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Shrimp Partial Harvesting Model: Decision Support System User Manual

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User Information & Program Requirements

This Shrimp Partial Harvesting Model, often hereafter referred to as "Model," includes worksheets to simplify data entry and navigation. This manual describes the data entry procedures, equations unique to the Model, and a simplified financial analysis.

Users of the Model should have a general working knowledge of Microsoft Excel®. For a detailed description of the program, its functions and commands, consult a Microsoft Excel® manual or one of the many books describing Microsoft Excel®.

This beta version of the Model requires a Windows PC or compatible that runs Microsoft Excel® 2002, 2003, or 2007. Free space of 1MB is required.

This application requires the Solver® add-in available with Microsoft Excel®. This application is not compatible with the Premium version of the Solver® available through Frontline Systems Inc. If you have installed the Premium Solver, you must uninstall the advanced version of the add-in in order to use this Model software. The providers are not responsible for conflicts between versions of the Solver® and Microsoft Excel®.

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SHRIMP PARTIAL HARVESTING MODEL
DECISION SUPPORT SYSTEM
USER MANUAL

1. Introduction

In traditional shrimp culture and other intensive aquaculture systems, an entire crop can be harvested at one time. However, since growth and survival are density-dependent, single-batch harvesting can lead to competitive pressures that lower individual growth and increase mortalities. In comparison to single-batch harvesting, a partial harvesting approach can enhance growth rates and total yield, since a reduction in total biomass reduces competitive pressure. In partial harvesting, a crop can be partially-harvested so that only a portion of the crop is extracted. This Shrimp Partial Harvesting Model was created to simulate the effects of partial harvesting and assist farm managers in deciding the most profitable harvesting schedule.

This Shrimp Partial Harvesting Model, often hereafter referred to as "Model," is a decision support system based on a network-flow approach. This Model determines the optimal harvesting times that maximize the overall net revenue based on biological and economic factors (e.g., survival, growth, and price). This Model was implemented in a spreadsheet form using Microsoft Excel. The model requires the use of the Solver add-in. See Part B of the Appendix for instructions on installing the standard Solver. Details of the Model development also can be found in the Appendix.

Click **Begin** on the introduction screen to begin using the Partial Harvesting Model (Figure 1-1).

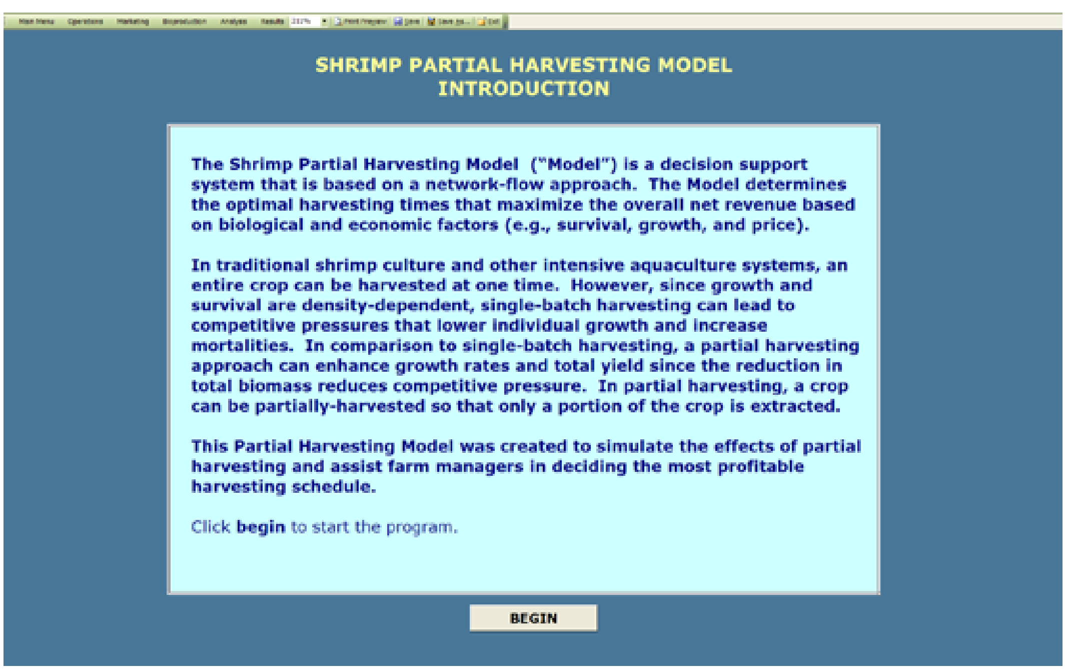


Figure 1-1. *View of the introduction screen.*

2. Main Menu

The **Main Menu** of this spreadsheet Model provides access to worksheets to enter information about farm operations **(Operations)**, market price and demand information **(Market Info)**, and bioproduction technology performance (**Bioproduction**). Use the **Analysis** button to determine the optimal harvesting strategy. Use the **Results** button to find the production schedule and overall net revenue solution for the most recent analysis.

In compatible versions of Excel, a navigation toolbar is located at the top of the screen. The navigation toolbar provides access to the worksheets, file, viewing, and printing options. The navigation toolbar is not available in Microsoft Office® 2007.

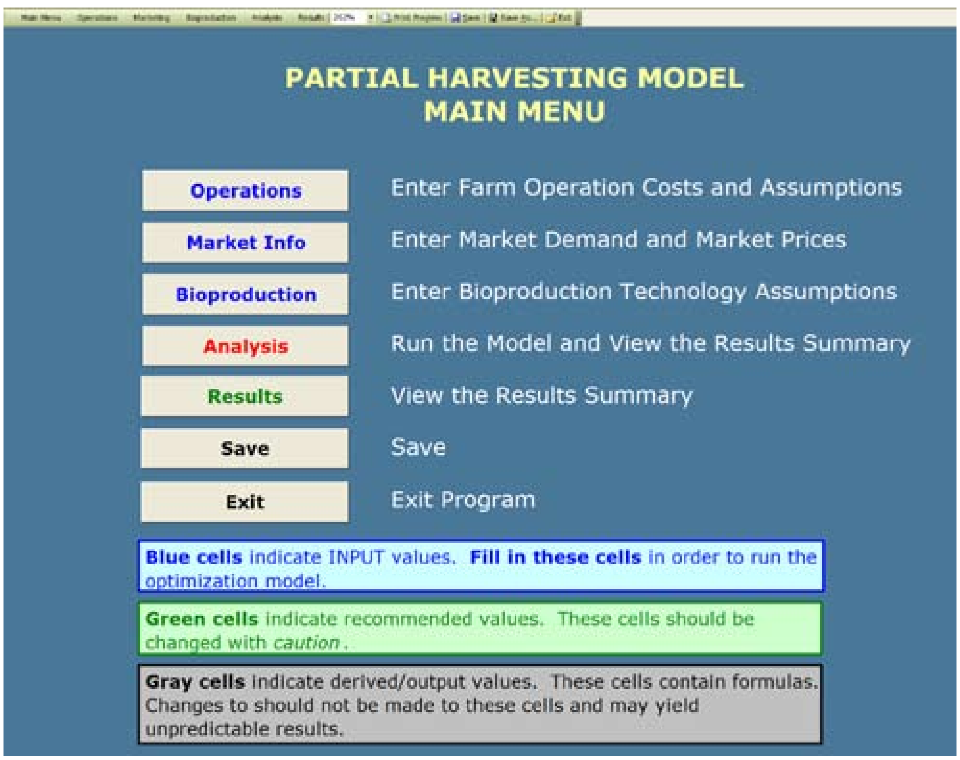


Figure 2-1. *View of the Main Menu used for navigation.*

3. Operations

Information about farm operations is needed to estimate the operating expenses that a farm will incur.

The **total pond area** must be specified in acres. The total pond area refers to the size of a single pond. Multiple ponds are not considered in this simplified partial-harvesting model. Multiple ponds introduce a more complex scheduling problem (Yu and Leung 2005).

Key farm costs are required, including the expenses listed as examples below:

- weekly **maintenance cost** ($/week),
- **feed cost** ($/lb),
- **harvest cost** ($/harvest),
- and **seed cost** ($/1000).

This Model is designed to determine if it is more advantageous to engage in multiple small "partial harvests" in comparison to a single (or few) very large harvests. In order to investigate the benefits of the partial-harvest strategy, users must specify the cost for a traditional full harvest and a partial harvest.

Figure 3-1. *View of the input screen for Operations.*

In this partial harvesting software, users specify the maximum size of the partial harvest (**partial harvest limit**) in lbs/harvest. The partial harvest limit should be greater than 0 and indicates the maximum amount that can be harvested at the **partial harvest cost** ($/harvest).

In Figure 3-1, for example, the cost to harvest any amount over 1,000 lb. is $1,000. For harvests less than or equal to 1,000 lb., the cost is $250.

Specify the **seed size** in grams. The seed cost must be specified in conventional units of dollars per thousand pieces ($/1,000). The cost is converted into $/lb based on the **seed size** entered.

Note: If there is no distinction between a partial harvest and large harvest, the harvest cost should be the same. Do not leave either of these cells blank. For large pond sizes, it may make sense to increase the partial harvest limit accordingly.

4. Market Information (Input)

Information about the market size and demand is needed to determine the potential revenue available to the farm enterprise.

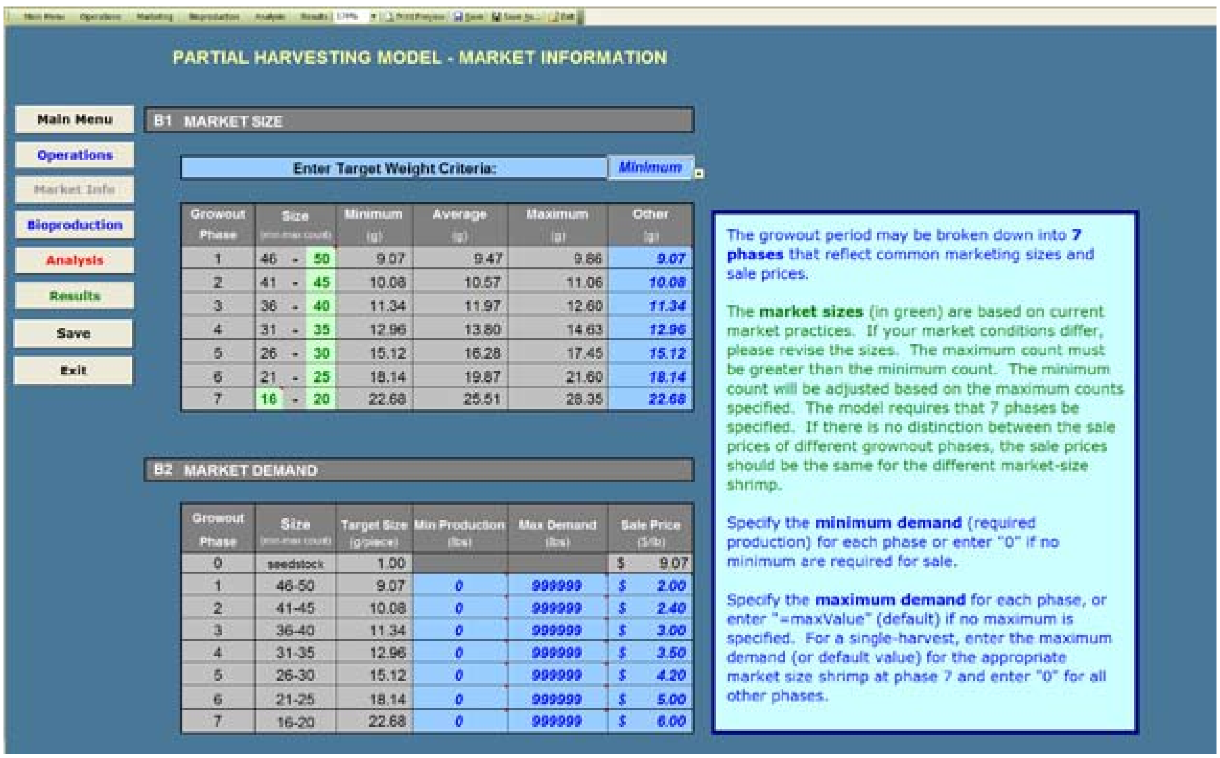


Figure 4-1. *View of the Market Information input screen.*

4.1. Market Size (B1)

This spreadsheet divides the market demand for shrimp products into seven common count sizes. Since market sizes are specified as ranges corresponding to the number of shrimp per pound, a farmer can specify his target weight criteria. In particular, a farmer may choose to meet the ***minimum***, ***average***, ***maximum***, *or* ***other*** weight criteria corresponding to each range. In this example, the farmer has chosen to meet the minimum shrimp sizes, which are 9.07 g (40–50 count), 10.08 g (41–45 count) … and 22.68 g (16–20 count).

The **minimum** setting is the most conservative and recommended for most production systems. High criteria require more efficient bioproduction technologies. This Model will not be able to provide a harvest solution if bioproduction technology (discussed in Section 5) cannot achieve the size criteria specified. Therefore, if you have difficulty running your model, you may want to revise your Market Size information.

The count ranges are based on current market demand but can be customized by a user. As illustrated in Figure 4-2, a user can customize the range settings by modifying the **maximum count** corresponding to each growout phase and the overall minimum count (i.e., the largest shrimp). The maximum count of shrimp for each market range should be decreased for successive ranges. The length of a growout period corresponds to shrimp size and shrimp count. Specifically, extending the length of growout means increasing shrimp size and reducing shrimp counts. This Model requires consecutive ranges such that the maximum counts for each range decrease for later growout phases. This Model will verify whether sizes are sequential before conducting analysis.

A user can specify target sizes in the **Other** column. When selecting "Other" for criteria, weights must be specified for each range in the far right column. These target weights should fall between the minimum and maximum count sizes for each size range. The values in the **Other** column cells are only active when the **target weight criteria** is set to "***Other***" from the drop down menu.


B1 MARKET SIZE

Enter Target Weight Criteria: Minimum

Growout Phase	Size [illegible]	Minimum [illegible]	Average [illegible]	Maxi[illegible]	[illegible]
1	46 - 50	9.07	9.47	9.86	9.07
2	41 - 45	10.08	10.57	11.06	10.08
3	36 - 40	11.34	11.97	12.60	11.34
4	31 - 35	12.96	13.80	14.63	12.96
5	26 - 30	15.12	16.28	17.45	15.12
6	21 - 25	18.14	19.87	21.60	18.14
7	16 - 20	22.68	25.51	28.35	22.68

Figure 4-2. *Specifiying target weight criteria and market size range.*

4.2. Market Demand

The **Target Size** (in grams) should reflect the weight corresponding to your **target weight criteria**. Enter the **Minimum Production** corresponding to each size. If no production is required for a size category, enter 0. In Figure 4-5, no minimum production is required. Enter the **Maximum Demand** corresponding to each size. If demand is unknown or not very large, type "=MaxValue" and the maximum default value will appear.

B2 MARKET DEMAND

Growout Phase	Size (min-max count)	Target Size (g/piece)	Min Production (lbs)	Max Demand (lbs)	Sale Price ($/lb)
0	seedstock	1.00			$ 9.07
1	46-50	9.07	0	999999	$ 2.00
2	41-45	10.08	0	999999	$ 2.40
3	36-40	11.34	0	999999	$ 3.00
4	31-35	12.96	0	999999	$ 3.50
5	26-30	15.12	0	999999	$ 4.20
6	21-25	18.14	0	999999	$ 5.00
7	16-20	22.68	0	999999	$ 6.00

Figure 4-3. *Default Minimum Production and Maximum Demand (Partial Harvest Scenario).*

Farms may be required to fulfill a minimum production level if they have contracts with shrimp wholesalers. If a minimum level of production is required, the **Minimum Production** amount must reflect the required production for each size. Figure 4-4 illustrates the case where a farm is required to produce a minimum volume of 5,000 lb. of 36–40 count and 14,000 lb. 16–20 count shrimp.

For the *single-batch harvest scenario*, the **Minimum Production** for all product sizes should be set to 0. The **Maximum Demand** should also be equal to 0 for all growout sizes except for the final harvest size (see Figure 4-5). The minimum production required must be less than the carrying capacity. The Maximum Demand for the final harvest (growout phase) cannot be equal to zero.

B2 MARKET DEMAND

Growout Phase	Size (min-max count)	Target Size (g/piece)	Min Production (lbs)	Max Demand (lbs)	Sale Price ($/lb)
0	seedstock	1.00			$ 9.07
1	46-50	9.07	0	999999	$ 2.00
2	41-45	10.08	0	999999	$ 2.40
3	36-40	11.34	5000	999999	$ 3.00
4	31-35	12.96	0	999999	$ 3.50
5	26-30	15.12	0	999999	$ 4.20
6	21-25	18.14	0	999999	$ 5.00
7	16-20	22.68	14000	999999	$ 6.00

Figure 4-4. *Specifying a production requirement (Partial Harvest Scenario with Production Requirement).*

B2 MARKET DEMAND

Growout Phase	Size (min-max count)	Target Size (g/piece)	Min Production (lbs)	Max Demand (lbs)	Sale Price ($/lb)
0	seedstock	1.00			$ 9.07
1	46-50	9.07	0	0	$ 2.00
2	41-45	10.08	0	0	$ 2.40
3	36-40	11.34	0	0	$ 3.00
4	31-35	12.96	0	0	$ 3.50
5	26-30	15.12	0	0	$ 4.20
6	21-25	18.14	0	0	$ 5.00
7	16-20	22.68	0	999999	$ 6.00

Figure 4-5. *Single-batch harvest scenario (baseline scenario).*

5. Bioproduction (Input)

In order to measure the financial performance of a shrimp farm, information about bioproduction technology is needed. Recommended bioproduction performance data is available in the Bioproduction worksheet. Values are based on data collected from a commercial shrimp farm in Hawai`i, which operated 40 one-acre intensive shrimp ponds (Yu, Leung, and Bienfang 2007). Growth and mortality information is based on traditional single-batch harvest practices.

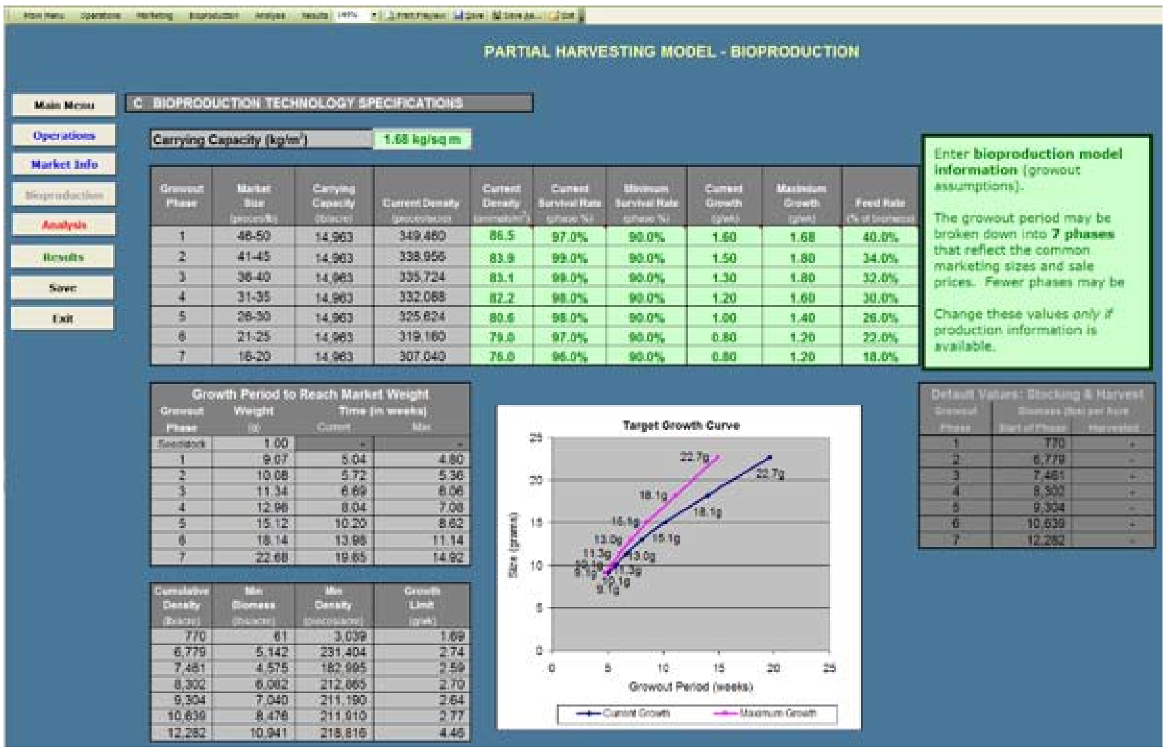


Figure 5-1. *View of input screen for Bioproduction Technology.*

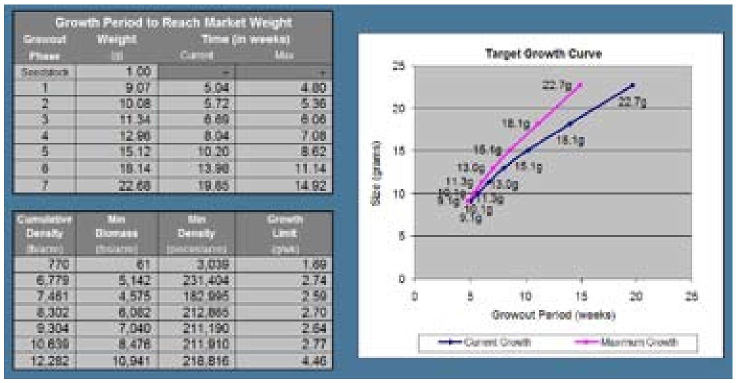
Bioproduction performance values may be changed based on your farm's production specifications:

Indicate the **carrying capacity** for your pond (kg/m^2). The carrying capacity is assumed to be the same for all phases and is based on the value you specify.

- Provide the initial stocking density for the <u>first</u> growout period in shrimp per square meter (i.e., first row in the **current density** column). Estimate the density for subsequent phases based on your pond performance. These density estimates should be based on single-batch harvest practices.
- Estimate the weekly **growth rate** (g/week) for each growout phase.
- Provide the **current survival rate** for each phase (% survival).

- Enter the **maximum growth** rate for each phase (g/week). Current growth rates should always be less than maximum growth rates.
- Enter the **feed rate** as a percentage of pond biomass.

The worksheet also provides a summary about the growth curve, time required to reach market weight, and growth limits based on the production technology specified.



Growth Period to Reach Market Weight			
Growout Phase	Weight (g)	Time (in weeks) Current	Max
Seedstock	1.00	-	-
1	9.07	5.04	4.00
2	10.08	5.72	5.36
3	11.34	6.69	6.06
4	12.96	8.04	7.08
5	15.12	10.20	8.62
6	18.14	13.90	11.14
7	22.68	19.65	14.92

Cumulative Density	Min Biomass	Min Density	Growth Limit
770	61	3,039	1.69
6,779	5,142	231,404	2.74
7,461	4,575	182,995	2.59
8,302	6,082	212,865	2.70
9,304	7,040	211,190	2.64
10,639	8,476	211,910	2.77
12,282	10,941	218,816	4.46

Figure 5-2. *Bioproduction growth and limit summary.*

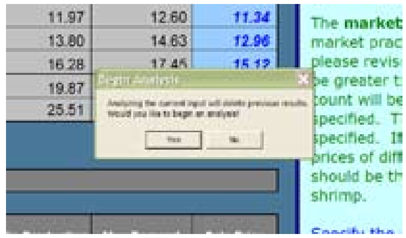
6. Analysis

To run a partial harvest analysis based on your input, click the **Analysis** button.

Some validation has been built into this Model. This worksheet verifies that entered values are consistent or acceptable within the workbook. This program will verify that the following constraints are met:

- Count sizes should decrease for subsequent phases.
- Maximum growth is less than the growth limit for each phase.

Please be patient as the analysis runs through a sequence of six different algorithm settings. If your analysis is successful, you will be directed to a summary report. The optimal solution is compared to the single-batch harvesting solution in this report.



Please wait while the program determines the optimal production schedule based on your input.

Please keep this window active during the analysis.

Press escape (Esc) to stop the analysis.

Figure 6-1. *Beginning the analysis.*

Note: If the program is not able to run successfully based on your input, a partial-harvest solution will not be given. You will receive a message that requests revision of your inputs.

7. Results

Results include summary information about bioproduction performance (D1), market summary (D2), revenue and expenses (D3), and net revenue (D4).

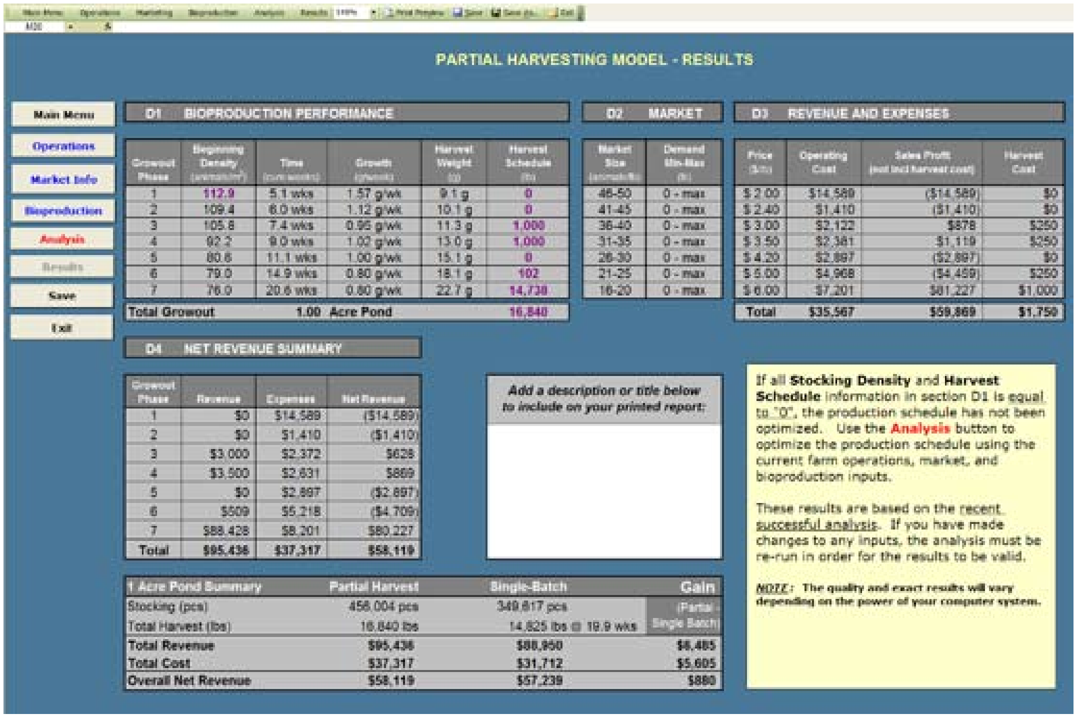


Figure 7-1. *Results spreadsheet.*

7.1. Bioproduction Performance

Information about Bioproduction Performance includes initial density, duration of each phase, weekly growth rates, harvest weight, and harvest schedule. The optimal partial harvesting solution for a scenario with no production requirement and unlimited demand is indicated in Figure 7-2. According to these results, the stocking density should be 112.9 shrimp/m^2 with harvests after 7.4 weeks (1,000 lb. of 36–40 count shrimp), 9.0 weeks (1,000 lb. of 31–35 count shrimp), 14.9 weeks (102 lb. of 21–25 count shrimp), and 20.6 weeks (14,738 lb. of 16–20 count shrimp). The total weight harvested by the end of the 20.6 weeks is 16,840 lb. of shrimp.

7.2. Market Demand

In the **Market** section, the minimum demand (required production) and maximum demand values entered earlier by a user in the Bioproduction sheet input are displayed. These demand ranges indicate market constraints imposed on the farm. The count ranges used in this analysis are also displayed for reference. This market information is illustrated in Figure 7-2.

D1 BIOPRODUCTION PERFORMANCE						D2 MARKET		D3 REVENUE AND EXPENSES			
Growout Phase	Beginning Density (animals/m^2)	Time (cum weeks)	Growth (g/week)	Harvest Weight (g)	Harvest Schedule (lb)	Market Size (animals/lb)	Demand Min-Max (lb)	Price ($/lb)	Operating Cost	Sales Profit (not incl harvest cost)	Harvest Cost
1	112.9	5.1 wks	1.57 g/wk	9.1 g	0	46-50	0 - max	$ 2.00	$14,589	($14,589)	$0
2	109.4	6.0 wks	1.12 g/wk	10.1 g	0	41-45	0 - max	$ 2.40	$1,410	($1,410)	$0
3	105.8	7.4 wks	0.95 g/wk	11.3 g	1,000	36-40	0 - max	$ 3.00	$2,122	$878	$250
4	92.2	9.0 wks	1.02 g/wk	13.0 g	1,000	31-35	0 - max	$ 3.50	$2,381	$1,119	$250
5	80.6	11.1 wks	1.00 g/wk	15.1 g	0	26-30	0 - max	$ 4.20	$2,897	($2,897)	$0
6	79.0	14.9 wks	0.80 g/wk	18.1 g	102	21-25	0 - max	$ 5.00	$4,968	($4,459)	$250
7	76.0	20.6 wks	0.80 g/wk	22.7 g	14,738	16-20	0 - max	$ 6.00	$7,201	$81,227	$1,000
Total Growout	1.00 Acre Pond				16,840			Total	$35,567	$59,869	$1,750

Figure 7-2. *Bioproduction performance and market information.*

7.3. Revenue and Expenses

Operating costs, profit from sales (revenue – operating costs), and harvest costs are listed in the results worksheet (D3). Profit from sales (revenue – production costs) is calculated for each growout phase (Figure 7-2).

7.4. Net Revenue Summary

The **Net Revenue Summary** provides information on revenue from sales, expenses (operating costs and harvest costs), and net revenue for each growout phase.

The **Pond Summary** is based on user-entered information on operations, bioproduction, and market. The partial harvest solution is always compared to the single-batch, full-harvest optimal solution. In the example above (Figure 7-3), the partial harvest solution is expected to generate an overall net revenue of $58,119 in comparison to the single-batch harvest of $57,239 at 19.9 weeks. Therefore, the partial harvest method is expected to increase overall net revenue by $880.

D4 NET REVENUE SUMMARY			
Growout Phase	Revenue	Expenses	Net Revenue
1	$0	$14,589	($14,589)
2	$0	$1,410	($1,410)
3	$3,000	$2,372	$628
4	$3,500	$2,631	$869
5	$0	$2,897	($2,897)
6	$509	$5,218	($4,709)
7	$88,428	$8,201	$80,227
Total	$95,436	$37,317	$58,119

Add a description or title below to include on your printed report.

1 Acre Pond Summary	Partial Harvest	Single-Batch	Gain
Stocking (pcs)	456,004 pcs	349,617 pcs	(Partial - Single Batch)
Total Harvest (lbs)	16,840 lbs	14,825 lbs @ 19.9 wks	
Total Revenue	$95,436	$88,950	$6,485
Total Cost	$37,317	$31,712	$5,605
Overall Net Revenue	$58,119	$57,239	$880

Figure 7-3. *Partial harvest result compared to single-batch baseline scenario.*

7.5. Production Requirement Example

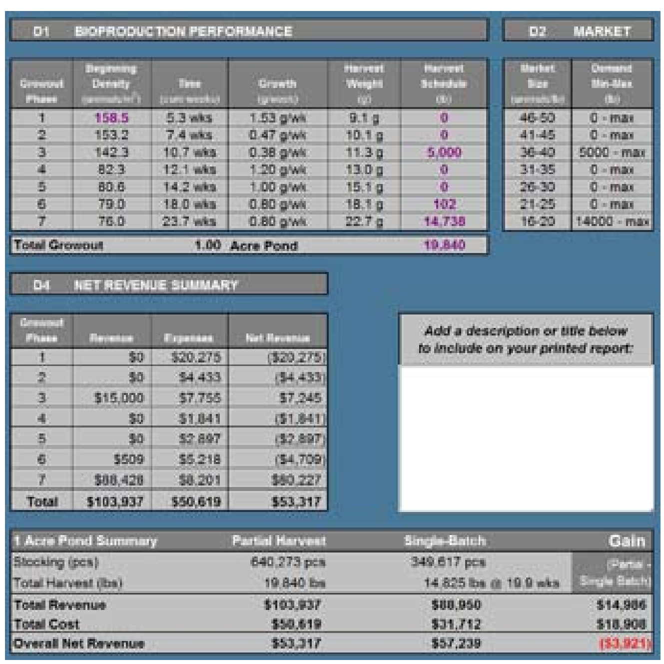
The following example (Figure 7-4) illustrates the impact of market constraints on the partial harvest solution. In contractual business relationships, a farm may be required to produce a minimum level of production for a certain market size of shrimp. Given these constraints, a producer is forced to harvest a minimum volume of product at specific times during the growout period.

In this production requirement (PR) example, the farm is required to produce 5,000 lb. of 36–40 count shrimp and 14,000 lb. of 16–20 count shrimp. The market demand inputs for this scenario are entered as illustrated earlier in Figure 4-4.

Note: Whenever changes are made to input values, the analysis must be run in order to determine the harvest schedule based on the new information.

Using the Shrimp Partial Harvesting Model on this example produces the following analysis. Optimal stocking is 158.5 animals per square meter. Shrimp should be harvested as follows: 5,000 lb. at 10.7 weeks (36–40 count), 102 lb. at 18.0 weeks (21–25 count) and 14,738 lb. at 23.7 weeks (16–20 count). The result of this production schedule is overall net revenue of $53,317 and a total harvest of 19,840 lb. These production requirements, then, result in a loss of $3,921 in comparison to the traditional single-batch harvest method.

In comparison to the optimal partial harvest solution with no production requirement exhibited in Figure 7-3, the projected loss is $4,801 (= $58,119 - $53,317). This example illustrates the case where a farmer is disadvantaged by a wholesaling contract that imposes production requirements.



D1 BIOPRODUCTION PERFORMANCE

Growout Phase	Beginning Density (animals/m²)	Time (cum weeks)	Growth (g/week)	Harvest Weight (g)	Harvest Schedule (lb)
1	158.5	5.3 wks	1.53 g/wk	9.1 g	0
2	153.2	7.4 wks	0.47 g/wk	10.1 g	0
3	142.3	10.7 wks	0.38 g/wk	11.3 g	5,000
4	82.3	12.1 wks	1.20 g/wk	13.0 g	0
5	80.6	14.2 wks	1.00 g/wk	15.1 g	0
6	79.0	18.0 wks	0.80 g/wk	18.1 g	102
7	76.0	23.7 wks	0.80 g/wk	22.7 g	14,738
Total Growout	1.00	Acre Pond			19,840

D2 MARKET

Market Size (animals/lb)	Demand Min-Max (lb)
46-50	0 - max
41-45	0 - max
36-40	5000 - max
31-35	0 - max
26-30	0 - max
21-25	0 - max
16-20	14000 - max

D4 NET REVENUE SUMMARY

Growout Phase	Revenue	Expenses	Net Revenue
1	$0	$20,275	($20,275)
2	$0	$4,433	($4,433)
3	$15,000	$7,755	$7,245
4	$0	$1,841	($1,841)
5	$0	$2,897	($2,897)
6	$509	$5,218	($4,709)
7	$88,428	$8,201	$80,227
Total	$103,937	$50,619	$53,317

Add a description or title below to include on your printed report:

1 Acre Pond Summary	Partial Harvest	Single-Batch	Gain (Partial - Single Batch)
Stocking (pcs)	640,273 pcs	349,617 pcs	
Total Harvest (lbs)	19,840 lbs	14,825 lbs @ 19.9 wks	
Total Revenue	$103,937	$88,950	$14,986
Total Cost	$50,619	$31,712	$18,908
Overall Net Revenue	$53,317	$57,239	($3,921)

Figure 7-4. *Partial harvest result for required production compared to the single-batch baseline scenario.*

8. References

R. Yu and P.S. Leung. 2005. Optimal harvesting strategies for a multi-pond and multi-cycle shrimp operation: a practical network model. *Mathematics and Computers in Simulation* 68(4): 339–354.

R. Yu, P.S. Leung, and P. Bienfang. 2007. Modeling partial harvesting in intensive shrimp culture: a network-flow approach. *European Journal of Operational Research*. doi:10.1016/j.ejor.2007.10.031.

APPENDIX

A. The Mathematical Model

Suppose a shrimp production cycle is comprised of N growout phases. Let H^i and P_s^i denote the amount of shrimp harvested at the i[th] growout phase in kg and its associated shrimp price ($/kg),

$$\sum_{i=1}^{N} P_s^i \cdot H^i - \sum_{i=1}^{N} (C_f^i + C_m^i) - \sum_{i=1}^{N} HC^i$$

$$\text{s.t.} \quad HC^i = 0, \quad \text{if } H^i = 0 \qquad (1)$$

$$HC^i = C_h, \text{ if } H^i > 0$$

$$H_{max}^i \geq H^i \geq H_{min}^i$$

respectively. The overall net revenue from this production cycle can be estimated as follows:

where C_f^i, C_m^i, HC^i are feed cost, maintenance cost , and harvest cost occurring in the i[th] growout phase, respectively. Only a quasi-fixed harvest cost, C_h , is considered in the present model. In other words, if the producer decides to do a harvest, it will result in a fixed expenditure; C_h. H_{max}^i and H_{min}^i are the maximum and minimum amount of shrimp that can be extracted by the i[th] harvest.

Let D^i and B^i denote the density of shrimp stock (e.g., kg/m^2) at the beginning and end of the i[th] growout phase, respectively. Define V as the total area (or volume) of the water body of the growout facility (e.g., m^2). Assume there is no restocking between two successive growout phases. The amount of shrimp that is extracted by the i[th] harvest at the end of the i[th] growout phase, H^i , then can be estimated as $H^i = VB^i - VD^{i+1}$, i.e., the difference between the biomass at the end of the i[th] growout phase and that at the beginning of the i+1[th] growout phase. Since all the shrimp will be harvested at the end of the growout cycle, it implies $H^N = VB^N$. Assume the objective of the producer is to maximize overall net revenue.

The partial harvesting problem can be expressed as follows:

$$\underset{D^i}{\text{Max}} \sum_{i=1}^{N-1} [P_s^i \cdot V \cdot (B^i\text{-}D^{i+1})\text{-}C_f^i\text{-}C_m^i\text{-}HC^i] + P_s^N \cdot V \cdot B^N\text{-}C_f^N\text{-}C_m^N\text{-}HC^N \tag{2}$$

Let W^i denote the target weight of shrimp in the i[th] growout phase (e.g., g/shrimp). Define $D^{N+1}=0$ and $P_s^0 = C_s$, where C_s is seed cost per unit (e.g., \$/kg). Problem (2) then can be rewritten as follows:

$$\underset{D^i}{\text{Max}} \sum_{i=1}^{N} [V \cdot (P_s^i \cdot B^i\text{-}P_s^{i\text{-}1} \cdot D^i)\text{-}C_f^i\text{-}C_m^i\text{-}HC^i] \tag{3}$$

s.t.

$$G^i = g(D^i) = \begin{cases} 0, & \text{if } D^i > D_{max} \\ G_{max}, & \text{if } D^i < D^i_{min} \\ G_{max}\text{-}(D_{max}\text{-}D^i)(G^i_{max}\text{-}G^i_{current})/(D_{max}\text{-}D^i_{current}), & \text{otherwise} \end{cases} \tag{4}$$

$$S^i = s(D^i) = \begin{cases} 0, & \text{if } D^i > D_{max} \\ S_{max}, & \text{if } D^i < D^i_{current} \\ (D_{max}\text{-}D^i)(S^i_{current}\text{-}S^i_{min})/(D_{max}\text{-}D^i_{current}) + S^i_{min}, & \text{otherwise} \end{cases} \tag{5}$$

$$B^i = \frac{W^i}{W^{i\text{-}1}} D^i S^i \tag{6}$$

$$C_f^i = P_f \frac{V \cdot (D^i + B^i)}{2} \frac{W^i\text{-}W^{i\text{-}1}}{G^i} \cdot FR^i \tag{7}$$

$$C_m^i = P_m \frac{W^i\text{-}W^{i\text{-}1}}{G^i} \tag{8}$$

$$H^i_{max} \geq V \cdot (B^i\text{-}D^{i+1}) \geq H^i_{min} \tag{9}$$

$$HC^i = \begin{cases} 0, & \text{if } V(B^i\text{-}D^{i+1})=0 \\ C_h, & \text{otherwise} \end{cases} \tag{10}$$

$$P_s^0 = C_s,\ D^{N+1}=0, \tag{11}$$

where G^i and S^i are the growth (e.g., g/week) and survival rates (%) of shrimp in the i^{th} growout phase and equations (4) and (5) are the corresponding density-dependent growth and survival functions used to estimate the impacts of density on growth and survival. As illustrated in Figures 1 and 2, D_{max} is the density at the carrying capacity (e.g., kg/m^2), $D^i_{current}$ is the density under the current practice, and G^i_{max} and D^i_{min} are the maximum possible growth (e.g., g/week) and its associated minimum possible density. Similarly, $S^i_{current}$ is the survival rate under the current density level ($D^i_{current}$) and S^i_{min} is the survival rate at the carrying capacity (D_{max}). Equation (6) defines that the density at the end of the i^{th} growout phase (B^i) is the product of the density at the beginning of the i^{th} growout phase (D^i), the associated survival rate (S^i), and the rate of increased shrimp weight ($\frac{W^i}{W^{i-1}}$). Equation (7) estimates total feed costs in the i^{th} growout phase, where P_f and FR^i are, respectively, feed cost per unit (e.g., \$/kg) and average feeding rate in terms of percentage of the prevailing biomass. Equation (8) calculates total maintenance costs, where P_m is maintenance cost per unit (e.g., \$/week). Equation (9) specifies the maximum and minimum possible amount of shrimp that can be harvested by the i^{th} harvest. Equation (10) is the quasi-fixed harvest cost function.

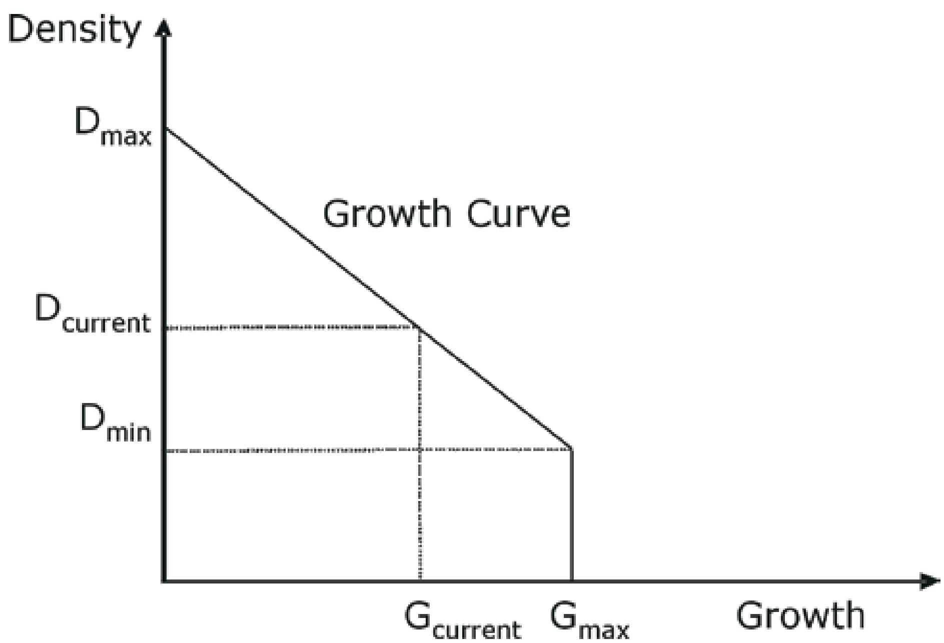


Figure A-1. *Density-dependent growth.*

Note: D_{max} denotes the density at the carrying capacity (e.g., kg/m^2); $D_{current}$ and $G_{current}$ denote the density (e.g., kg/m^2) and growth (e.g., g/week) under the current practice; G_{max} and D_{min} denote the maximum possible growth (e.g., g/week) and associated minimum possible density (e.g., kg/m^2).

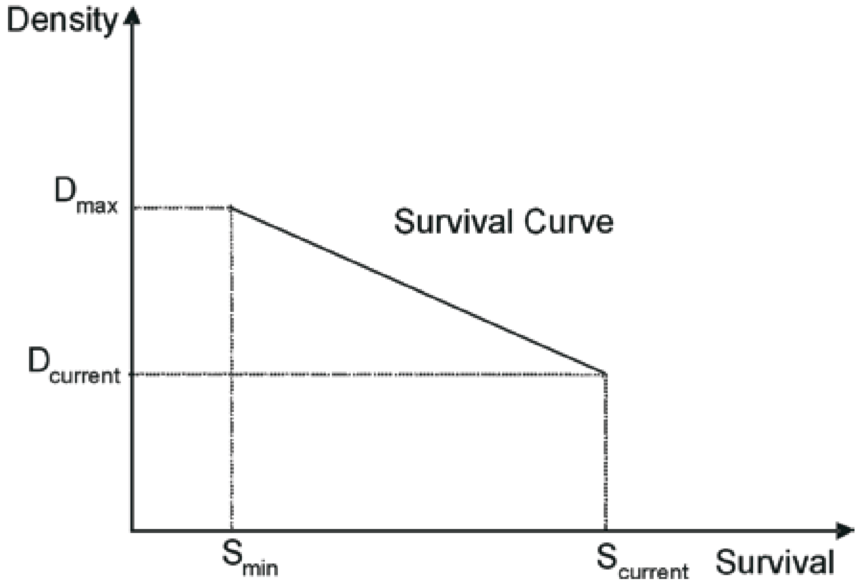


Figure A-2. *Density-dependent survival.*

Note: D_{max} denotes the density at the carrying capacity (e.g., kg/m^2), $D_{current}$ and $S_{current}$ denote the density (e.g., kg/m^2) and survival rate (%) under the current practice, and S_{min} denotes the survival rate (%) at carrying capacity.

B. Installing the Solver

The Frontline Solver is required in order to run this Shrimp Partial Harvesting Model. If the Solver add-in has already been activated in your Microsoft Excel software, it will appear in your Tools drop-down menu.

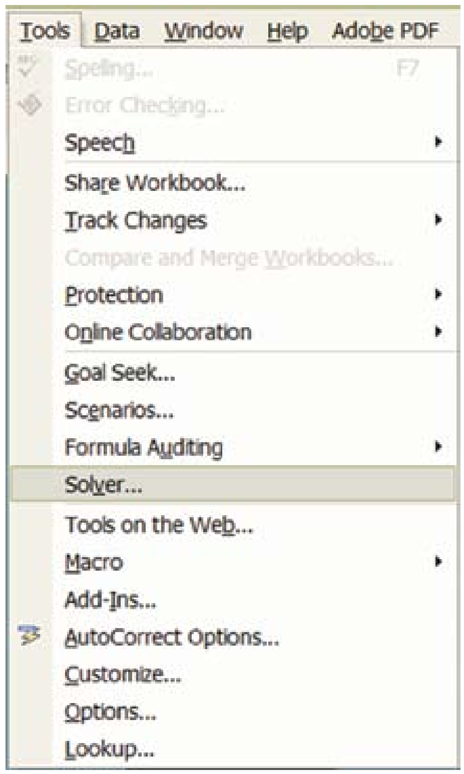


Figure B-1. *Solver appears in the Tools menu of Excel.*

B.1. Solver is <u>not</u> located in the Tools menu

If the Solver is not located in the Tools menu, the following steps will assist you in loading the Solver add-in.

1) Start Excel and click on **Tools** on the menu. Then click on **Add-ins...**
2) A box should appear with a list of add-ins.
   If there is no checkbox for "Solver Add-in," go to **B.2.** on the next page.
3) Check the checkbox for the Solver add-in
4) Click **OK**.
5) The Solver should now be listed on the Tools menu in Excel (see Figure B-1).

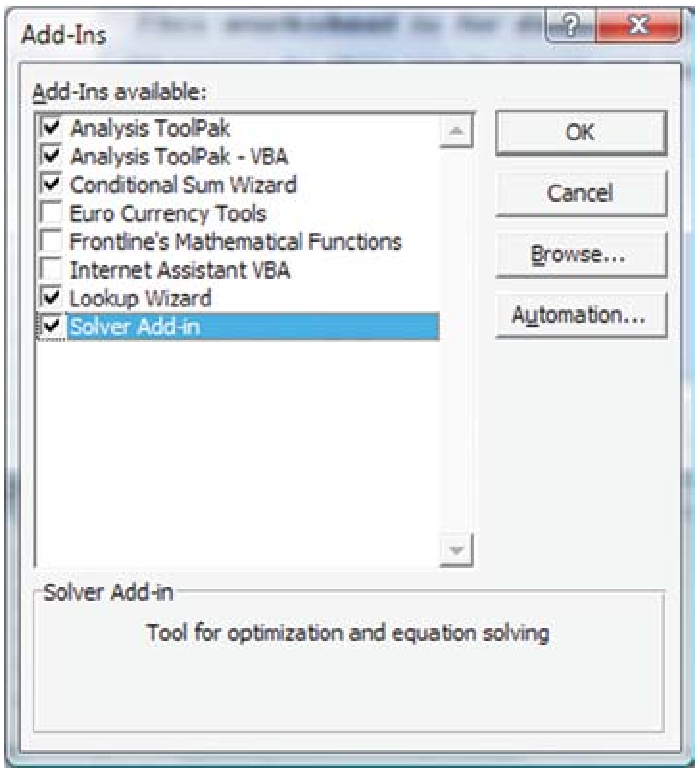


Figure B-2. *Select the Solver add-in.*

B.2. Solver is not located in the list of available add-ins.

If the Solver is not located in your list of add-ins, you will need your Microsoft Office CD-ROM. The following steps will assist you in installing the Solver add-in.

1) Insert the Microsoft CD-ROM. If the CD does not run the setup program automatically, open My Computer, locate and double-click the **setup.exe** file on the CD.
2) Click the **Add or Remove Features** button.
3) In the graphic that then appears, click the little plus sign next to Microsoft Excel for Windows. This opens up the outline under that box.
4) Click the plus sign next to “Add-ins” in order to expand the list. The Solver should be listed in the expanded list of add-Ins.
5) Click on **Solver** and choose Run from My Computer, so that the box is white, with no yellow “1.” This picture illustrates how it should look when you’re done.
6) Then click **Update Now** to proceed with the installation. Depending on your version of Microsoft Office, your screen may be different, but this procedure will be similar.
7) Go to step **B.1** on the previous page.

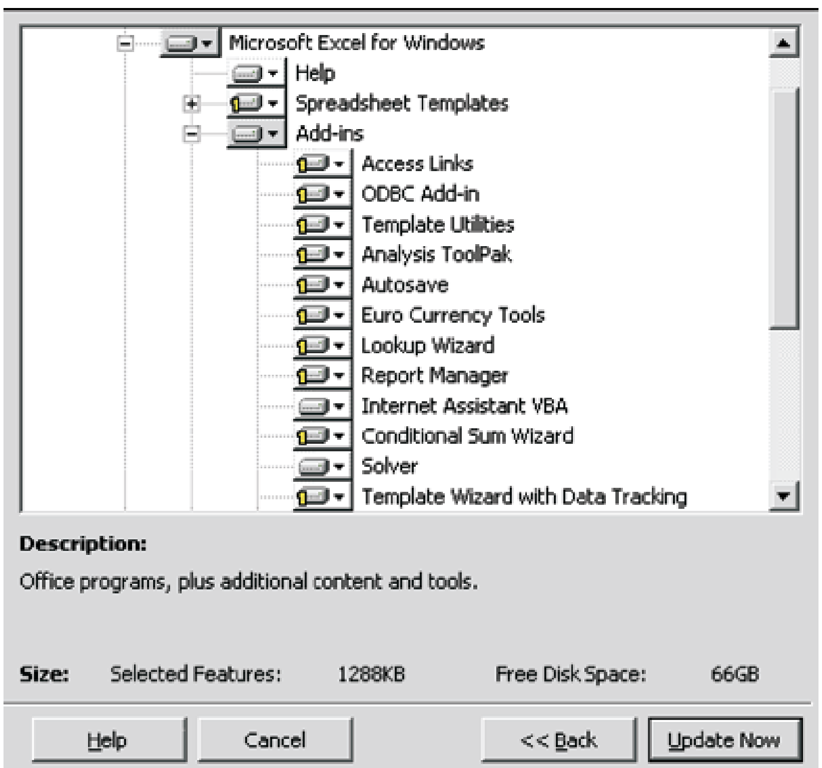


Figure B-3. *Installing the Excel Solver add-in.*

C. Macros used in the Model

This Shrimp Partial Harvesting Model contains macros and executable VBA script. Macros must be enabled in order to use this Model. When opening this Model in Microsoft Excel, the following warning about macros may appear:

C.1. Enabling macros

Click on the **Enable Macros** options in order for this Model to run properly.

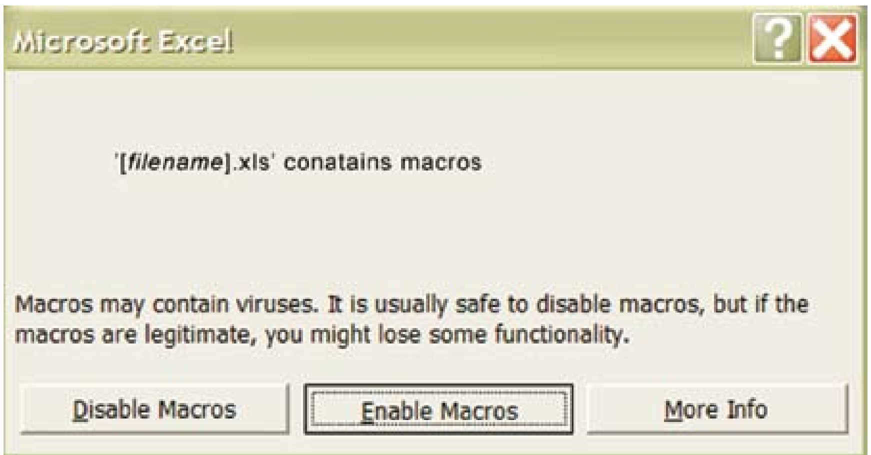


Figure C-1. *Enable Macros dialog box.*

If you open the file and the Enable Macros dialog box does <u>not</u> appear, please *change your security settings* in Excel (see **C.2.** on the next page).

C.2. Changing your security settings

1) From the Excel **Tools** Menu, select **Macro** > **Security**.

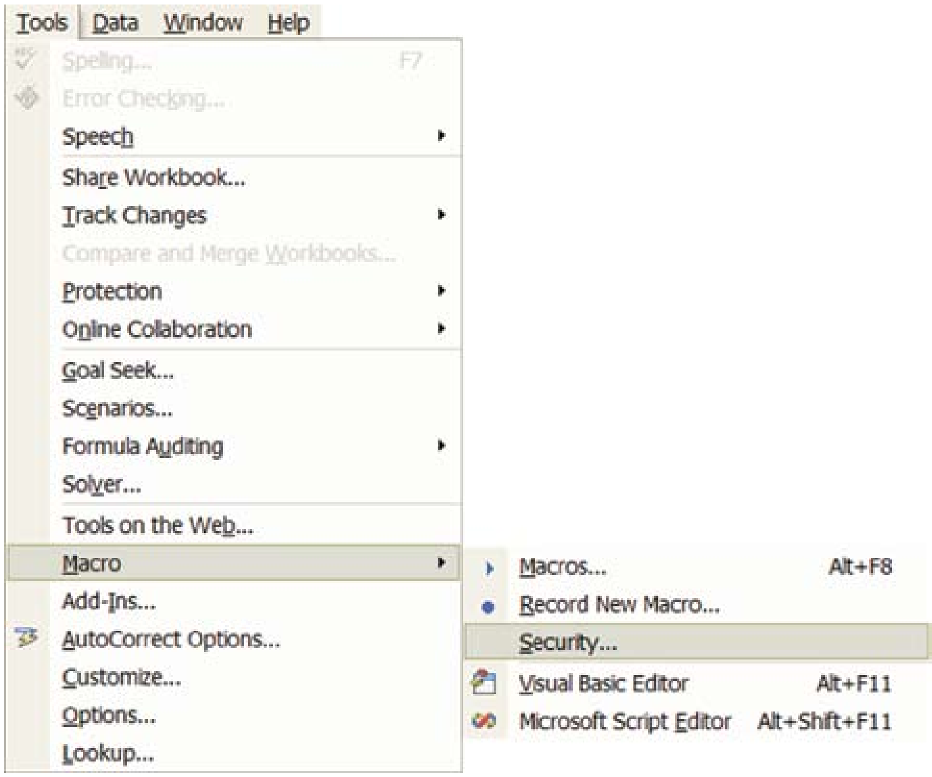


Figure C-2. *Changing Macro Security settings.*

2) In the Dialog box, select **Medium** security
3) Press OK.
4) Close the file, and then open it again. You should see the Enable Macros dialog box (Figure C-1)

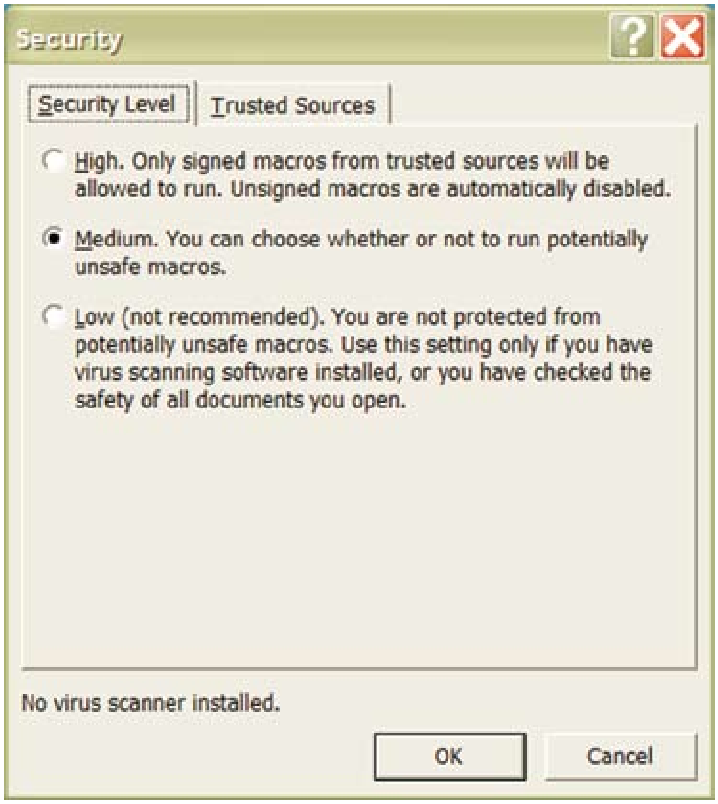


Figure C-3. *Changing the macro security level.*

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