SIMULATION MODEL FOR AQUACULTURE POND HEAT BALANCE: II MODEL EVALUATION AND APPLICATION.

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ABSTRACT:

The performance of a model developed by Ali (2006) to simulate aquaculture pond temperature was evaluated using sensitivity analysis and the model verified with data from aquaculture pond. The sensitivity analysis showed that output varied linearly with changes in average air temperature and solar radiation. Results from model verification runs showed that the model performance was satisfactory with respect to aquaculture pond temperature. In the future, the model will be used to investigate the effects of aquaculture pond temperature on daily growth rate to obtain the weight of individual fish throughout the year.

Keywords: *Simulation Model – Aquaculture pond - sensitivity analysis – Validation – Heat Balance.*

1. INTRODUCTION

An energy balance was developed to estimate or predict aquaculture pond temperature (Ali, 2006). This paper presents results of simulation to validate and apply the model. Validation was accomplished by comparing simulation model output to historical data under similar environmental conditions as described by El-Haddad (1977).

Model testing should be conducted as an integral part of the process of model construction. As the model is being built, each component is tested separately and again after integration with other components. This process is continued until the entire model is tested and verified. The model can be tested by letting each appropriate variable approach its specified limits and

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checking if the simulation results are logical. Artificial data can be created and used to test the behavior of the model (Cuenco, 1989).

Every variable in the model should be defined precisely and clearly, dimensionally correct and consistently used. Symbols representing variables should be chosen with three considerations in mind: ease of recognition, brevity, and conformity with established use (Riggs 1963).

Sensitivity analysis as defined by Saltelli (2000) is "the study of how the variation in the output of a model can be apportioned, qualitatively or quantitatively, to different sources of variation, and how the given model depends upon the information fed into it." For the pond model, sensitivity analysis revealed which changes in the input caused greater or lesser changes in the output. The sensitivity analysis also identified certain scenarios where varying a certain input variable had a counter-intuitive effect on the results.

Validation is the process of testing how much confidence can be placed on the model results as applicable to the real system. Given proper inputs, a valid model produces results that are consistent with reality and meaningful when properly interpreted. It is not difficult to build a model that mimics the effect of each factor independent of the other factors. The main difficulty lies in linking and structuring the components of the model together in such a way as to capture all relevant interactions. It is in this phase that data are usually absent and models fail to simulate known interactions. The model can be validated by comparing simulated results with experimental data or historical values from the real system and computing statistics of fit. Discrepancies between model output and reality can save as a guide to improving the model. After construction and validation, the model should be documented. Documentation should include the assumptions that were made in building the model, the intended uses of the model, the output produced by the model and its interpretation, and the data required for using the model (Cuenco, 1989).

The experimentation phase of simulation has received relatively little attention (Wright, 1971). Many of the problems studied using simulation will be concerned with the comparison of alternatives. Even if the model is not sufficiently realistic to give a good estimate of the absolute level of system performance, it may be quite suitable for estimating the relative merits of different alternatives (Wright, 1971).

A model developed by Ali (2006) considers four major climatic parameters (temperature, relative humidity, wind speed and incident radiation) to determine aquaculture pond temperature.

The objectives of this study were:

1) to quantify model sensitivity,
2) to compare the measured values with those predicted (model Validation), and
3) to conduct experiments with the model.

2. MODEL EVALUATION

2.1. Sensitivity Analysis

The computer model used to predict the temperature for small well mixed ponds requires data inputs of various kinds that describe the weather and the physical characteristics of the pond.

The standard model simulation consisted of running the model for 2 days for a hypothetical pond with dimensions 1.0 x 1.0 x 1.0 meter. The weather during these 2 hypothetical days was clear (no clouds) with an average air temperature of 20°C. The air temperature varied sinusoidally (Figure 1). The daytime high, 25°C, occurred at 14:00 (2 P.M.) and the daytime low, 15°C, occurred at 2:00 (2 A.M.). Solar radiation varied sinusoidally (Figure 1) between 6:00 and 18:00 (6 A.M. and 6 P.M.), with the maximum (1355 W m^{-2}) occurring at 12:00 (noon). The relative humidity was set constant at 90%. There was no wind (wind speed = 0 m/s). During simulation temperature thus was changed while all other weather conditions remained constant at their hypothetical standard value. The average air temperature was set at either 0, 10, 20, 30 or 40°C.

Simulation results for the pond temperature were compared to the standard model run over the two day period. The difference in temperature between each trial and the standard conditions was then plotted against average air temperature (Figure 2). The curve in this plot is called the sensitivity curve and graphically represents relative changes in output for relative changes in input.

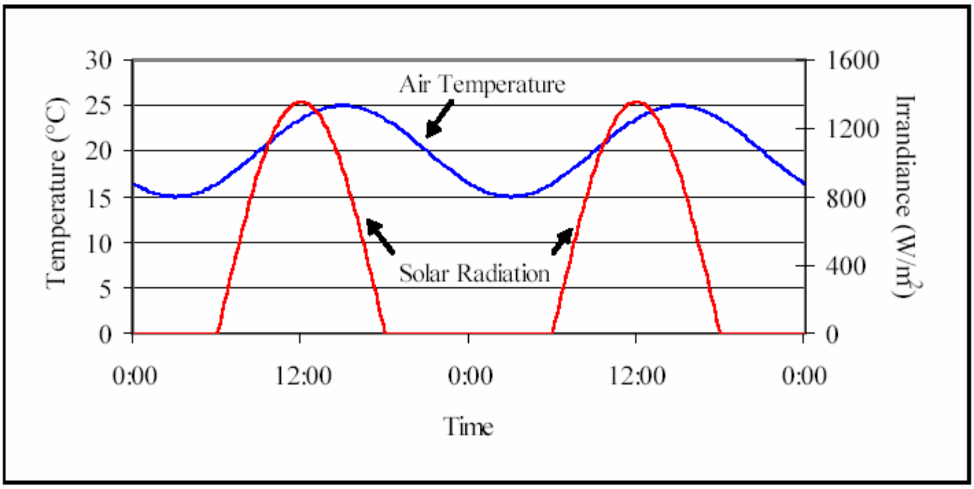

Figure (1): Air temperature and solar radiation were modeled as sinusoidal curves, with a period of one day. At night, solar radiation was held constant at 0 W m^{-2}. The air temperature and the solar radiation described by these two curves were used as input data in the sensitivity analysis.

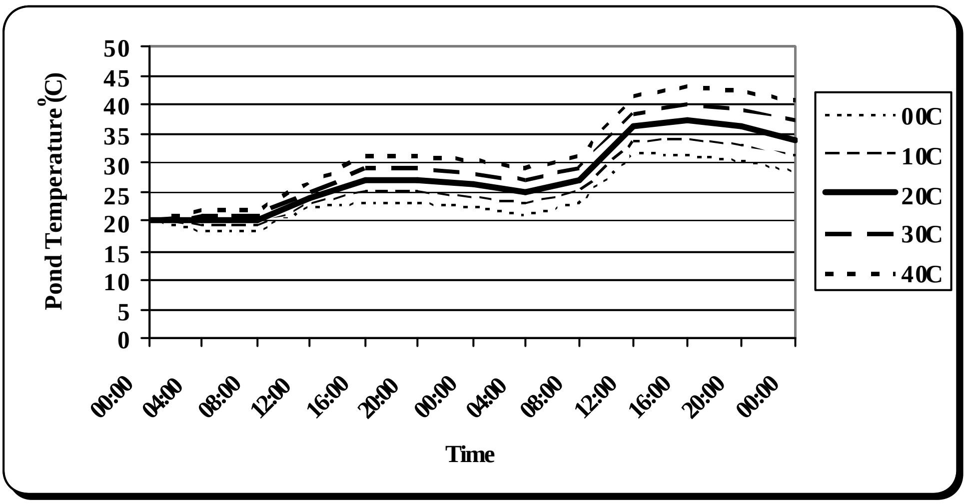

Figure 2: These curves describe how the pond temperature changed over 2 days of hypothetical weather. The temperature labels on the right hand side of the graph were the average air temperature for the sensitivity analysis trials. Cooler air temperatures caused the pond temperature to decrease with respect to the standard (shown here as the 20°C curve). Warmer air temperatures caused the pond temperature to increase with respect to the standard.

Quantitatively, the model's sensitivity to an average air temperature is the derivative (slope) of the sensitivity curve. To generate an equation to describe the sensitivity curve mathematically, the data points in the sensitivity curve were entered into Curve Expert (Hyams, 2001), a shareware program specifically designed for curve fitting. The derivative of the resulting equation of best fit was then calculated. Substituting statistically determined constants (determined by Curve Expert - Hyams, 2001)) and the input variables into the derivative equation yielded numerical valued for sensitivity.

Lowering the average air temperature resulted in relatively lower pond temperatures at the end of the two days period (see Figure 2). For instance, the pond temperature, after being exposed to an average air temperature of 0°C for 48 hours, was 28.3°C, 5.7°C below that obtained with the temperature of 20°C. Alternately, increasing the average air temperature raised the pond temperature. As an example, the pond temperature, after being exposed to 40°C air for 48 hours, was 40.6°C, 6.6°C above the standard condition temperature. As time progressed, the absolute difference between the temperature obtained at 20°C and that obtained in trials at other temperatures increased. Therefore, the model's sensitivity to changes in air temperatures were dependant on time, as shown by the different slopes for the sensitivity curves in Figure 3.

Linear regression was applied to each curve in Figure 2. The correlation coefficients and the slopes for each curve are shown in Table 1. As the time step increased from 12 to 48 hours, the slope also increased from 0.1025 °C/°C to 0.3075 °C/°C. Because the slope of a line is also the derivative of a line, and because the curves in Figure 2 were lines ($r = 0.99$ for all time steps), the slopes in Table 1 are measures of the model's sensitivity.

To determine if any relationship existed between the slope of each sensitivity curve and time, the slopes were plotted against time (see Figure 4). The slopes were found to vary linearly with time ($r = 0.97$). The rate of change of the slopes was 0.00569 °C/°C/hr and the intercept for this line was 0.05 °C/°C.

Table 1: The sensitivity curves in figure 3 were statistically quantified with linear regression parameters. Note how the slope (sensitivity) increased with time.

Time (hr)	Slope ($^{\circ}C_{output}/^{\circ}C_{input}$)	Correlation coefficient (r)
12	0.1025	0.993
24	0.2025	0.996
36	0.2475	0.998
48	0.3075	0.997

This information is useful when determining the effects of measurement errors or poor data on the model's output. For instance, suppose an error of 5°C was present in the air temperature data set. The error was present for 30 hours. What was the corresponding error in the output?

The model's sensitivity to air temperature was found to vary with time. For a 30 hour period, the sensitivity was:

$$0.00569 \times 30 + 0.05 = 0.2207^{o}C/^{o}C$$

A 5°C error in input translates into an output error of 1.1035°C.

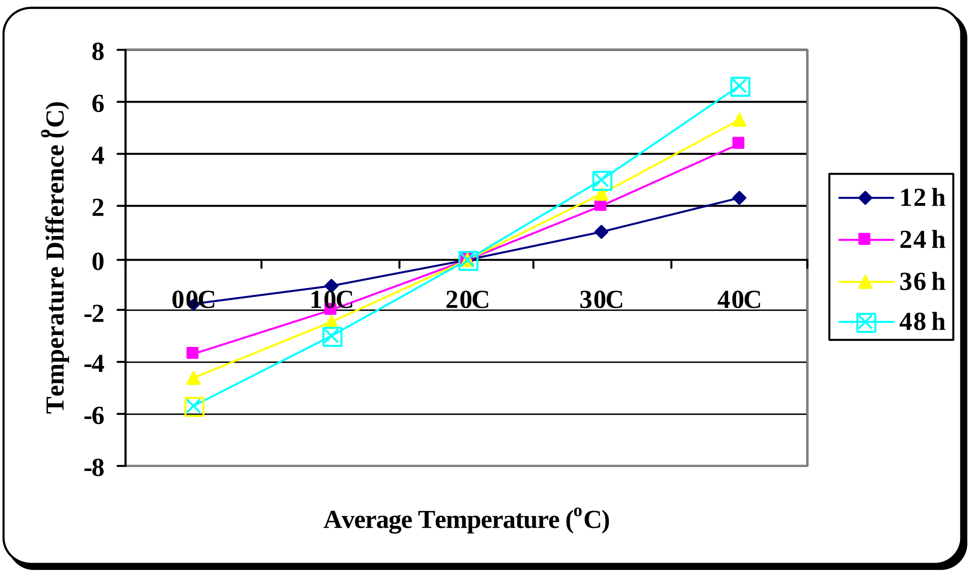

Figure 3: The sensitivity curves with respect to the average air temperature are linear (for all curves, r = 0.99). The temperature difference is the difference between the standard and the trials at either 12 hours, 24 hours, 36 hours or 48 hours. The slope of each line represents the model sensitivity to changes in the average air temperature.

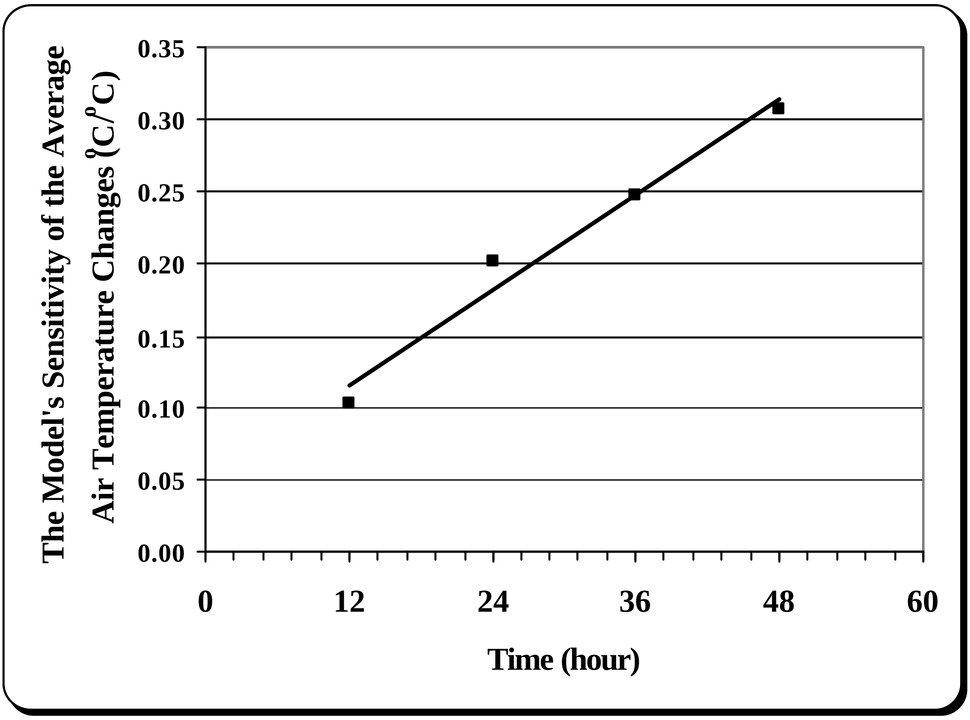

Figure 4: The model's sensitivity to the average air temperature increased with time at a rate of 0.00569 (°C/°C)/hr. The slope of each sensitivity curve was plotted against time to generate this graph.

3.2. Validation.

Ali (2006) described the model which runs utilizing input data from a 400m^2 tilapia production pond at the World Fish Center, Regional Center for Africa and West Asia, Abbassa, Abou Hammad, Sharkia, Egypt on Julian Day (JD) 201-202. The available data at this center were air temperature, wind speed and direction and water pond temperature recorded every five minutes. The simulation model uses the first two parameters to predict water pond temperature were compared to the measured values for model validation.

Correlation, Regression and Relative Percentage of Error, RPE, [(Actual – Prediction)/Actual, El-Haddad, 1977] were used as indicators of the level of agreement degree between the predicted and measured values.

The simulated temperature was fluctuated between -0.06 to 0.54 °C lower and higher than the measured temperatures for most of the 24-hour simulation (Figure 5). The RPE for the 24 hours of simulation was 0.0499%

and the correlation coefficient between simulated and measured temperatures was 0.976.

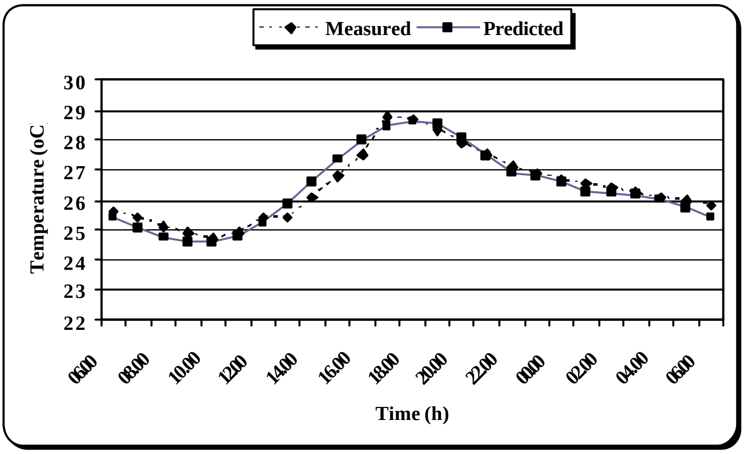

Figure (5): Measured and predicted temperatures.

3. MODEL APPLICATION.

The main objective for aquatic system is to increase the efficiency of fish growth. Fish growth is influenced not only by intrinsic factors such as fish size but also by a variety of environmental factors, including water temperature, photo-period, dissolved oxygen, unionized ammonia and food availability. Fish growth is influenced by water temperature (Brett et al., 1969; Elliot, 1976). This factor affects fish growth via their impact on food consumption (Brett, 1979; Cuenco et al., 1985). Brett and Groves (1979), found that, the growth, like other physiological processes, is regulated by body temperature, which is equal to the ambient water temperature in fish. Relative growth rate increases with rising temperature, reaches a peak at the optimum temperature for growth and falls steeply above the optimum temperature. Soderberg (1995) reported that, at about 18°C, reproductive behavior begins to be affected. Feeding and growth cease at about 15°C and the fish become inactive and disoriented.

In order to calculate the daily growth rate “DGR” (g/day), for individual fish, the model developed by Yang Yi (1998) was used. It includes the main environmental factors influencing fish growth. Those factors are temperature, dissolved oxygen and unionized ammonia. The temperature was generated from Ali model's and the other water quality parameters was entered at the optimum levels for obtain the weight of individual fish throughout the year (Table 1).

$$DGR = \{0.2914\ \tau\ \kappa\ \delta\ \varphi\ h\ f\ W^{m}\} - KW^{n} \qquad (1)$$

where: τ is the temperature factor ($0<\tau<1$, dimensionless),
κ is the photoperiod factor ($0<\kappa<1$, dimensionless),
δ is the dissolved oxygen factor ($0<\delta<1$, dimensionless),
φ is the unionized ammonia (UIA) factor ($0<\varphi<1$, dimensionless),
h is the coefficient of food consumption (g^{1-m} day^{-1}),
f is the relative feeding level ($0<f<1$, dimensionless), and
K is the coefficient of catabolism.

Brett (1979) stated that food consumption of a given fish species tended to increase with water temperature (T) increasing from a lower limit (T_{min}) below which fish did not feed to the optimum level (T_{opti}) and to decrease rapidly to zero with temperature further increasing from (T_{opti}) to an upper limit (T_{max}) above which fish did not feed. Svirezhev et al. (1984) and Bolte et al. (1995) described the effects of temperature on food consumption and therefore anabolism using the function (τ) as following:

$$t = \mathrm{EXP}\left\{-4.6\left[\frac{T_{opti} - T}{T_{opt} - T_{min}}\right]^{4}\right\} \qquad \text{if} \quad T < T_{opt} \qquad (2)$$

$$t = \mathrm{EXP}\left\{-4.6\left[\frac{T - T_{opti}}{T_{max} - T_{opti}}\right]^{4}\right\} \qquad \text{if} \quad T \geq T_{opt} \qquad (3)$$

Based on laboratory experiments with Nile tilapia, T_{min}, T_{opt} and T_{max} appear to be about 15°C (Gannam and Phillips, 1993), 28°C (Lawson, 1995) and 41°C (Denzer, 1967), respectively.

Ursin (1967) assumed that the coefficient of catabolism (K) increases exponentially with temperature. Nath et al. (1994) modified this exponential from to include the minimum temperature (assumed to be equivalent to T_{min}) below which the fish cannot survive as follow:

$$K = k_{min}\ \mathrm{EXP}\ \{\ j\ (\ T - T_{min})\} \qquad (4)$$

where: k_{min} is the coefficient of fasting catabolism (g^{1-n} day^{-1}) at T_{min}, and

j is the constant to describe temperature effects on catabolism.

Nath et al. (1994) used data on fasting Nile tilapia from Satoh et al. (1984) to estimate k_{min} and j to be 0.00133 and 0.0132, respectively.

The value of parameters ‘h’, ‘n’ and ‘m’ were assumed to be 0.80 (Bolte et al., 1995), 0.81 (Nath et al., 1994) and 0.67 (Ursin, 1967), respectively.

Table (5): Parameters used in Yang Yi model.

Parameter	Value	Reference
Photoperiod factor (κ)	1	Caulton (1982)
Dissolved oxygen factor (δ)	1	Cuenco et al. (1985) Bolte et al. (1995) (Yang Yi, 1998)
Unionized ammonia factor (φ)	1	Colt and Armstrong (1981) Cuenco et al. (1985) Bolte et al. (1995) Abdalla (1989)
Coefficient of food consumption (h)	0.81	(Bolte et al., 1995)
Relative feeding level (f)	0.37	Racoky, (1989)

Equation (1) is used to predict the daily growth rate. Equation (5) is used to calculate the accumulate growth starting by one gram of individual fish to the marketable weight of 250 grams.

$$W_n = W_{n-1} + DGR_n \tag{5}$$

where: W = average fish weight, g

n = number of day from the start.

An Excel program was constructed and used to predict the growing period of the fish. A series of experiments were carried out on the Excel program for predicting the weight of individual fish corresponding to the expected variation of pond water temperature through the growing period which is predicted by Ali model.

Figure (6) shows the daily weight gain (g/day) and weights of individual fish (g) versus growing period (day). The results indicated that the total cycle time between the stocking and the harvesting is about 180-190 days; compared with the total cycle time in natural setting is about 210-240 days. These differences were probably due to differences in water quality with respect to both dissolved oxygen and total ammonia nitrogen.

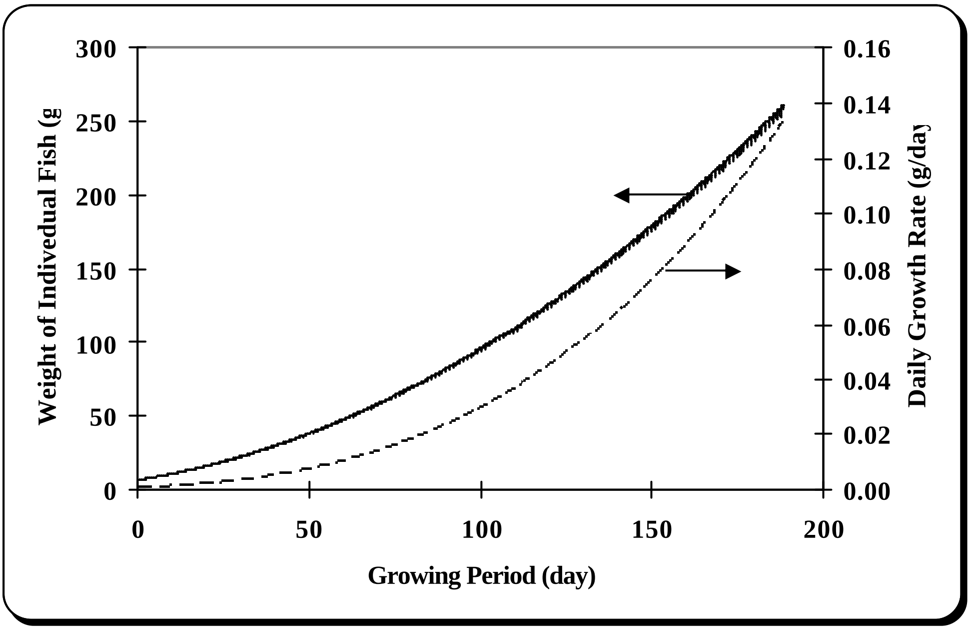

Figure (6): The weight of individual fish (g) and daily weight gain (g/day) versus growing period (day) at dissolved oxygen ≥ 3mg/L and unionized ammonia < 0.06 mg/L.

4. SUMMARY AND CONCLUSIONS.

An energy balance model was tested, validated and experimented, based on the temperature in 400 m^3 earthen aquaculture ponds, given information about the weather and pond characteristics. The model estimated energy surpluses and deficits which needed to be balanced to control the pond temperature.

A sensitivity analysis was performed to determine how the model's output was influenced by average air temperature into the pond. Variations in air temperature caused the model output to vary linearly (0.00569°C/°C/hr).

Results from model verification runs showed that the model performance was satisfactory with respect to aquaculture pond temperature. The RPE for the 24 hours of simulation was 0.0499% and the correlation coefficient between simulated and measured temperatures was 0.976. The simulated temperature was fluctuated between -0.06 to 0.54 °C lower and higher than the measured temperatures for most of the 24 hour simulation.

The application results indicated that the total cycle time between the stocking and the harvesting is about 180-190 days during the summer months; compared with the total cycle time in natural setting is about 210-240 days.

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