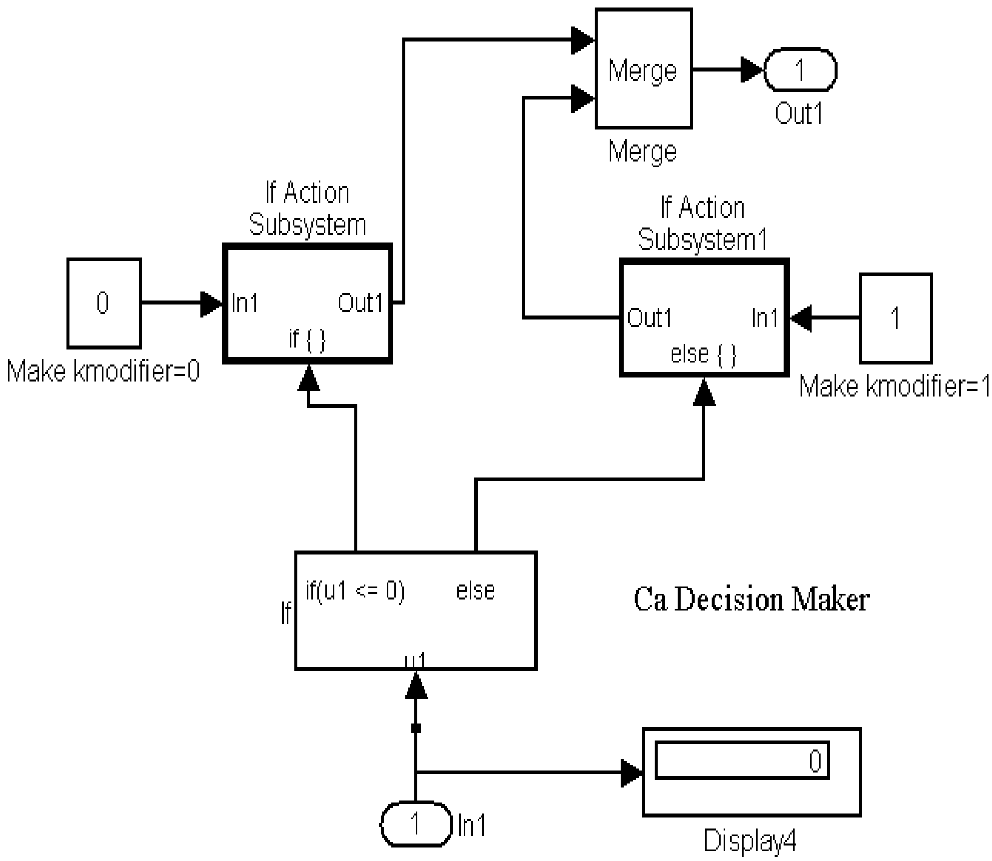


Figure 3.12 Logic blocks to nutrient level above zero.

The next chapter presents the simulation results.

CHAPTER 4

SIMULATION RESULTS

The chapter presents simulation results for a hypothetic pool with the following properties:

1.Fixed:

Surface area: 15.94 square meters

Volume: 29.2 cubic meters

Location: Phoenix, Arizona.

Weather data: July 1990

Pump size: 1 ½ HP (flow= 40gpm).

Pump on: 4 times/day

Chlorine addition: 2 tablets that last 2 days

Simulation time: 7days

2.Variables:

Size of Chlorine tablets

On time for the pump

The Chlorine concentration, C_h increases until it reaches its maximum in two days then it starts to decrease as the simulation progresses. N_p and n_p both reach their lowest point around the fourth day. C_a is ever increasing because the win is blowing nutrients in. Since the pool pump only comes on four times a day, for thirty minute intervals, C_a has a chance to increase in the pool. Shown below are three simulation results corresponding to three pump on-time intervals. Of all the simulations, the one that has the greatest impact on the pool is shown in Figure 4.3. Since the pump being on so long, it makes the algae concentration stay low over a considerable amount of time.

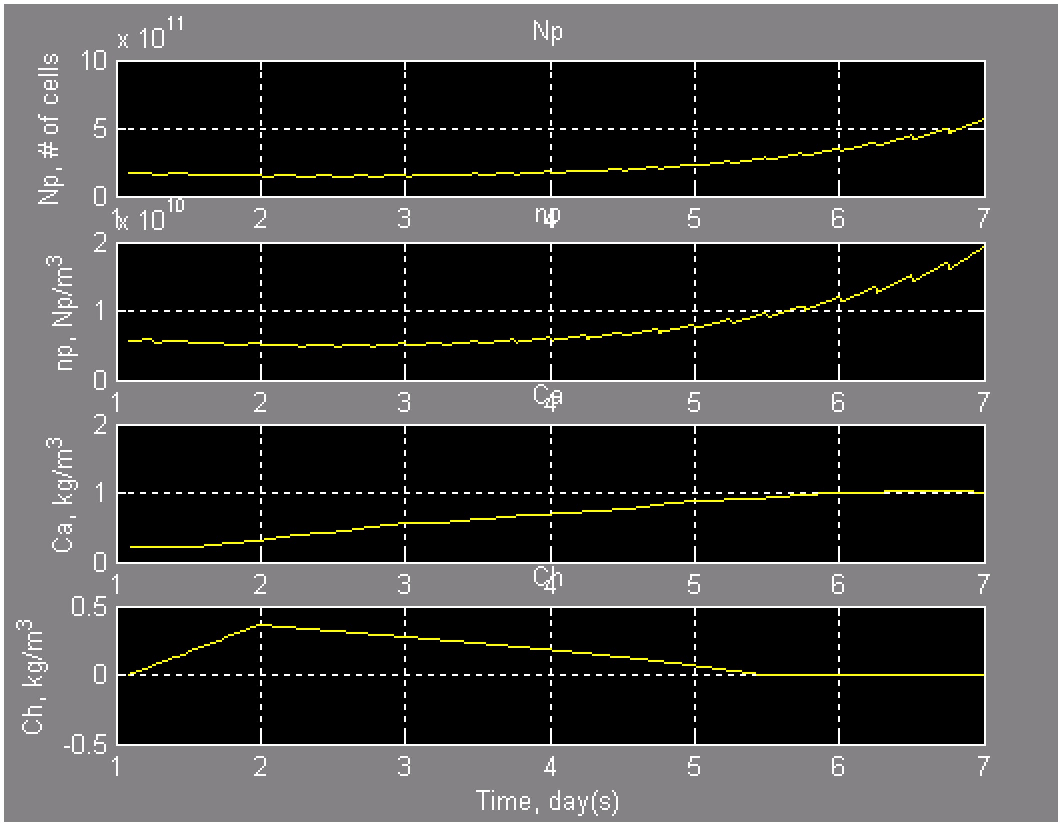


Figure 4.1. Simulation results: 2 tablets, 15 minute pump on time, 4 times a day.

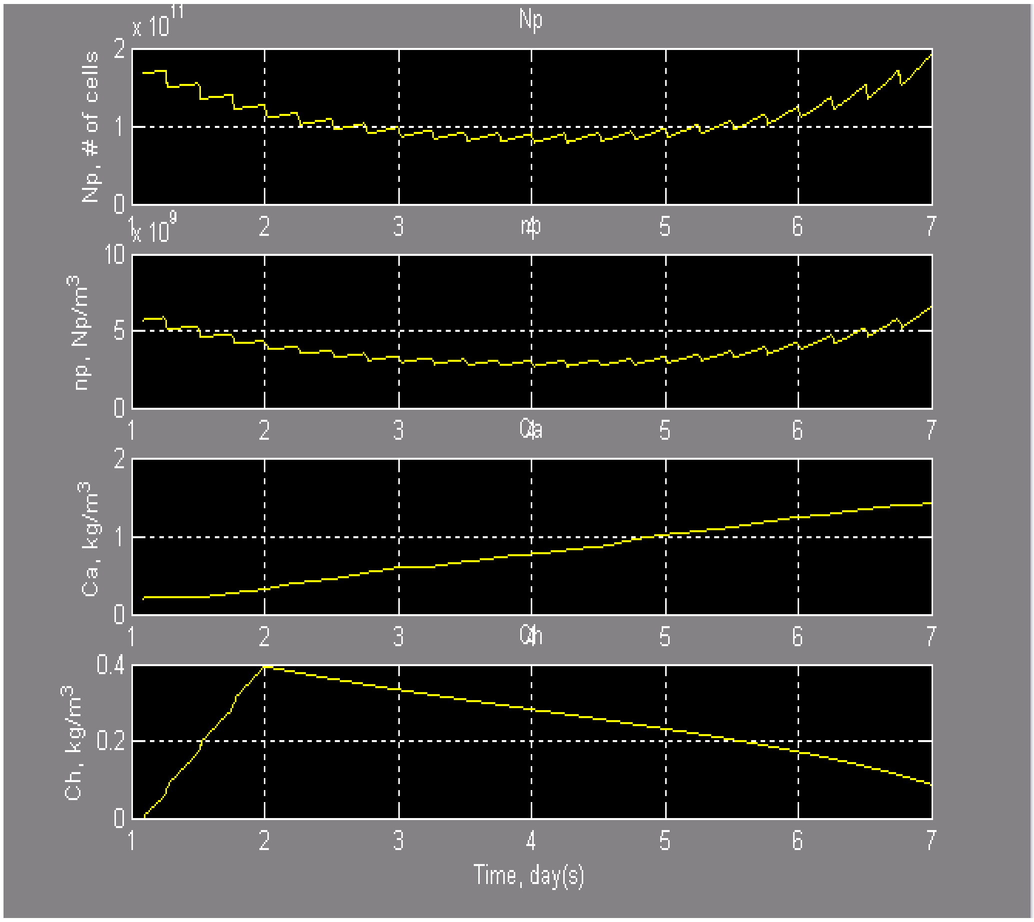


Figure 4.2 Simulation Results: 2 tablets, 30 minute pump on time, 4 times a day.

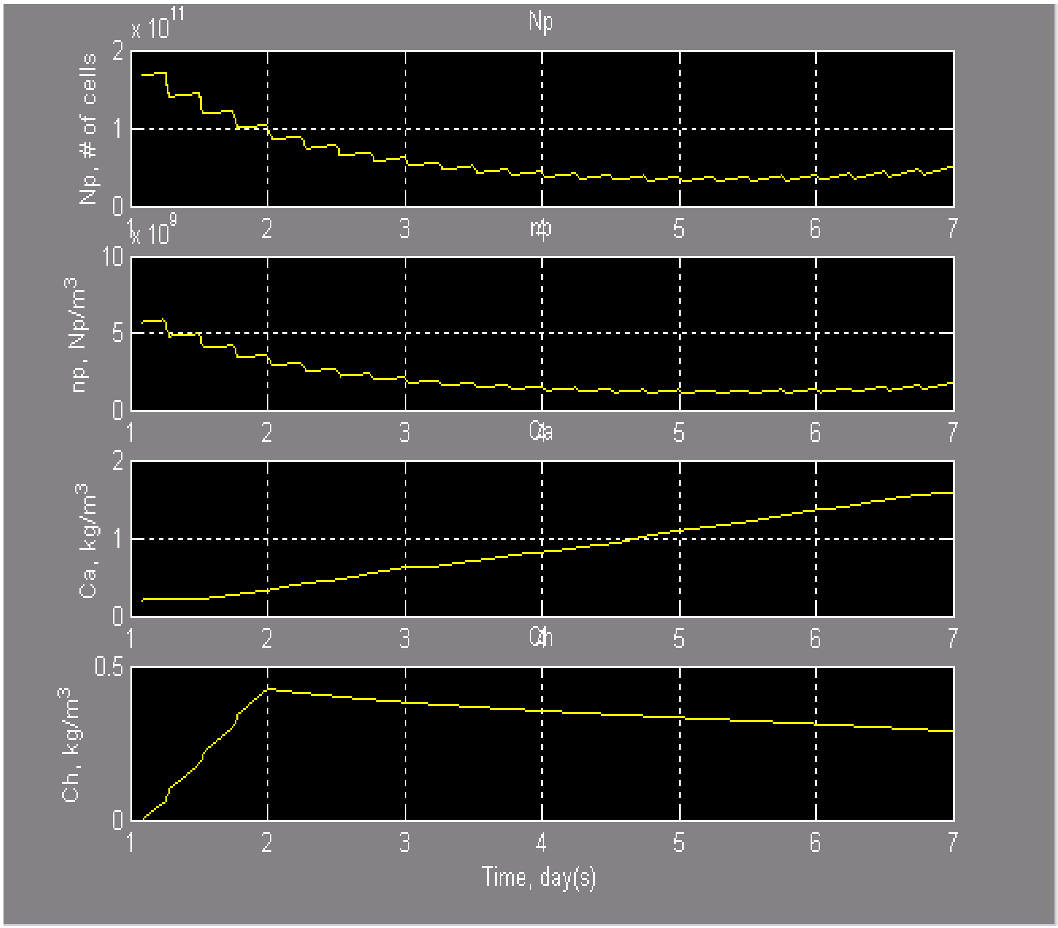


Figure 4.3 Simulation Results: 2 tablets, 45 minute pump on time, 4 times a day.

Table 4.1 shows an overall comparison of the monthly cost of pump usage based on hours per day. The traditional way to operate a pool is to run the pump one hour for every ten degrees of outside temperature (in ^{0}F). The following assumptions were made in calculating the figures in the table: electrical energy cost is \$0.12 /KWh, pump size 1.5HP, maximum daily temperature for the month of July, 110 degrees Fahrenheit. If the pump is run in traditional way based on daily temperature, the monthly cost would be approximately \$45. On the other hand, running the pump non-traditionally four times a day, at 45 minute duration intervals, would cost the customer \$12 for the entire month. This gives the customer a net savings of $33. The $45 is considered as a reference value that is subtracted from to get the savings. Table 4.2 shows the impact of pump usage on eliminating algae cells. As expected, algae cell count was decreased the most when the pump was operated four times per day with the 45 minute time interval.

Table 4.1

Pump costs1

Pump Operation hr/day	Estimated Monthly for pump usage($)	Saving ($)
11	45	Reference
1	4	41
2	8	37
3	12	33

Table 4.2

Algae pool percentage. 1

Pump Operation Time (minutes)	% Cell Count
15	229
30	12
45	0

note: % cell count is computed using:

$$\frac{N_{p_f} - N_{p_o}}{N_{p_o}} * 100\%$$

N_{p_f} = final cell count at end of simulation

N_{p_o} = cell count at the beginning of simulation

CHAPTER 5

CONCLUSION and RECOMMENDATIONS

Conclusions

Algae have been an ongoing problem for swimming pool owners. Pool filtration systems are frequently over-utilized in hopes to stop future algae growth. This leads to time and financial losses for the pool's owner, since typical operational guidelines for keeping the algae under acceptable limits suggest over-use of the pool circulation equipment. This thesis begins to address this problem and provides the first step in the solution to this problem. It presents a general model that predicts algae population in a pool, based on an assumed weather profile, and application of chemicals that hinder algae growth.

Characteristics of Model

The model developed has been implanted in, Matlab/Simulink which predicts algae population in a swimming pool. The model also includes concentration of agents which aid and hinder algae growth. The model also incorporates components of a previously-developed thermal model that predict pool water temperature, depending on weather conditions. The weather variables included in the model include: wind speed, ambient temperature, relative humidity solar irradiation, and cloud cover. All of these variables are used to calculate pool water temperature. In addition, the pool's filtration system is modeled in terms of its ability to remove algae and the nutrients that aid its growth. The model also captures the effect of adding chemicals that stop growth of algae. The model is simulated for a period of seven days, under the assumption that such a period is representative of pool dynamics. The water quality and chemistry parameters associated with this model do not correspond to a specific pool. Instead, these model parameters have been chosen so that simulation results appear reasonable. Parameters for the thermal part of the model correspond to a typical pool.

Recommendations

The next step in the solution to this problem is to correlate the model developed to a specific pool. This process will require the adjustment of parameters in the model so that the model does indeed predict the behavior of the specific pool. This process is typically called parameter estimation. Once a model is available for a specific pool, the next step is to develop a control scheme, and implement proposed control action in hardware, most likely using a microcontroller. This microcontroller will turn the pool pump on, only as much as it is necessary to keep algae under control. Two possible control schemes are suggested. The first one utilizes multiple sensors, while the second one utilizes only one sensor.

Control Implementation #1

Figure 5.1 offers a possible implementation. This control implementation utilizes the behavior predicted by the model and compares it with actual conditions in the pool. It uses the differences between these two to adjust the pumps on time that was predicted by the model.

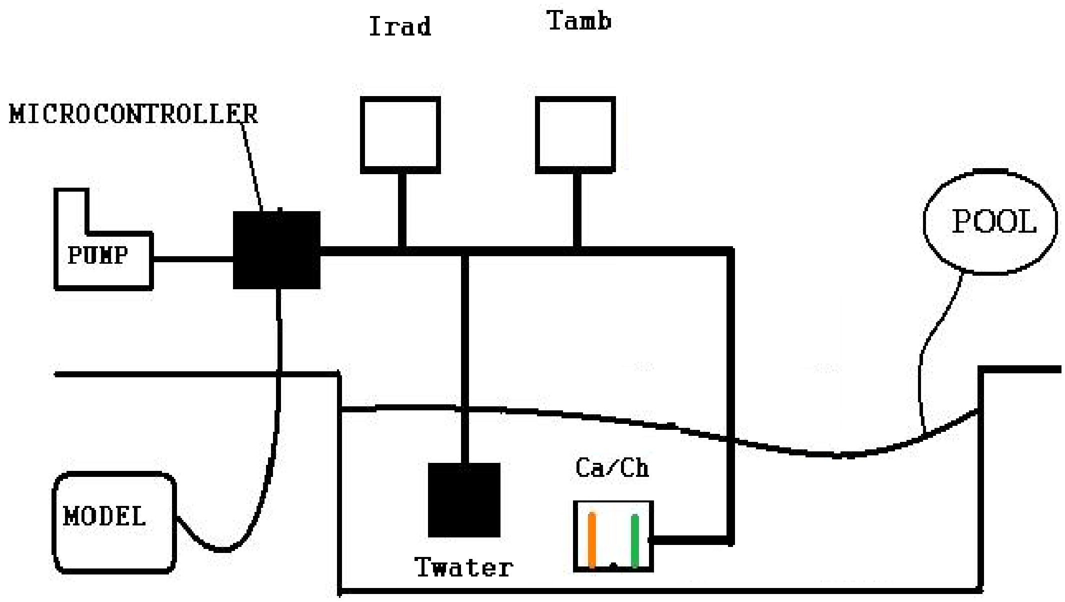


Figure 5.1 Control Implementation#1.

The system will incorporate sensors that measure the following variables: *Irad* represents the amount solar irradiation hitting the pool, *Tamb* is the air temperature, *Twater* is the temperature of the water in the pool, C_a/C_h are indicative of the concentrations of chemicals that aid and hinder algae growth (i.e. nutrients and chemicals such as chlorine). For these last sensors, the type electrode used in them will depend on the type of chemicals or nutrients that need to be measured. Finally, the pump will run based on the command given by the microcontroller. Since the pump is operating much less than the conservative guidelines used in the pool industry, the system will save energy, and also save electricity costs for the pool owner. This saving is realized by operating the pump being operational only to keep the algae at acceptable levels.

Control Implementation #2

This control implantation is a simplified version of the first one. It is shown in Figure 5.2.

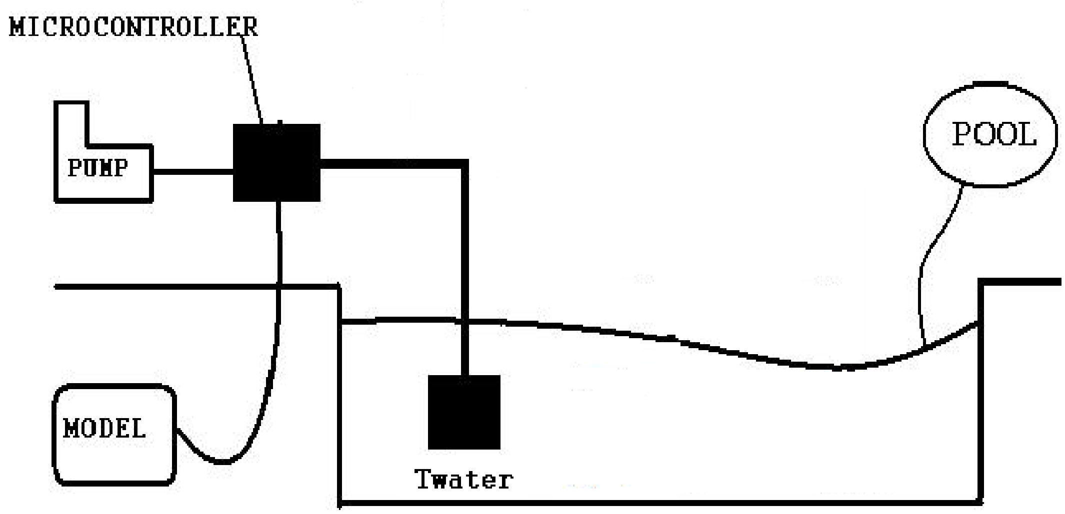


Figure 5.2: Control Implementation #2.

It only uses water temperature (T_{water}). Water temperature is particularly a key variable, since it reflects the combined effect of many other environmental variables (solar irradiation, relative humidity, ambient temperature). In this implementation, the actual water temperature of the water is compared with the values used in the internal model. If the actual water temperature is higher than what was assumed in the internal model, the on-time that the pump is on is increased. This process is shown in Figure 5.3.

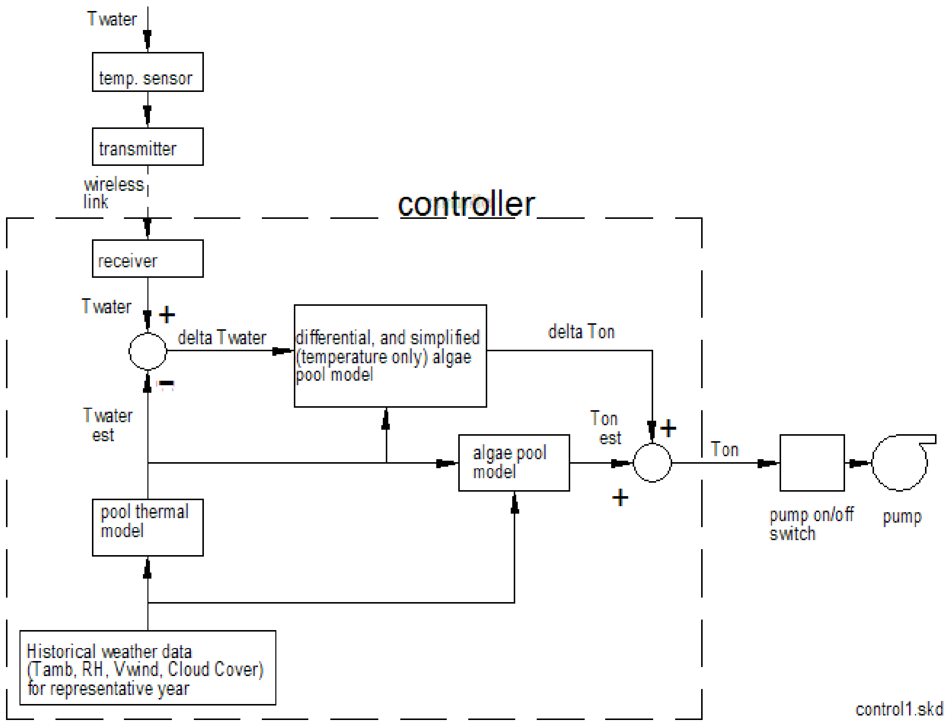


Figure 5.3: Diagram for Control Implementation #2.

Investigating degradation of pool chemicals due to sunlight

An aspect that is extremely relevant to pool dynamics is the degradation of pool chemicals due to sunlight. Notice that the differential equation:

$$\frac{dCh}{dt} = \frac{m_{dot\_h}}{V} - k_{sun} A_{pool} I_t - k_{hinder} N_p - k_{temp} decay(T_{water})$$

has two environmental factors that reduce C_h : solar irradiation (I_t) and pool water temperature factor $decay(T_{water})$. An important task that should be carried out on the next phase of this project is to determine the relative weights of these two factors. Results of such study might have an impact on the time of day when the pump is operated. It might also reveal that it is advantageous to dispense chlorine only after the sun goes down.

Possible sources for low-cost sensors

A key concept for making the proposed systems cost effective is to use hobby-type components, rather than laboratory-type sensors. The website http://www.scitoyscatalog.com/ sells parts that can be utilized in the set up. The following website shows how to build the electrochemical sensors: http://sci-toys.com/scitoys/scitoys/echem/batteries/batteries.html

Specific Types of Algae

The model that has been developed is a general model; it does not address a specific type of algae. The University of Texas at Austin has a biology department that is known for its expertise in algae. They have extensive information on the different strands of algae (which are also available for purchase). They also have information regarding the methods used to detect their presence along with which nutrients needed to grow them. In other words, the availability of the nutrient is also an indication that particular algae is likely to occur. There were three compounds that stood out: KCL, $NaNO_{3,}$ and $Na_2EDTA*2H_2O$. It would be beneficial to further investigate the type algae found in Arizona pools and their characteristics.

REFERENCES

1.Biogas and Alcohol Fuels Production: Proceedings of a Seminar on Biomas Energy for City, Farm, and Industry. Emmaus, PA: JG, 1980. Print.

2."Black Algae." Aquatic Community. Aquaticcommunity.com, 2004. Web. 19 Aug. 2009. <www.aquaticcommunity.com/algae-control/black.php>.

3.Bold, Harold Charles, and Michael James Wynne. Introduction to the Algae: Structure and Reproduction. Englewood Cliffs, NJ: Prentice-Hall, 1978. Print.

4.Boudreau, Diana. Fuels of Green Fall/Winter 2007. Publication. Tempe: ASU Research, 2007. Print.

5.Canham, D. Charles., Jonathan J. Cole, and William K. Lauenroth. Models in Ecosystem Science. Princeton [etc.: Princeton UP, 2003. Print.

6."Chemical Batch Processing." The Classic Edition Of: Tut's Blocks [Palo Alto] June 1991, Issue 0691 ed.: n. pag. Print.

7.Collins, Frank S. The Green Algae of North America,. Lehre: J. Cramer, 1970. Print.

8.Company, Clorox. Material Safety Data Sheet. Oakland: Clorox, 2009. Print.

9.Dempster, Thomas. "Questions about Algae." Personal interview. 09 Feb. 2011.

10."Ecoklear - The Ultimate in Pool Water Conservation." Ecoklear - The Ultimate in Pool Water Conservation. Aqua Labz, 2008. Web. Oct. 2008. <http://www.aqualabz.com/>.

11.Goodman, Louis J., and Ralph N. Love. Biomass Energy Projects: Planning and Management. New York [etc.: Pergamon, 1981. Print.

12.Graham, Linda E., and Lee Warren. Wilcox. Algae. Upper Saddle River, NJ: Prentice Hall, 2000. Print.

13.Green, Jenny. "Questions to an A.S.U. Chemistry Professor about Molarity." Telephone interview. 30 Apr. 2012.

14.HASA 12.5% SODIUM HYPOCHLORITE SOLUTION Material Safety Data Sheet. Saugus: HASA, 2011. Print.

15."Home - The Association of Pool and Spa Professionals." Home - The Association of Pool and Spa Professionals. APSP, 2012. Web. Feb. 2009. <http://www.apsp.org/>.

16.Hu, Qiang. "Questions about Algae." Personal interview. Apr. 2009.

17."Instructions." 33rd International Chemistry. International Chemistry Olympiad, n.d. Web. <olmpiads.ijs.si/icho/database/olimpiads/Icho/icho33/Theory/Inst.pdf>.

18.Jennifer. "Questions about the Units of the Formulas in the Mediums on the Algae Culture of UTEX Website." Telephone interview. 25 Apr. 2012.

19.Katz, Larry. "Glossary of Swimming Pool Terms A-B - Pool Wizard." Glossary of Swimming Pool Terms A-B - Pool Wizard. Larry Katz, 2011. Web. Mar. 2009. <http://www.havuz.org/glossary/pool-a-b.htm>.

20.Krauss, Robert W. "The Effects of Light Intensity on the Growth Rates of Green Algae." The Effects of Light Intensity on the Growth Rates of Green Algae. Department Of Botany, University Of Maryland, 1958. Web. Oct. 2008. <http://www.plantphysiol.org/cgi/reprint/33/2/109>.

21.Lawler, Chris. "Questions to a Geology Major on Where to Find Minerals." Personal interview. 16 Jan. 2012.

22."Light Spectrum." Wikipedia. Wikimedia Foundation, 30 Oct. 2012. Web. 30 Oct. 2012. <http://en.wikipedia.org/wiki/Light_spectrum>.

23.Macia, N. "Questions About My Thesis." Telephone interview. May 2009.

24.Macia, N. "Questions About My Thesis." Telephone interview. Sept. 2008.

25.Macia, Narciso F., and George J. Thaler. Modeling and Control of Dynamic Systems. Clifton Park, NY: Thomson Delmar Learning, 2005. Print.

26.Messe, Jean Y. Psychro Program (Swimming Pool). ThermExcel, 2004. Web. Sept.-Oct. 2010. <www.thermexcel.com/english/program/pool.htm>.

27.Middlebrooks, E. Joe., Donna H. Falkenborg, and Thomas E. Maloney. Biostimulation and Nutrient Assessment. Ann Arbor, MI: Ann Arbor Science, 1976. Print.

28.Miller, G. Tyler. Chemistry: A Basic Introduction. Belmont, CA: Wadsworth Pub., 1987. Print.

29."MISCELLANEOUS FRESH WATER MICROALGE IDENTIFICATION FREMONT AREA." MICROALGE. MATH/SCIENCE NUCLEUS/RAY WONG, n.d. Web. 19 Aug. 2009. <http://www.msnucleus.org/watersheds/biological/microalgaegen.html>.

30.Narveson, Brentt. "Algae in the Swimming Pool Q/A 2010 to 2012." Personal interview. 2010.

31.Nirmalakhandan, N. Modeling Tools for Environmental Engineers and Scientists. Boca Raton, FL: CRC, 2002. Print.

32.Nustad, Harry L. Algebra for College Students. 3rd ed. Dubuque: Wm. C. Brown, 1993. Print.

33.Oswald, William J. The Influence of Physical Environment upon the Over-all Efficiency of Light Energy Conversion by Chlorella in the Process of Photosynthetic Oxygenation. Berkeley: Sanitary Engineering Research Laboratory, 1952. Print.

34.Pena, Stephen. "Question about the Algae Culture at the UTEX." Telephone interview. 20 Sept. 2010.

35."Pink Pool Slime, Cause, Prevention, Treatment, Par Pool & Spa." Pink Pool Slime, Cause, Prevention, Treatment, Par Pool & Spa. Par Pool & Spa, 2000. Web. 19 Aug. 2009. <http://www.parpools.com/Page/Help/Pool/Pink_Slime.html>.

36."Pool & Spa." Myron L. Company. Myron L. Company, 28 May 2012. Web. 20 July 2010. <http://www.myronl.com/applications/Pool_%26_Spa.htm>.

37."Production and Use of Potassium Chloride." Production and Use of Potassium Chloride. N.p., n.d. Web. 27 Sept. 2011. <http://www.ipipotash.org/udocs/Chap-1_potash_production.pdf>.

38.Pump Technician, Jandy. "Asks Questions of the Efficiency Jandy Pool Pumps." Telephone interview. 2011.

39.Haro, Ramon. "General Pool Upkeep Questions from Property Caretaker of LaEstancia Apartments." Personal interview. Jan. 2011.

40.Schuster, Alan. "Black Pool Algae Problems." Resistant Black Swimming Pool Algae. Aqualab Systems, 2002. Web. 19 Aug. 2009. <http://www.askalanaquestion.com/black_pool_algae.htm>.

41.Sears, Francis Weston, Mark Waldo Zemansky, and Hugh D. Young. College Physics. Reading, MA: Addison-Wesley Pub., 1985. Print.

42.Smith, Gilbert Morgan. The Fresh-water Algae of the United States. New York: McGraw-Hill, 1950. Print.

43.Sodium Hypochlorite General Information for the Consumer. Odyssey Manufacturing Co., 06 Apr. 2012. Web. 17 Mar. 2012. <www.odysseymanfacturing.com/bleach_information..doc>.

44.The Student Edition of MATLAB: The Ultimate Computing Environment for Technical Education : User's Guide. Englewood Cliffs, NJ: Prentice Hall, 1995. Print.

45.Subramanian, Dipika. "Questions to a Manufacturing Engineering Technology Graduate Student on How to Physically Test for Algae." Personal interview. 31 Jan. 2011.

46.Tennessen, Daniel J., Raymond J. Bula, and Thomas D. Sharkey. "Efficiency of Photosynthesis in Continuous and Pulsed Light Emitting Diode Irradiation." Kluwer Academic Publishers, 23 Sept. 1994. Web. 11 Feb. 2010. <https://mywebspace.wisc.edu/tsharkey/web/My_papers/Tennessen%20Bula%20and%20Sharkey%20Pulsed%20light%201995.pdf>.

47.Trainor, Francis R., and Gwen M. Wilmes. "Using Commercial Fertilizers as Algal Media." JSTOR:The American Biology Teacher Vol. 56, No. 6, Sep., 1994. JSTOR, 2000-2012. Web. 2011. <http://www.jstor.org/discover/10.2307/4449852?uid=3739552&uid=2&uid=4&uid=3739256&sid=21101248734753>.

48.UTEX The Culture Collection of Algae at The University of Texas at Austin. The University of Texas at Austin, n.d. Web. <web.biosci.utexas.edu/utex/media.aspx>.

49.Venkataraman, G. S. Algae: Form and Function. New Delhi: Today & Tomorrow's Printers &, 1974. Print.

50 Vermaas, William V. "Given Info about a Report on Algae by Dr. Sheeha of Department of Energy." Telephone interview. 24 July 2009.

51."Visible Spectrum." Wikipedia. Wikimedia Foundation, 11 May 2012. Web. 05 Nov. 2012. <http://en.wikipedia.org/wiki/Visible_spectrum>.

52.Williams, Peter J. LeB., David N. Thomas, and Colin S. Reynolds. Phytoplankton Productivity: Carbon Assimilation in Marine and Freshwater Ecosystems. Oxford: Blackwell Science, 2002. Print.

53 Xiong, Ladislav Nedbal, Vladimír Tichý, Fusheng, and Johan U. Grobbelaar. "Microscopic Green Algae and Cyanobacteria in High-frequency Intermittent Light." SpringerLink. Springer Science Business Media, 28 Aug. 1996. Web. 11 Feb. 2010. <http://www.springerlink.com/content/h171w516607p8723/>.

APPENDIX

A ALGAE SCRIPT CODE

```
%Script file for algae Matlab files
%Calculate the amount of chemical per day being used...
%qho=.0714; %m^3/day
pumpfactor_on=2.8;
pumpfactor_off=1;
%Ch=.03;
%main block
% filter ratio of the input vs output
filter_ratio=.1;
% flowrate into the pool "qi" and "qo" for out of the pool
% qi=qo
 qi=.0025*60*60*24; % units m3/day
 qo=.0025*60*60*24; % units m3/day
% volume of the pool"V" with units in m^3
V=29.2; %m^3
% Np equals the number cells in the pool
% np equals the number cells/volume
liquidounceNp=10e6;%when it becomes visible per liquid ounce (US)
Np= (1/.00003)*liquidounceNp; %when it becomes visible per cubic meter
Np0=.5*Np; % 1/2 half of when algae becomes visible
pumptimer=.031;%.0104 15mins, .021 30mins, .031 45mins represents when the
pump is on.
% pool size 7700 gal = 29.2 m^3,
% according to B&B pools a chemical called solid shock must be applied 1 lb per
% 10000 gallon, since our pool size is 7700 gal then .77 lb is needed
% .77 lb = .3493 kg
% let's assume that nutrients coming in is the quantity as chemicals coming
% in .77 lb = .3493 kg

%thermal block
%hinder block
%qh=.00002; %rate at which chemicals are dropped into the pool m^3/hr
Apool=15.94; % area of the swimming pool m^2
m_dot_h= ((.5*.99)/2.205)*2; % amount of chemicals being dropped in kg for 2
tablets
kalg_h=1.7e-11; % constant for the amount of algae being hindered kg/
(cells*day) 1.7e-11
%It=1413; %solar irradiation/intensity w/m^2
ksun=1e-9; %constant involving cloud cover 1e-8
ktemp=1e-2;% proportionality constant 1e-3
Tref=70+460% converts the pools Tref from 70 degrees F to degrees R
```

```
%Ch0=.3493/29.2;% the intial value of chemicals in kg/m^3 FOR THE
MOMENT ASSUME QUANITY EQUAL TO Ca (Nutrients)
%also the amount of chemicals to eliminate algae when it becomes visual
%Ch00=.5*Ch0% only half of the chemicals to remove have of the algae when it
becomes visible
%Aid block units kg/ (m^3*hr*watts)
%Ca0=.3493/29.2;% the intil value of nutrients in kg/m^3
kwind=1e-6; %constant involving Vwind units kg/m^3 value 1e-6

Apool=15.94; % area of the swimming pool units m^2
Vwind_multiplier=44448; %wind speed that blows in cells and nutrients into the
pool in knots from NOAA July data file in knots the
%multiplier converts it to m/day
kaid=1.7e-11; % constant for the amount algae consuming nutrients
kg/(cells*day) value 1e-11
init_ca=0.2
%total_ca= 45.09e3 %the nutrients in kilograms
%m_dot_a= m_dot_h;
%np0=.5*Np; % 1/2 half of when algae becomes visible
%main block
kp=1e-1;%m^3/(kg*day)value range 1-9
ka=7.5e-1;%m^3/(kg*day)value range 1-9
kh=1e-1;%m^3/(kg*day)value range 1-9
%Np_blown_in=3;
%This section controls pool pump operation with respect to temperatures
%reads in input data for June, July, August...
 %data_jun= wk1read ('phxjun90.wq1');
 data_jul= wk1read ('phxjul90.wq1');
 %data= xlsread ('phxjul90.xls');

global Wfactor
global L nu
global Twater Pwater_vapor
global k_evap
global rho
% pool parameters
L=26;
W=20;
Area= (L*W)*.0929; % now it is converted m^2 /% pool surface area, ft^2
Vol= (18000/7.48)*.02832; %now it is converted m^3/% pool volume, ft^3
(intially in gal)
Tground=60; %ground temperature, degF
Awet=970*.0929; %now converted to m^2/% pool wet area, ft^2
rho =(62.4/2.205)*(1/.02832) ; % desity of water , lbm/ft^3
```

```
Cp=1; % ratio of specific heat
nu=0.001;
Wfactor=0.5; % wind attenuation factor
k_evap=1.2; % evaporation coeffficent (in-floor=??)
% Ttp=50;
% Tbp=45;
Twater= [35 40 45 50 60 70 80 90 100 110 120];
Pwater_vapor= [.09992 .12166 .14748 .17803 .2563 .3632 .5073 .6988 .9503
1.2763 1.6945];
%time_array= data_jul(:,1);
time_array= data_jul(:,1);
% get first and last elements
t_initial=time_array (1);
t_final=time_array (length (time_array));
% establish sunrise-sunset
t_zenith= 12.75/24;       % when sun is at the highest
t_sr =   7/24   ;       % sun rise
t_ss =   18.5/24;       % sun set
%average daily insolation (Btu/hr/ft^2) % now converted to (kWh/hr/m2)
ave_daily_inso=2737*(1055/3600e6)*(1/.0929); % for Jul
%simulate the model (note: this executes it, but it does not open the file
sim ('the_total_algae_model_10_22_12_kmodifier.mdl')
% Set required parameters for the Simulink model
  set_param ('the_total_algae_model_10_22_12_kmodifier', 'SaveOutput', 'on');
  set_param ('the_total_algae_model_10_22_12_kmodifier', 'SaveFormat',
'StructureWithTime');
  simplot (CombinedPlots);
[hfig, haxes, hlines] = simplot (CombinedPlots); % Plot the data and obtain
handles to the axes
% Label the axes
set (get(haxes(1),'ylabel'), 'string', 'Np, # of cells');
set (get(haxes(2),'ylabel'), 'string', 'np, Np/m^3');
set (get(haxes(3),'ylabel'), 'string', 'Ca, kg/m^3');
set (get(haxes(4),'ylabel'), 'string', 'Ch, kg/m^3');
xlabel ('Time, day(s)');
```

APPENDIX

B MODEL VALUES TABLE

Model Variables Explained Rev. 07

Variable	Description	Custom Units	Conversion Multiplier To Model Units	Model Units	Descriptions of Units	Variable or Constant
Filter main block						
qo	outgoing flow	40 gal/min	5.45	280m3/day	V/T	Variable
qi	ingoing flow	40 gal/min	5.45	280m3/day	V/T	Variable
V	pool volume	7700 gal	3.78E-03	29.2 m3	V	Constant
Apool	pool area	171.57 ft2	0.093	15.94m2	L2	Constant
Np	number of cells in order to be visible in pool	9.856 E12	none	9.856 E12	# or cells	Variable
np(0)	np(0)=.5*np	640 million/gal	264	168960 million/m3	# or cells/V	Variable
np	number of cells per unit volume	1280 million/gal	264	337920 million/m3	cells/V	Constant
no	filter input	1280 million/gal	264	337920 million/m3	cells/V	Constant
ni	filter output	.1*no		.1*no	cells/V	Constant
f	filter efficiency	0.9		0.9	unit less	Constant
ka	constant involving the amount nutrients	gal/(lb*day)	0 to 9	m3/(kg*day)	V/(W*T)	Variable

	consumed					
Ca	amount of the nutrients to grow algae in the pool	lb/gal	119	kg/m3	W/V	Cons tant
Ch	amount of the chemicals to stop algae growth in the pool	lb/gal	119	kg/m3	W/V	Cons tant
kh	amount of chemicals consumed	gal/(lb* day)	0 to 9	m3/(kg*day)	V/(W *T)	Vari able
kp	amount of Vwind permitted to get into pool area	gal/(lb* day)	0 to 9	kg/(m3*day)	V/(W *T)	Vari able
Vwind	Velocity wind that blows in cells and nutrients in the pool. Data come NOAA file for July month in Knots	# knots	44448	(44448m/day)* knots values	L/T	Vari able
m_dot_ h	m_dot_h0(1+ pumpfactor) helps in calculating the total chemical in the pool over a given time period	lb/day	0.454	kg/day	W/T	Vari able
pumpon	pumpfactor	2.8	none	2.8	unit less	Cons tant
pumpof f	pumpfactor	1	none	1	unit less	Cons tant

Nutrients						
1/V	inverse of pool volume	1/7700 gal	264	1/29.2 m3	1/V	Constant
kwind	amount of the Vwind that is permitted to blow in cells or nutrients	lb/gal	1.00E-07	kg/m3	W/V	Constant
Apool	pool area	171.57 ft2	0.093	15.94m2	L2	Constant
Vwind	Velocity wind that blows in cells and nutrients in the pool. Data come NOAA file for July month in Knots	# knots	44448	(44448m/day)* knots values	L/T	Variable
kaid	amount of nutrients consumed per hour by algae	lb/(cells*day)	1e-5 to 1e-11	kg/(cells*day)	W/(cells*day)	Variable
Np	number of cells	9.856 E12	none	9.856 E12	# or cells	Variable
Ca	amount of the nutrients to grow algae in the pool	lb/gal	119	kg/m3	W/V	Constant
m_dot_a	m_dot_a0(1+pumpfactor) helps in calculating the total nutrients in the pool over a given time period	lb/day	0.454	kg/day	W/T	Variable
Chemic						

als						
1/V	inverse of pool volume	1/7700 gal	264	1/29.2 m3	1/V	Constant
qh	rate chemicals are placed in the pool	gal/day	3.80E-03	m3/day	V/T	Variable
ph	amount of chemicals per unit volume	lb/gal	119	kg/m3	W/V	Constant
ksun	amount of solar irradiation permitted to get through via cloud cover	lb/(day*hp)	1.00E-04	kg/(day*watts)	W/(T*P)	Variable
Apool	pool area	171.57 ft2	0.093	15.94m2	L2	Constant
It	solar irradiations	hp/ft2		1413 watts/m2	P/L2	Variable
kalg_h	amount chemicals being consumed	lb/(cells*day)	1e-6 to 1e-11	kg/(cells*day)	W/(cells*day)	Variable
Np	number of cells	9.856 E12	none	9.856 E12	# or cells	Variable
Ch	amount of the chemicals to stop algae growth in the pool	lb/gal	119	kg/m3	W/V	Constant
ktemp	proportionality constant	lb/(day*F)	4.54E+01	kg/(day*F)	W/(T*Temp)	Variable
decay	affects the amount of chlorine		none			Variable

note: explanation of the descriptive units:
V= volume, T= time, L=length, cells= amount of algae, W= weight or mass, P= power, Temp= Temperature in degrees Fahrenheit

APPENDIX

C MATH EQUATIONS AND EXPLANATION

Model Equations

Primary model

$$\frac{dN_p}{dt} = -q_o n_o + q_i n_i + k_a C_a N_p - k_h C_h N_p - k_p A_{pool} V_{wind}$$

Pool pump characteristics

Flowrate conversion factor

$$40\frac{gal}{\min} = 40\frac{gal}{\min} * \frac{60\min}{1hr} * \frac{24hr}{1day} * \frac{m^3}{264gal} = 218\frac{m^3}{day}$$

Initial Parameter Values

$$n_p = \frac{N_p}{V}$$

$$\frac{n_i}{n_o} = 1 - 0.9 = .1$$

$$\lambda = 1 - \frac{n_i}{n_o} = 0.9$$

$$n_p(0) = .5 * n_{visible}$$

$$q_o = 40\frac{gal}{\min} = 218\frac{m^3}{day}$$

$$q_i = 40\frac{gal}{\min} = 218\frac{m^3}{day}$$

$$V = 7700gal = 29.2m^3$$

$$Apool = 171.57\,ft^2 = 15.94m^2$$

$$np(0) = 640*10^6\frac{cells}{gal} = 168960*10^6\frac{cells}{m^3}$$

$$n_o = 1280*10^6\frac{cells}{gal} = 337920*10^6\frac{cells}{m^3}$$

$$n_i = 0.1*n_o$$

$$f = filter\ efficiency = 0.9$$

Ca Subsystem

$$\frac{dC_a}{dt} = k_{wind} A_{pool} V_{wind} - k_{aid} N_p$$

$$[k_{wind}] = \frac{lb}{gal} or \frac{kg}{m^3}$$

Nutrients that are consumed by algae

$$[k_{aid}] = \frac{lb}{(cells * day)} or \frac{kg}{(cells * day)}$$

Factor that brings balance to kaCaNp

$$[k_a] = \frac{gal}{(lb * day)} or \frac{m^3}{(kg * day)}$$

Units of Ca

$$[\ C_a] = \frac{lb}{gal} or \frac{kg}{m^3}$$

Units of the term corresponding to nutrients being blown

$$[m_{dot\_a}] = \frac{lb}{day} or \frac{kg}{day}$$

Ch Subsystem

$$\frac{dCh}{dt} = \frac{m_{dot\_h}}{V} - k_{sun} A_{pool} I_t - k_{a\lg ae\_h} N_p - k_{temp} decay(T_{water})$$

Units of the derivative of Ch

$$\left[\frac{dC_h}{dt}\right] = \frac{kgm}{m^3 * day} = \frac{m_{dot\_h}}{V}$$

Ch units

$$\frac{kgm}{m^3 * day} = \frac{\frac{kgm}{day}}{m^3}$$

$$C_h = \frac{kgm}{m^3} \, or \, \frac{lbm}{gal}$$

Factor that controls how fast chemicals are dispersed in the pool as the water circulates

$$PUMPOFF \Rightarrow PUMPFACTOR = 1$$
$$PUMPON \Rightarrow PUMPFACTOR = 2.8$$
$$m_{dot\_h} = m_{dot\_h_0}(1 + PUMPFACTOR)$$
$$[m_{dot\_h}] = \frac{kgm}{day}$$

Decreases Ch

Factor that brings balance to the solar irradiation

$$[k_{sun}] = \frac{lb}{(day * hp)} \, or \, \frac{kg}{(days * watts)}$$

Solar Irradiation

$$[I_t] = \frac{hp}{ft^2} \, or \, \frac{watts}{m^2}$$

Consumption of the algae by the chemicals

$$[k_{hinder}] = \frac{lb}{(cells * day)} \, or \, \frac{kg}{(cells * day)}$$

Consumption of the temperature water

$$[k_{temp}] = \frac{lb}{(day *^{\circ} F)} \, or \, \frac{kg}{(day *^{\circ} F)}$$

Effect of pool water temperature on chemicals

$$decay(T_{water}) = e^{58\left[\frac{T_{water}+460}{T_{ref}} - 1\right]}$$

Keeps the khChNp in Balance

$$[k_h] = \frac{gal}{(lb * day)} \, or \, \frac{m^3}{(kg * day)}$$

Formula for calculating the monthly pump usage cost

$$monthly\ cost\ to\ run\ pump = \frac{hr}{day} * \frac{days}{month} * Hp * \frac{.74kW}{Hp} * \frac{\$}{kwhr}$$

Vwind Subsystem

Proportionality value keeps Vwind subsystem balanced

$$[k_p] = \frac{gal}{(lb*day)}\ or\ \frac{m^3}{(kg*day)}$$

Conversion of Wind data from knots to meters/day

NOAA wind data July in Knots $1\,knots = 44448\frac{meters}{day}$

Compound and pH levels concentration that both types of algae have in common

$NaNO_3 \quad (2.94mM, 880\mu M)$ green algae, $(.24mM)$ yellow algae
$Na_2EDTA*2H_2O \quad (2mM, 11.7\mu M)$ green algae, $(.012mM)$ yellow algae
$KCL \quad (.67mM)$ green algae, $(.13mM)$ yellow algae
yellow algae $pH = 6.7$
green algae $pH = 6.8, 6.2, 8.0, 7.0$

.