

CHAPTER 7 - USING PHATR FOR DESIGN AND MANAGEMENT APPLICATIONS

7.1 Introduction

PHATR, a computer model which solves 3.4, the differential equation describing the energy balance for a small (volume = 400 m³) well-mixed aquaculture pond (see Chapter 4), was specifically designed to determine the pond temperature for the “warm water ponds” at the Louisiana State University (LSU) Aquaculture Research Station (ARS). It was also meant to be used as a design tool for engineers or as a management tool for aquaculturists for the warm water ponds. Because the model still needs to be validated for larger ponds or ponds in different climates, PHATR should not be used by engineers or aquaculturists for the following types of ponds:

- ponds located in a climate different from that experienced in Louisiana
- ponds which are poorly mixed
- ponds which are much larger than 400 m³
- ponds where there is little recorded information about the weather.

However, for the warm water ponds at the Louisiana State University Aquaculture Research Station (LSU ARS), PHATR has been validated and was used to answer these design and management questions:

- 1) What is the pond temperature throughout a year?
- 2) What is the energy surplus or deficit when keeping the pond temperature constant?
- 3) By how much does the temperature decrease in one night if there is suddenly no way to keep the pond warm?
- 4) What are the flow requirements for increasing the pond temperature by 2°C/day during a typical week in January?

7.2 Materials and Methods

PHATR Version 1.2 was used with these added features:

- The effects of rainfall were included as a bulk movement of energy into the pond (see Chapter 3.5.1 for theoretical explanations).
- For a given pond temperature (given in a ASCII file), PHATR could calculate the amount of cold and warm water needed to maintain the pond at that temperature. The user specified the temperature of the cold and warm water sources at the user prompt.

Weather data were compiled and generated to produce three weather input files, one for a cold year, one for an average year and one for a hot year. All the data used to create the weather files, with the exception of solar radiation, were supplied by the Southern Regional Climate Center at LSU.

The air temperature, relative humidity and wind speed data used in each file were compiled from weather data collected between 1952 and 1992 in Baton Rouge every hour, except between 1965 to 1972, where the data were collected every 3 hours. No wind speed data were collected prior to 1964. Using a FORTRAN program called “Weather_Generator(a)” (code in Appendix 13), the data were sorted to determine the following weather statistics:

- the maximum temperature of every hour of the year
- the minimum temperature of every hour of the year
- the average temperature of every hour of the year
- the average relative humidity of every hour of the year
- the average wind speed of every hour of the year

The normal rainfall data for every day of the year were converted into average hourly rainfall rates. For instance, if 24 cm of rain fell in a day, it was assumed that 1 cm of rain fell every hour during that day.

Because no solar radiation data for every hour of the year was available, the extra-terrestrial solar radiation was calculated depending on the pond’s geographic location, the time of day and the time of year (Appendix 14). A “cloud” factor was multiplied by the solar radiation data to simulate the absorption of solar radiation by the atmosphere. The cloud factor was equal to 0.85 for a hot year and 0.25 for a cold year. For the average year weather data file, the average percentage of total solar radiation for a particular month was used as the cloud factor. The average percentage of total solar radiation was available through the Southern Regional Climate Center web site (<http://www.srcc.lsu.edu/6190/ccd.html>).

The “average year” data set consisted of :

- the average temperature of every hour of the year
- the average relative humidity of every hour of the year
- the average wind speed of every hour of the year
- the solar radiation for the average year
- the normal rainfall

The “cold year” data set consisted of:

- the minimum temperature of every hour of the year
- the average relative humidity of every hour of the year
- a constant wind speed of 10 m/s
- the calculated solar radiation with a cloud factor of 0.25
- the normal rainfall

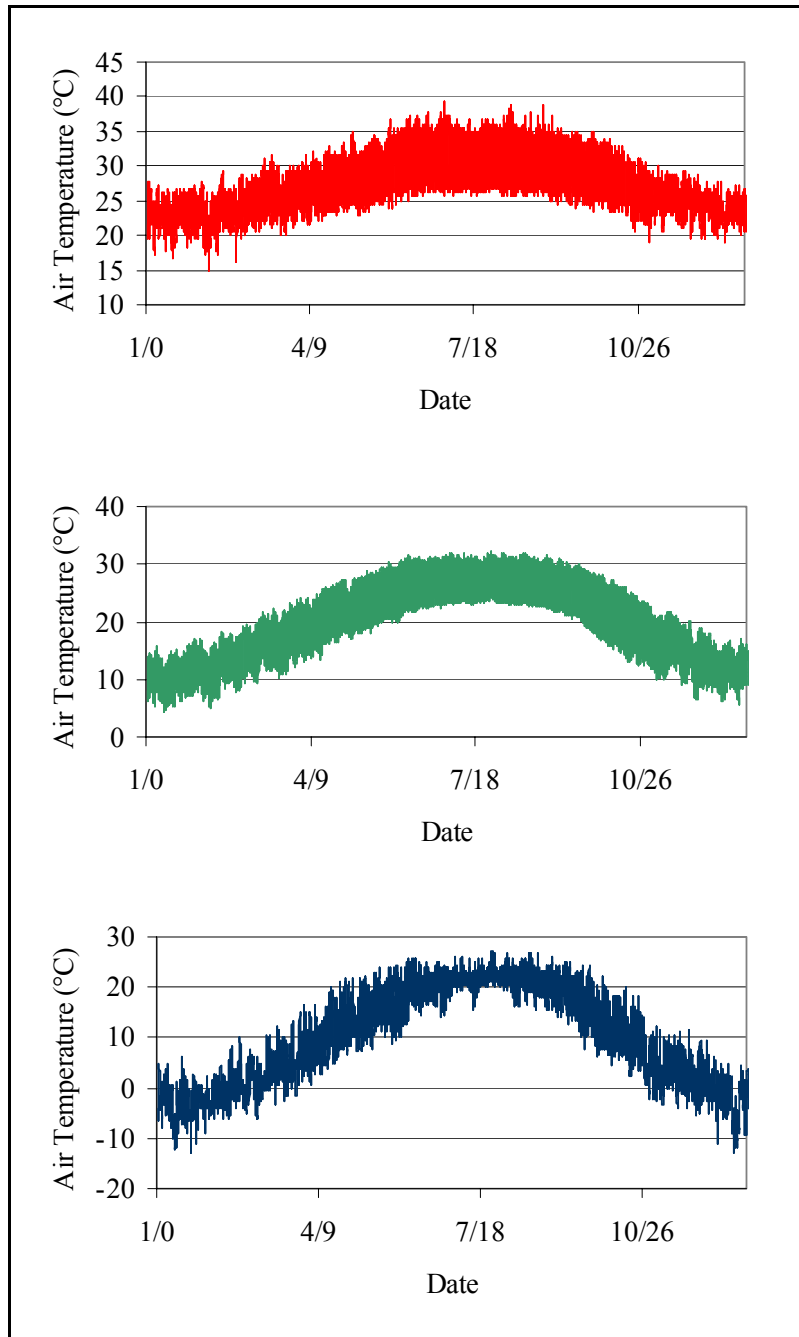


Figure 7.1: These are the maximum (top), average (middle) and minimum (bottom) air temperature compiled from hourly data collected between 1952 and 1992 for Baton Rouge, Louisiana.

m^3 ponds) were used to determine the surplus or deficit of energy throughout a cool, average or warm year. For these trials, the temperature of the cold inlet water was set to either 10 or 20°C. The temperature of the warm water inlet was always set to 36°C. The temperature of the pond was set to 15, 20, 25, 30 or 35°C (see Table 7.1 for details for each model run). For each trial,

The “hot year” data set consisted of:

- the maximum temperature of every hour of the year
- the average relative humidity of every hour of the year
- a constant wind speed of 0 m/s
- the calculated solar radiation with a cloud factor of 0.85
- the normal rainfall

The air temperature for all 3 model years is shown in Figure 7.1.

65 different model runs were performed in order to answer the four original questions. Trials 1, 2, and 3 were used to predict the pond temperature over an average, cold and hot year for an average warm water pond (volume = 400 m^3 , area = 329 m^2). Trials 31, 32 and 33 were used to predict the pond temperature for average, cold and hot years for normalized ponds (volume = 1 m^3 , area = 1 m^2). For each of these model runs, a step size of one hour was used.

Trials 4 to 30 (for 400 m^3 ponds) and trials 34 to 57 (for 1

Table 7.1: These are all the model runs used to determine the energy requirements for ponds kept at specific temperatures, depending on the type of year (hot, cold, average). “Natural” pond temperature listings refer to trials where the pond temperature was not controlled. For these ponds, the temperature of the hot or cold water influent was not necessary.

Trial	Pond Temperature (°C)	Year	Temperature of Inlet	
			Hot Water	Cold Water
1	Natural	Cold	---	---
2	Natural	Average	---	---
3	Natural	Hot	---	---
4	15	Cold	36	10
5	15	Average	36	10
6	15	Hot	36	10
7	20	Cold	36	10
8	20	Average	36	10
9	20	Hot	36	10
10	25	Cold	36	10
11	25	Average	36	10
12	25	Hot	36	10
13	30	Cold	36	10
14	30	Average	36	10
15	30	Hot	36	10
16	35	Cold	36	10
17	35	Average	36	10
18	35	Hot	36	10
19	20	Cold	36	20
20	20	Average	36	20
21	20	Hot	36	20
22	25	Cold	36	20

Table 7.1: continued

Trial	Pond Temperature (°C)	Year	Temperature of Inlet	
			Hot Water	Cold Water
23	25	Average	36	20
24	25	Hot	36	20
25	30	Cold	36	20
26	30	Average	36	20
27	30	Hot	36	20
28	35	Cold	36	20
29	35	Average	36	20
30	35	Hot	36	20
31	Natural	Cold	36	---
32	Natural	Average	36	---
33	Natural	Hot	36	---
34	15	Cold	36	10
35	15	Average	36	10
36	15	Hot	36	10
37	20	Cold	36	10
38	20	Average	36	10
39	20	Hot	36	10
40	25	Cold	36	10
41	25	Average	36	10
42	25	Hot	36	10
43	30	Cold	36	10
44	30	Average	36	10
45	30	Hot	36	10

Table 7.1: continued

Trial	Pond Temperature (°C)	Year	Temperature of Inlet	
			Hot Water	Cold Water
46	35	Cold	36	10
47	35	Average	36	10
48	35	Hot	36	10
49	25	Cold	36	20
50	25	Average	36	20
51	25	Hot	36	20
52	30	Cold	36	20
53	30	Average	36	20
54	30	Hot	36	20
55	35	Cold	36	20
56	35	Average	36	20
57	35	Hot	36	20

the energy surplus or deficit was calculated for every hour of the year. By knowing the energy surplus or deficit, the amount of cold or warm water needed to maintain the pond temperature constant was calculated. Trial 58 was used to find out how much warm geothermal well water would be needed on a cold January night to keep a 400 m³ pond at 27°C. Trial 59 was used to determine how quickly a 400 m³ pond, initially at 27°C, cools down during a cold night. Trials 58 and 59 used weather data collected during the night of the 23rd to the 24th of January, 2003, at the Ben Hur weather station. The night time low that night was -6.3°C. The air temperature profile, the relative humidity and the wind speed for the time period considered are shown in Figure 7.2. No rainfall was recorded during this time. Both model runs were done for the time period between 17:50, 01/23 (sunset), and 24:00, 01/24. The time step for both runs was 10 minutes.

Trials 61, 62, 63 and 64 were used to determine the change in pond temperature for the night of the 10th of March, 2003, under different scenarios. (That night was special because the geothermal well was only turned on at 1:00 AM on the 11th of March.) The weather conditions for that night were measured at the Ben Hur Weather Station and are presented in Figure 7.3. The trial ran for the time period 18:22, 03/10 (sunset), and 6:10, 3/11 (sunrise). The time step was 10 minutes. The initial pond temperature was measured at 28°C. Trial 61 made use of the

unmodified collected weather data. Trial 62 assumed a constant wind speed of 10 m/s after 1:00, 3/11. Trial 63 assumed a constant relative humidity of 30% after 1:00, 3/11. Trial 64 assumed a constant wind speed of 10 m/s and a constant relative humidity of 30% after 1:00, 3/11. The pond temperature throughout the night was compared to the measured temperature in pond 12. The temperature was measured 10 cm below the surface using a type T thermocouple connected to a data logger (Campbell Scientific 21X, Campbell Scientific Inc., North Logan, UT). The temperature was recorded every 10 minutes. Despite the well being turned on at 1:00, 3/11, the

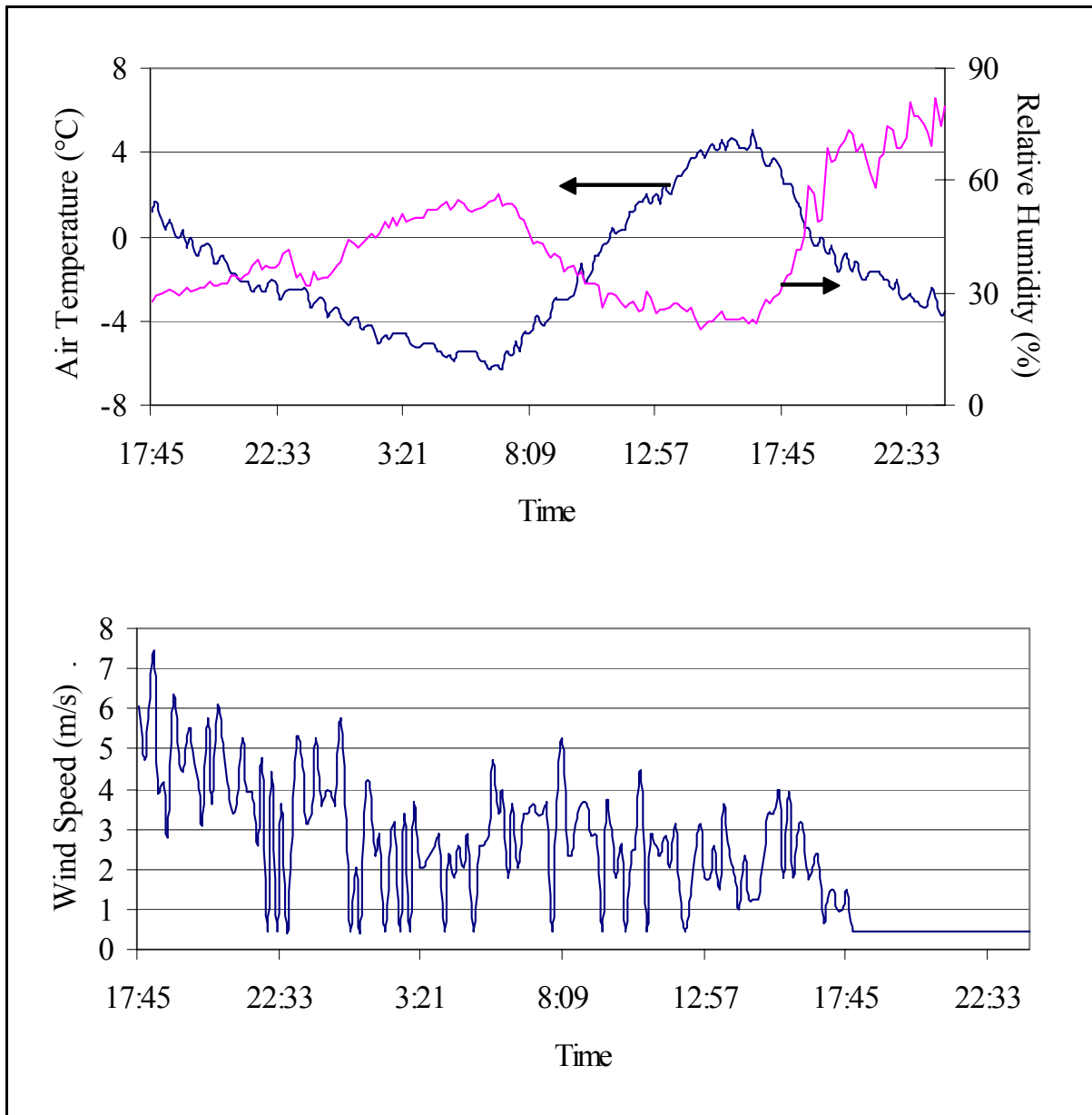


Figure 7.2: The air temperature, the relative humidity and the wind speed are shown from 17:45 on 01/23/03 to 24:00 on 01/24/03. The data, recorded at the Ben Hur Weather Station, represent weather conditions where evaporation, convection and longwave pond radiation are important.

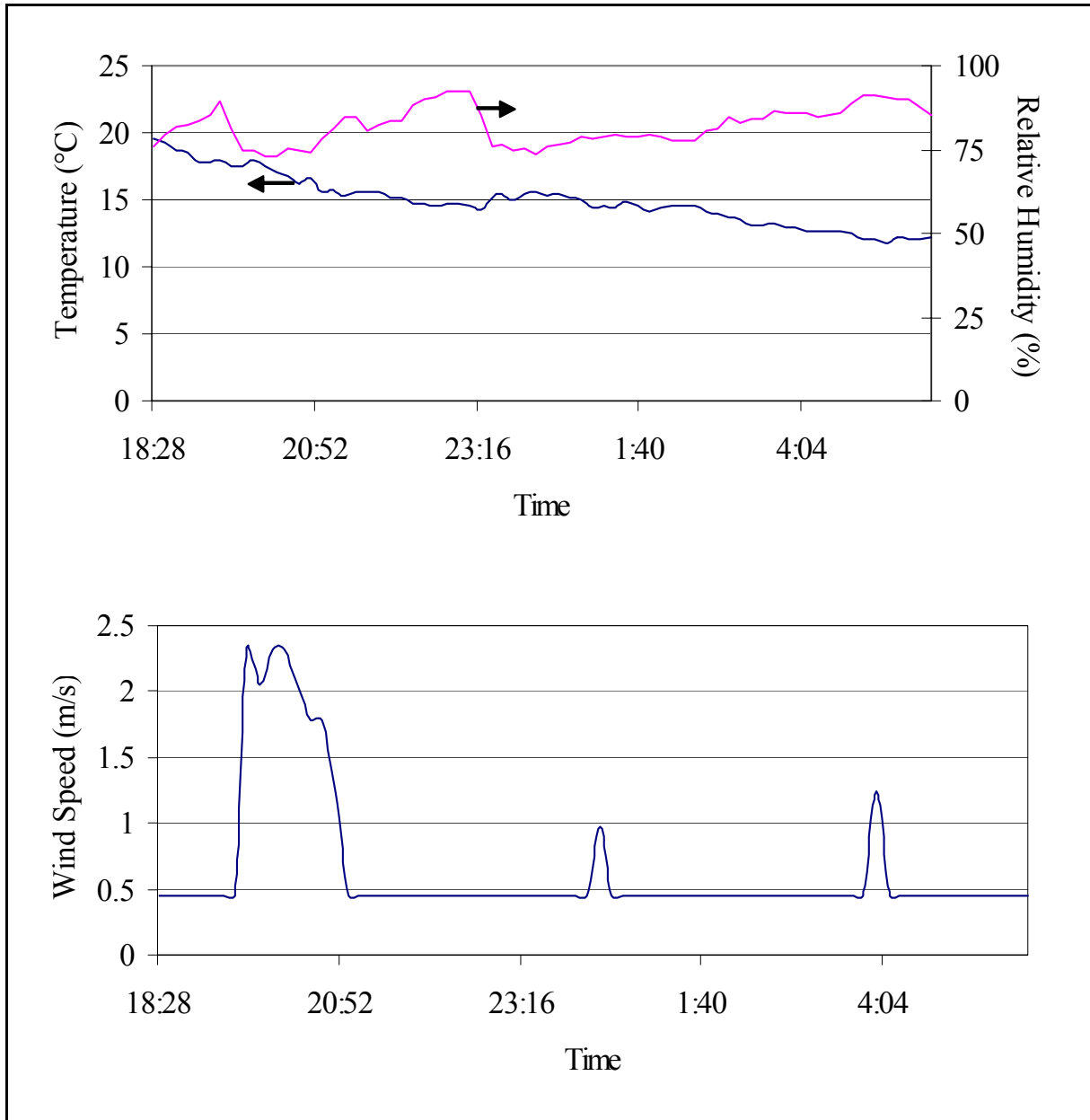


Figure 7.3: The air temperature, the relative humidity and the wind speed recorded at the Ben Hur Weather Station between 18:28, 03/10/2003 and 6:10, 03/11/2003. These data were used by PHATR to determine the pond temperature under different scenarios for that night.

model assumed that no water was added to the pond. This was done to see what would have happened if the well had remained off.

Trial 65 was done to determine the required flow rate needed to gradually increase the pond temperature from 10.5°C (the modeled pond temperature for January 15th at sundown, using the average year weather data file) to 27°C, the temperature maintained at the LSU ARS to

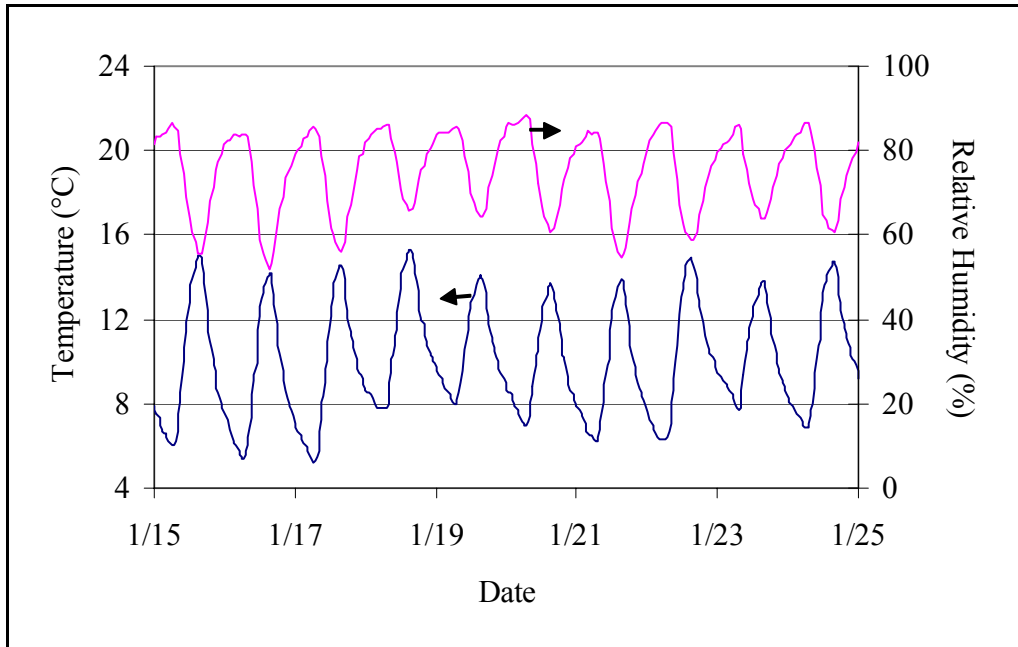


Figure 7.4: The air temperature and relative humidity data were determined for an average year. This data was used for trial 65.

artificially condition channel catfish, *Ictalurus punctatus*, to spawn out of season. The temperature was increased by 2°C every day for 8 days and 1°C on the last day. The pond volume was 400 m³. The model ran for the time period between 17:00, 01/15, and 17:00, 01/24, for an average year. The time step was 1 hour. The weather conditions for this time period are shown in Figure 7.4.

7.3 Results: Answers to Questions 1 through 4

1) What is the pond temperature throughout a “average” year?

The pond temperature (for a 400m³ pond) depended on the type of year. For a cold year, the pond’s maximum temperature, 22.2°C, happened on 07/27 at 15:00 while the minimum pond temperature (-9.2°C) happened on 01/12 at 8:00. The average pond temperature was 9.0°C (standard deviation = 8.8°C). Although the minimum pond temperature was well below 0°C, the freezing point for pure water, it must be remembered that the minimum pond temperature was the product of a model run which used the coldest possible weather data for every hour during the year. Normally, cold spells do not last an entire year. Therefore, the purpose of this model run was not to simulate a cold year, but to provide a lower boundary for the average pond temperature.

For a hot year, the pond’s maximum temperature, 54.9°C, happened on 07/02 at 17:00. The minimum temperature could not be determined because the initial pond temperature which PHATR required was also the lowest pond temperature. As a substitute to a minimum, on 01/12

at 8:00, the pond temperature was 30.0°C. The average pond temperature was 44.1°C (standard deviation = 7.9°C). Again, a pond temperature of 54.9°C is unlikely to happen in Baton Rouge, Louisiana. However, the purpose of the hot weather model run, not unlike the cold weather model run, was to provide an upper boundary for the average pond temperature.

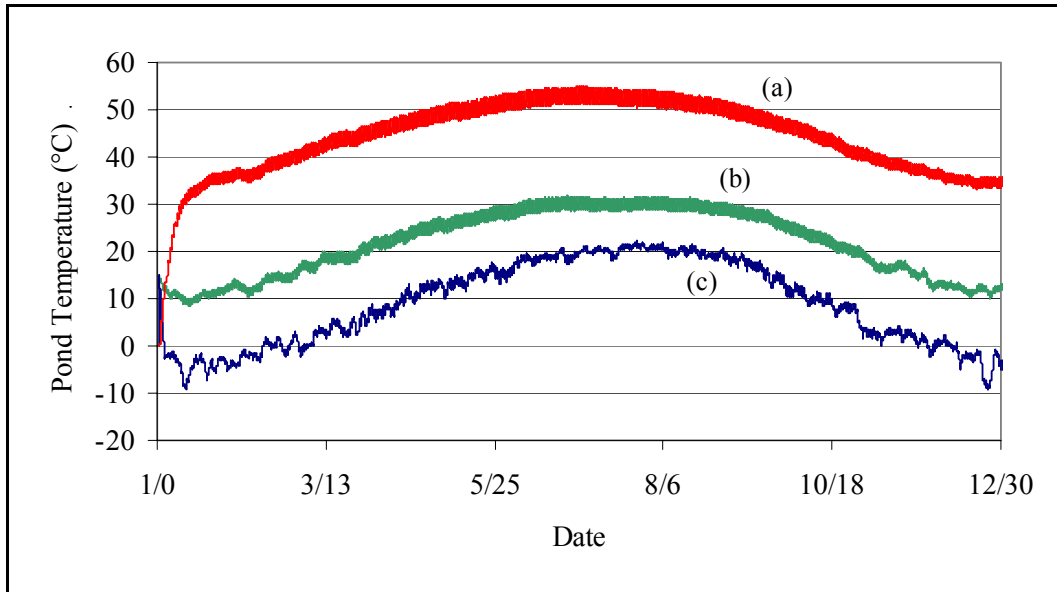


Figure 7.5: Modled pond temperature profiles for hypothetical hot (a), cold (b) and average (c) years are shown. The hot and cold years are not realistic (note the below freezing temperatures for the (c)) but they do bound the possible values for the average year.

For an average year, the pond’s maximum temperature, 31.7°C, happened on 06/26 at 17:00. The minimum pond temperature, 8.5°C, happened on 01/13 at 8:00. The average pond temperature was 21.8°C (standard deviation = 7.0°C). The pond temperature for a cold, hot and average year are shown in Figure 7.5 Because the model has not yet been validated for summers or early autumn in Baton Rouge, the values generated for this time of year should be considered with caution.

2) What is the energy surplus or energy deficit when keeping the pond temperature constant?

Energy demands are dependant on the weather. A cold year was shown to have greater energy demands for keeping the pond warm. For instance, to maintain the pond temperature at 15°C for an entire year, the total energy deficit was $1.18 \times 10^{11} \text{ J/m}^3$ (3 284 kWhr/m³). To maintain the pond temperature at 35°C during the same year, the total energy deficit was $7.56 \times 10^{11} \text{ J/m}^3$ (21 000 kWhr/m³). A hot year, on the other hand, always had a yearly surplus of energy. To maintain the pond temperature at 35°C, $4.9 \times 10^9 \text{ J/m}^3$ (1371 kWhr/m³) net had to be removed.

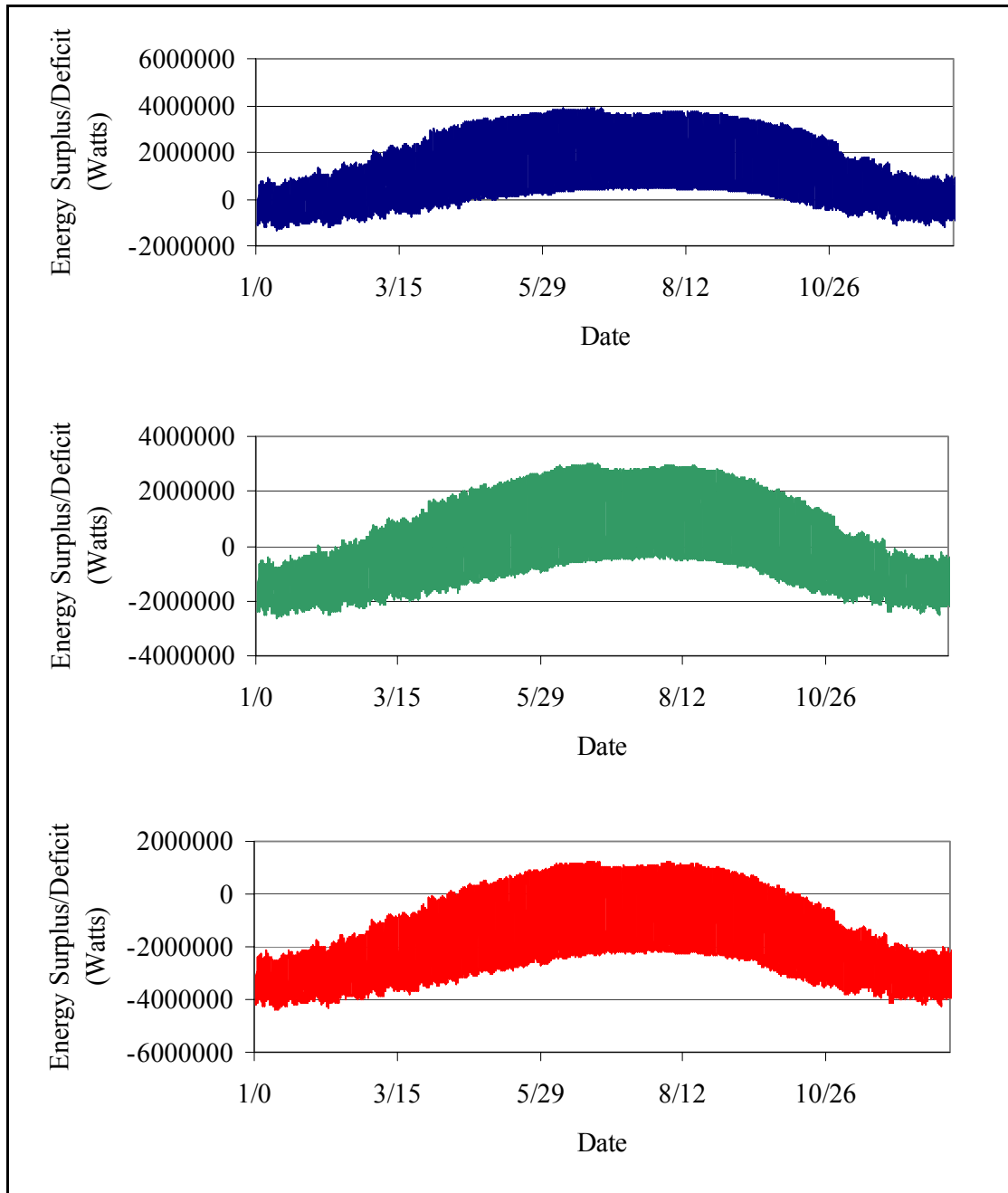


Figure 7.6: Surpluses and deficits of energy varied over the course of a day and a year. These plots show the energy requirements for a 1 m³ pond over an average weather year. The pond temperature was maintained at 15°C (a), 25°C (b) and 35°C (c). Not shown are plots for 20 and 30°C.

To maintain the pond temperature at 15°C, 1.2×10^9 J/m³ (3295 kWhr/m³) net had to be removed (see Table 7.2 for more details on energy requirements for maintaining pond temperature).

From a design perspective, the energy requirements for an average year were more interesting because the model results were more realistic. Maintaining the pond temperature between 20°C and 25°C during an average year required no additional energy, assuming the pond energy surpluses could be stored for use when the pond had an energy deficit. The total net energy surplus when maintaining the pond temperature at 15°C during an entire average year was $6.9 \times 10^9 \text{ J/m}^3$ (1919 kWhr/m³). The total net energy deficit when maintaining the pond temperature at 35°C during an entire average year was $1.9 \times 10^{10} \text{ J/m}^3$ (5175 kWhr/m³). These numbers do not reflect, however, how the pond energy surpluses or deficits changed throughout an average year (see Figure 7.6 for variations in pond energy surpluses/deficits throughout an average year).

Table 7.2: The total energy surpluses and deficits associated with maintaining a 1 m³ pond at a given temperature are such that the total energy surpluses are positive quantities while the total deficits are negative quantities. These values do not reflect how the energy surplus or deficit can change over a day or year.

Pond Temperature (°C)	Total Surplus/Deficit (J/m ³)		
	Cold Year	Average Year	Hot Year
15	-1.18×10^{10}	6.91×10^9	1.19×10^{10}
20	-2.38×10^{10}	2.52×10^9	1.05×10^{10}
25	-3.96×10^{10}	-3.24×10^9	8.90×10^9
30	-5.76×10^{10}	-1.03×10^{10}	7.03×10^9
35	-7.56×10^{10}	-1.86×10^{10}	4.9×10^9

Table 7.3: Here are estimates for the energy costs associated with maintaining the pond temperature at a set value for an average weather year. Holding the pond at 20°C was the most inexpensive pond temperature.

Pond Temperature (°C)	Energy Costs (\$/m ³)		
	2¢/kWhr	7¢/kWhr	15¢/kWhr
15	56	195	418
20	54	188	403
25	61	214	460
30	80	281	602
35	111	388	831

The cost associated with heating or cooling a 1 m³ pond was calculated every hour for an average year. The cost of heating or cooling one kilowatt-hour was assumed to be the same. The unit cost for electricity was assumed to be either \$0.02/kWh, \$0.07/kWh or \$0.15/kWh. (Based on 2003 rates, the cost for electricity for large-scale commercial operations in Baton Rouge, Louisiana, is \$0.0317 for the first 50 kWh, \$0.0297 for the next 100 kWh, \$0.02776 for the following 225 kWh and \$0.02576 kWh for any additional energy requirements.) The total cost to maintain the pond temperature constant during an average year is presented in Table 7.3. Keeping a pond at 20°C proved to be the least expensive (\$54/m³). This is not surprising since the average temperature of an unheated pond during an average year was 21.8°C.

If geothermally enriched warm water is used to control the pond temperature, the maximum and average flow rates, used for choosing a pump, were calculated. These values are dependant on the temperature of the incoming water. For the trials used here, the “warm” water was set to 36°C while the “cool” water was set to either 10°C and 20°C. Maximum and average flow rates for an average year for each temperature setting are presented in Table 7.4. The required flow rates were smaller if the difference between the inlet water temperature and the pond temperature was small. For instance, an average flow rate of 1.99×10^{-6} (m³/s)/m³ (0.032 gpm/m³) was required when using 10°C water to maintain the pond temperature at 25°C during an average year. When using 20°C water, the required average flow rate was 5.97×10^{-6} (m³/s)/m³ (0.095 gpm/m³) - 3 times as much water. There are other reasons why it is desirable to increase the difference between the pond and inlet water temperature for the purposes of pond temperature control:

- to reduce the sizing of pumps. For keeping the pond temperature at 25°C using 20°C water, 3 times as much water was needed on average than if the inlet water temperature was 10°C. The peak required flow rates were also greater when using 20°C water (4×10^{-5} (m³/s)/m³) as opposed to using 10°C inlet water (1.3×10^{-5} (m³/s)/m³).
- to reduce the amount of wasted water. By adding water into a pond, assuming the pond volume was kept constant, water must be displaced out of the pond. The water was not re-used, wasted and may be considered a loss to the farm.
- to reduce pumping costs. By reducing the amount of water needed, the costs associated with pumping could also be reduced.

3) By how much does the temperature decrease in one night if there is suddenly no way to keep the pond warm?

For the night of the 23rd to the 24th of January, 2003, the average air temperature was -3.1°C and the lowest pond temperature was -6.3°C. If the pond temperature, at sunset, was 27°C, then by sunrise, the pond temperature was 19.2°C. By sunset on the 24th of January, the pond temperature had gone down to 18.1°C and by 24:00, the pond temperature was 16.8°C (see Figure 7.7). There are several reasons for the large decline in pond temperature. Because the

Table 7.4: These were the flow requirements for 10°C, 20°C and 36°C water to maintain constant pond temperature during an average weather year (pond size = 1m³). The standard deviation (St. Dev.) was an indicator of how the average flow rate varied over the course of a year. For design purposes, both the maximum and the average flow rate were required. The 10°C and the 20°C water were used to cool the ponds. The 36°C water was used to warm up the ponds.

Inlet water temperature = 10°C					
T _{pond}	Maximum	Flow	Average	Flow	St. Dev.
(°C)	((m ³ /s)/m ³)	(gpm/m ³)	((m ³ /s)/m ³)	(gpm/m ³)	((m ³ /s)/m ³)
15	5.20 x 10 ⁻⁵	8.25 x 10 ⁻¹	1.30 x 10 ⁻⁵	2.06 x 10 ⁻¹	1.55 x 10 ⁻⁵
20	2.40 x 10 ⁻⁵	3.81 x 10 ⁻¹	4.67 x 10 ⁻⁶	7.41 x 10 ⁻²	6.98 x 10 ⁻⁶
25	1.30 x 10 ⁻⁵	2.06 x 10 ⁻¹	1.99 x 10 ⁻⁶	3.16 x 10 ⁻²	3.71 x 10 ⁻⁶
30	7.00 x 10 ⁻⁶	1.11 x 10 ⁻¹	7.86 x 10 ⁻⁷	1.25 x 10 ⁻²	1.80 x 10 ⁻⁶
35	3.00 x 10 ⁻⁶	4.76 x 10 ⁻²	2.01 x 10 ⁻⁷	3.19 x 10 ⁻³	6.48 x 10 ⁻⁷
Inlet water temperature = 20°C					
T _{pond}	Maximum	Flow	Average	Flow	St. Dev.
(°C)	((m ³ /s)/m ³)	(gpm/m ³)	((m ³ /s)/m ³)	(gpm/m ³)	((m ³ /s)/m ³)
15	---	---	---	---	---
20	---	---	---	---	---
25	4.00 x 10 ⁻⁵	6.35 x 10 ⁻¹	5.97 x 10 ⁻⁶	9.48 x 10 ⁻²	1.11 x 10 ⁻⁵
30	1.50 x 10 ⁻⁵	2.38 x 10 ⁻¹	1.58 x 10 ⁻⁶	2.51 x 10 ⁻²	3.59 x 10 ⁻⁶
35	6.00 x 10 ⁻⁶	9.52 x 10 ⁻²	3.36 x 10 ⁻⁷	5.33 x 10 ⁻³	1.06 x 10 ⁻⁶
Inlet water temperature = 36°C					
T _{pond}	Maximum	Flow	Average	Flow	St. Dev.
(°C)	((m ³ /s)/m ³)	(gpm/m ³)	((m ³ /s)/m ³)	(gpm/m ³)	((m ³ /s)/m ³)
15	4.00 x 10 ⁻⁶	6.35 x 10 ⁻²	5.66 x 10 ⁻⁷	8.98 x 10 ⁻³	1.03 x 10 ⁻⁶
20	8.00 x 10 ⁻⁶	1.27 x 10 ⁻¹	1.71 x 10 ⁻⁶	2.71 x 10 ⁻²	2.35 x 10 ⁻⁶
25	1.60 x 10 ⁻⁵	2.54 x 10 ⁻¹	4.97 x 10 ⁻⁶	7.89 x 10 ⁻²	4.91 x 10 ⁻⁶
30	3.80 x 10 ⁻⁵	6.03 x 10 ⁻¹	1.46 x 10 ⁻⁴	2.31	1.19 x 10 ⁻⁵
35	2.94 x 10 ⁻⁴	4.67	51.48x 10 ⁻⁴	2.35	8.67 x 10 ⁻⁵

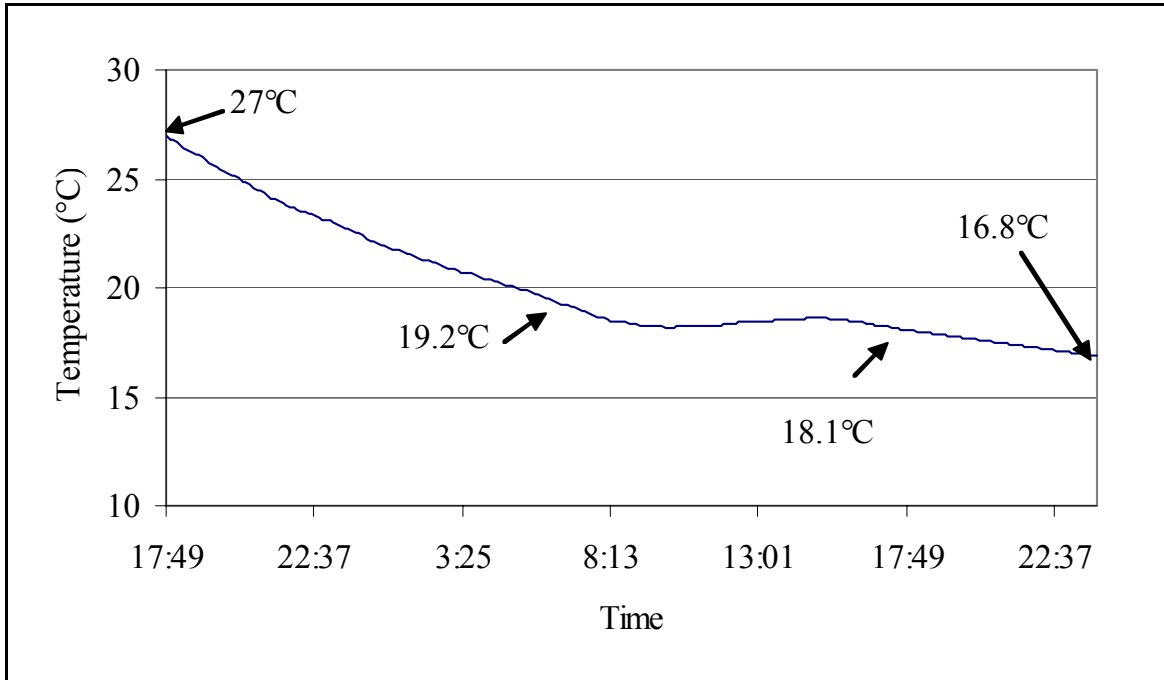


Figure 7.7: The modeled pond temperature, for the night between 01/23/03 and 01/24/03 dropped from 27°C (sunset) to 19.2°C (sunrise). During the following day (01/24), the pond temperature decreased further. The pond temperature was 18.1°C by sunset and 16.8°C by 24:00. The average air temperature during the 1st night was -3.1°C.

pond was initially very warm (27°C) with respect to its surroundings, the difference between the pond radiation and the sky radiation (-63 498 W) was greater (see Figure 7.8) than what would have been observed for an unheated pond (-38 655 W; initial pond temperature equal to 10°C). The wind driven energy transfer mechanisms (i.e. convection and evaporation) also contributed to lowering the pond temperature quickly. Energy losses due to convection on 01/23 at 24:00 represented 27% of all energy transfer mechanisms. Energy losses due to evaporation at the same time represented 25% of all energy transfer mechanisms (see Figure 7.9) Wind driven mechanisms were important in part because of the windy conditions that night (maximum wind speed = 7.38 m/s = 16.5 mph) but also because the temperature and vapor pressure gradients between the water and the air were large (maximum temperature difference between the pond and the air = 26.4°C, maximum vapor pressure difference = 3.35 kPa). When the wind speed died down an hour latter (from 5.2 to 0.4 m/s), the relative importance of evaporation and convection diminished. Energy losses due to convection on 01/24 at 1:00 represented 13% of all energy transfer mechanisms. Energy losses due to evaporation at the same time represented 9% of all energy transfer mechanisms. On average for that night, pond radiation accounted for 20% to 51% of all energy transfer mechanisms (average = 34%). Sky radiation accounted for 11% to 28% of all energy transfer mechanisms (average = 18%). Wind driven energy transfer mechanism varied in importance, depending on the wind speed. Convection represented 13% to 32% of all energy transfer mechanisms (average = 25%). Evaporation represented 8% to 38% of

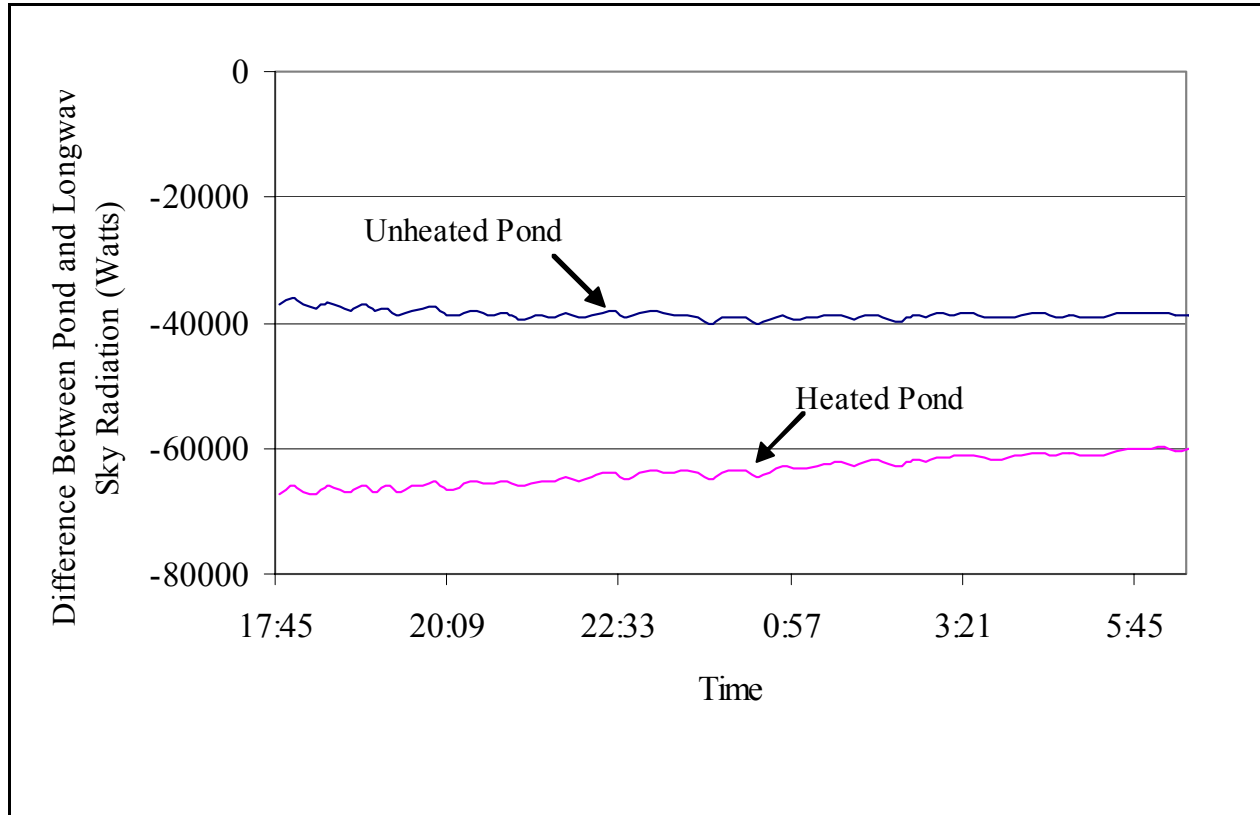


Figure 7.8: Each line represents the difference between longwave pond radiation and longwave sky radiation for a heated or unheated pond. The heated pond, maintained at 27°C, was assumed to lose its source of warm 36°C water at 17:45 (sunset) on 01/23/03, at which point, the pond cooled naturally. The unheated pond model run had an initial pond temperature of 10°C. Because the heated pond was warmer, it radiated and lost more heat than the unheated pond. The average temperature for the night was -3.1°C.

all energy transfer mechanisms (average = 23%). The amount of 36°C water required to keep a 400 m³ pond at 27°C from sunset on 01/23 to 24:00 on 01/24, ranged from 0 to 15.1 x 10⁻³ m³/s (0 to 240 gpm) with an average flow rate of 5.90 x 10⁻³ m³/s (0 to 94 gpm) (see Figure 7.10 for flow demands for the model run).

For a warmer night (3/10 to 3/11, 2003, average air temperature = 14.9°C), changes in pond temperature were not as drastic. Between 18:22, 03/10 and 6:00, 03/11, the pond temperature decreased by 2.0°C. If the wind speed was 10 m/s as opposed to 0.6 m/s, the average wind speed for that night, the decrease in pond temperature would have been 5.1°C. If the relative humidity had been 30% as opposed to 82%, the average relative humidity for that night, the decrease in pond temperature would have been 2.2°C. If both the relative humidity and the wind speed were changed (relative humidity = 30% instead of 82% and wind speed = 10 m/s instead of 0.6 m/s), the change in pond temperature would have been 6.0°C.

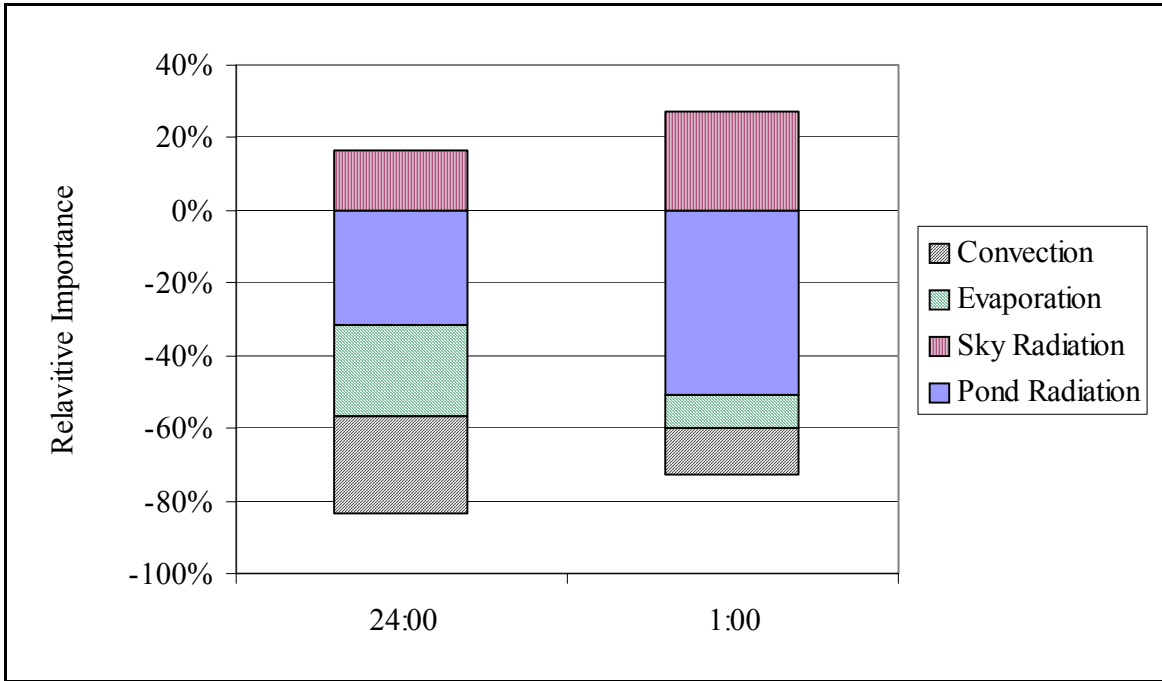


Figure 7.9: At 24:00 on 01/23/2003, the wind speed was 3.65 m/s. At this time, wind driven energy transfer mechanisms (convection: 27%, evaporation: 25%) were as important as long wave radiation mechanisms (pond radiation: 31%, sky radiation: 17%). One hour later, at 1:00, the wind speed was 0.5 m/s. As a result, convection (13%) and evaporation (9%) were not as important as pond radiation (51%) or sky radiation (27%). The energy balance was performed for a 400 m³ pond.

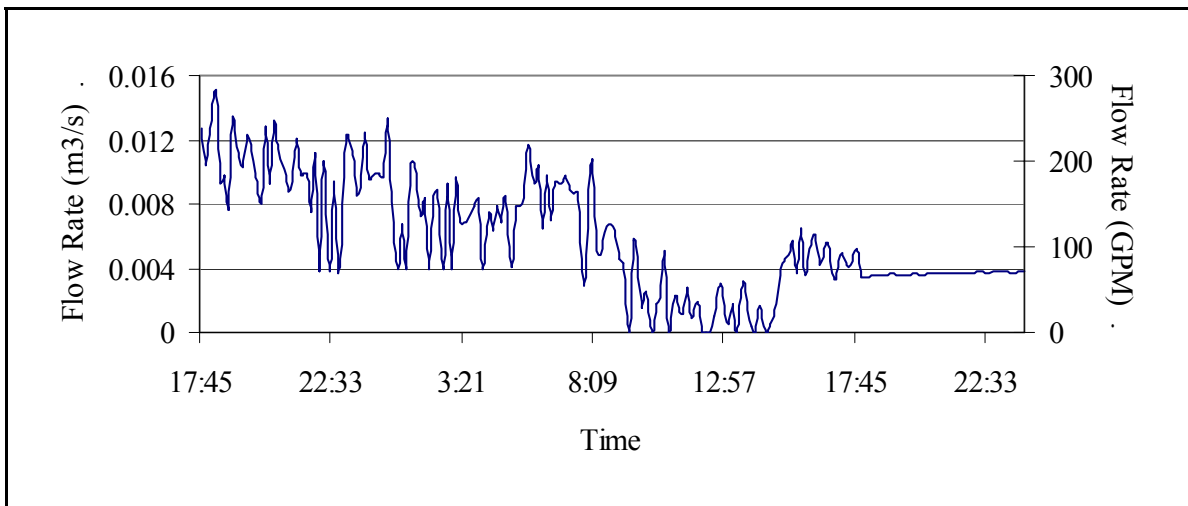


Figure 7.10: Between 17:45, 01/23/03 and 24:00, 01/24/03, the flow rate of 36°C water needed to maintain a pond temperature of 27°C was estimated. The flow rates varied between 0 and 15.1 x 10⁻³ m³/s (0 to 240 gpm) with an average flow rate of 5.90 x 10⁻³ m³/s (94 gpm). The pond was 400 m³. The average night time temperature during the first night was -3.1°C.

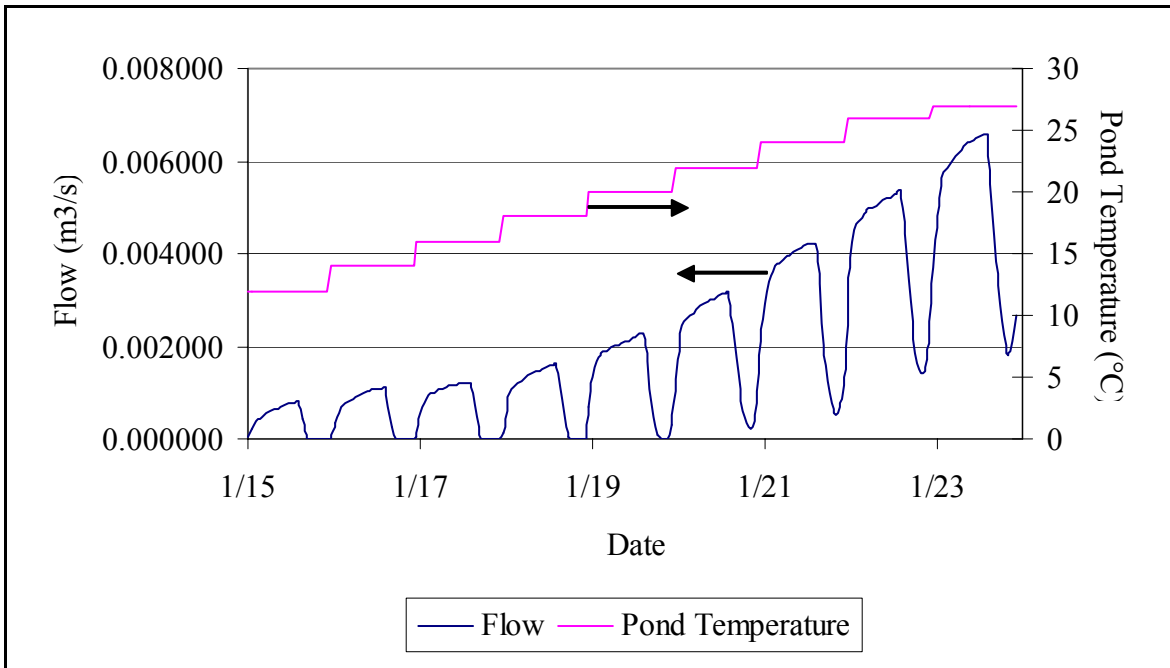


Figure 7.11: The required flow rate required to gradually increase the pond temperature from 10.5°C to 27°C at a rate of 2°C/day is shown here. The flow rates were calculated between 01/15 and 01/24 for an average year. Each tick on the date axis approximately represents sunset (16:50), when the temperature is stepped by 2°C.

Table 7.5: The maximum flow rates for a hypothetical model run are presented here. The purpose of the model run was to determine the flow rate required to warm a 400 m³ from 10.51°C to 27°C over 9 days (2°C/day). The trial ran for the time period between 01/15 and 01/24 for an average weather year.

Night	Maximum flow rate (m ³ /s)	Maximum flow rate (gpm)
1	8.19 x 10 ⁻⁴	13
2	1.12 x 10 ⁻³	18
3	1.22 x 10 ⁻³	19
4	1.62 x 10 ⁻³	26
5	2.28 x 10 ⁻³	36
6	3.17 x 10 ⁻³	50
7	4.20 x 10 ⁻³	67
8	5.36 x 10 ⁻³	85
9	6.59 x 10 ⁻³	105

PHATR has a tendency of over-predicting the pond temperature so actual decreases in pond temperature were most likely greater than what was calculated here.

4) What are the flow requirements for increasing the pond temperature by 2°C/day during a typical week in January?

Because January is the coldest month of the year, warming the ponds to induce channel catfish spawning at this time of year represented the worst case scenario. For a 400 m³ pond, with an initial pond temperature of 10.51°C, the required flow rate of 36°C water for each night is graphically shown in Figure 7.11. Each night, the peak flow rate increased as shown in Table 7.5, with the maximum flow rate happening on the last night before sunrise ($6.59 \times 10^{-3} \text{ m}^3/\text{s} = 105 \text{ gpm}$). No warm water was needed during the daytime until the 5th day (01/20). The maximum flow rate required during noon, $2.04 \times 10^{-3} \text{ m}^3/\text{s}$, occurred on the 01/24. The total energy required to warm the pond over this time period was $7.64 \times 10^{10} \text{ J}$ (21 236 kWh).

7.4 Conclusions

The model answered four design and management questions for the warm water ponds at the LSU ARS. These results should not be seen as an exact answer but rather as an approximation of what could happen. Because Fisfhfry has a tendency of over-predicting the pond temperature, reported calculated energy deficits are smaller than those in reality and reported calculated energy surpluses were larger than those in reality. Furthermore, using the results presented in this chapter for ponds other than the LSU ARS warm water ponds should be done with great caution. In addition to assuming the ponds were well mixed, PHATR was validated only for research-sized ponds (400 m³) in a temperate humid climate during the late fall, winter and spring. Using the model despite these warnings is left to the user's own risk.

The temperature for an unheated pond during cold, hot and average years were estimated. Results from the cold and hot years were seen as boundaries for possible pond temperatures and not as a pond temperature profile during an extreme case year. The average pond temperature for an average year was 21.8°C with a maximum temperature of 31.7°C and a minimum temperature of 8.5°C.

The net energy needed to maintain the pond temperature at 15, 20, 25, 30 and 35°C was calculated for a cold, hot and average year. For an average year, maintaining the pond temperature between 20 and 25°C required less energy. This is understandable since the average pond temperature for an average year for an unheated pond, 21.8°C, was between 20 and 25°C.

Temperature decreases for heated ponds in one night were dependant on the specific weather conditions. For instance, on a cold night, where the average night time temperature was -3.1°C and the maximum wind speed was 7.4 m/s, the modeled pond temperature decreased from 27°C to 19.2°C in one night. This was in part because of the unbalanced loss of energy through longwave pond radiation. Because the pond's surroundings were at least 20°C cooler than that

of the surroundings, back radiation was much greater than sky radiation, causing the pond to lose energy. Pond radiation accounted for 20% to 51% of all energy transfer mechanisms (average = 34%). Wind driven energy transfer mechanism varied in importance, depending on the wind speed. Convection represented 13% to 32% of all energy transfer mechanisms (average = 25%). Evaporation represented 8% to 38% of all energy transfer mechanisms (average = 23%). On a warmer night (average temperature = 14.9°C), the modeled pond temperature decreased from 27°C to 25°C. This is because there was little wind that night and the temperature difference between the pond and the surroundings was smaller than during the cold night.

The amount of energy needed to raise the pond temperature (volume = 400 m³) from 10.5°C to 27°C at a rate of 2°C/day was modeled to be 7.64×10^{10} J over 9 days. The required flow rate of warm 36°C water was calculated. On the final night, the maximum required flow rate was 2.04×10^{-3} m³.

Because the model has proven itself as a good design and management tool, it could be used to address other questions about the warm water ponds. By validating PHATR for other situations, the model's applicability would become more universal.