NUTRIENT REDUCTION COST EFFECTIVENESS ANALYSIS, 1996 UPDATE

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**Statutory Citations: Federal - Pub. L. 91-575, 84 Stat. 1509 (December 1970); Maryland - Natural Resources Sec. 8-301 (Michie 1974); New York - ECL Sec. 21-1301 (McKinney 1973); and Pennsylvania - 32 P.S. 820.1 (Supp. 1976).*

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TABLE OF CONTENTS

PROJECT BACKGROUND INFORMATION 1
GETTING STARTED 1

System Requirements 1
Installation and Setup 1
Windows Help File 2

SYSTEM OVERVIEW 2

Description of What's Best! 2
Use of MS-Access and MS-Excel 2
Program/Model Flow 3

MS Access 3
MS Excel 3

CEA MODEL OPERATION 5

Starting the Model 5
MS-Access 5

Import screen 5
Access main menu 6
View form 6
Edit data 6
Print data 6
Additional options 6

MS-Excel 6

Main menu 6
Model overview 6
Status display 6
Scenario summary 7
Buttons 7

Nonpoint #1 (nonpoint source options) 7
Point #1 (point source options) 7
Effluent limits (point effluent limits) 7
Threshold values (point thresholds) 7
Discount and period (cost equation variables) 7
Built-in scenario (built-in optimization options) 8
Custom scenario (customizable optimization options) 8

Solving the scenario 9
Output sheet 9

Nonpoint summary 9
Nonpoint details 9
Point source 9

Data Model Worksheets 9

Menu 9
Output sheet 9
Point source loading 10
Optimization dialog 10
Nonpoint options 10
Point source options 10
Added BMPs 10
Return values 10
Acres by land use 10
Nitrogen loading 10
Nitrogen transport 11
Phosphorus loading 11
Phosphorus transport 11
Nitrogen reduction efficiency 11
Phosphorus reduction efficiency 12
BMP costs 12
HEL and SBF acres 12
Base point loads TB 13
Base nonpoint loads TB 14
Phosphorus loads after 14
Nitrogen loads after 14
Land use after optimization 15
Costs 15
Phosphorus reduction results 15
Nitrogen reduction results 16
Point source data 17
Point source costs per retrofit 18
Point nitrogen reduction 18
Point phosphorus reduction 18
Point adjustables 18
Point costs after optimization 18
Point nitrogen reduction after 18
Point phosphorus reduction after 19
Pt phos red sheet 19
Pt nit red sheet 19
Pt costs sheet 19
Retrofit Cap&O&M cost parameters 20
Macro 1 20

DEFINITION OF TERMS 20

MODEL SCENARIOS 22

Scenario 1 – Minimized Costs 22
Scenario 2 – BNR Only 22

Scenario 3 – Phos. Only 22
Scenario 4 – BNR & Phosphorus Reduction 22
Results 22

SUMMARY 24

REFERENCES 25

APPENDIXES

A. Supporting Documents 27

Pennsylvania Nutrient Reduction Strategy, Summary of Nutrient Reduction Factors and Nutrient Reduction Calculations 29

Matrix of BMP Efficiencies Determined by the Tributary Strategy Workgroup, Table 1. BMP Efficiency Matrix 37

Tech Memos 41

B. Built-in Scenario Results 57

Scenario 1 – Minimized Costs 59

Scenario 2 – BNR Only 77

Scenario 3 – Phosphorous Only 95

Scenario 4 – BNR and Phosphorous Reduction 113

PLATES

1. Flow Diagram ..... Back

TABLES

1. Cost Effectiveness Analysis Summary Results for Four Built-in Scenarios 23

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Copies of the model code are available from:

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PROJECT BACKGROUND INFORMATION

Under the terms of the 1992 Chesapeake Bay Agreement, the Pennsylvania Department of Environmental Protection (Pa. DEP) is responsible for developing and implementing tributary-specific strategies to achieve certain nutrient reduction goals by the year 2000. In April of 1993, Pa. DEP contracted with the Susquehanna River Basin Commission (SRBC) to develop a strategy for the Susquehanna River Basin in Pennsylvania. SRBC analyzed options to determine the least costly means for achieving a 40 percent reduction in the controllable load of nutrients reaching the Chesapeake Bay from the Susquehanna River (Seay, 1995). SRBC then produced the report, "Nutrient Reduction Cost-Effectiveness Analyses Component 2, Nutrient Reduction Strategy."

Ongoing efforts by the Chesapeake Bay Program (CBP) in recalibrating the watershed model and recent discharge data collected by Pa. DEP on point source loads indicated a need for a reevaluation and refinement of the work completed in 1995 by Seay. The Pa. DEP requested SRBC to reanalyze the cost/benefit strategy utilizing an optimization solver program that uses a mix of nonpoint best management practices (BMPs) and point source retrofits to test different scenarios in the Susquehanna and Potomac River drainages in Pennsylvania. These scenarios include: (1) identify the absolute minimum cost in reaching a 40 percent reduction in controllable load; (2) maximize nutrient reductions with only biological nutrient removal (BNR) available for point source reductions; (3) maximize nutrient reductions with only phosphorus reduction retrofits available for point source reductions; and (4) maximize nutrient reductions with both BNR and phosphorus only retrofits available for point source reductions.

SRBC designed the Cost Effectiveness Analysis (CEA) model for this project. This model will benefit the Pa. DEP by providing a model that updates the strategies proposed or in use to meet the CBP year 2000 nutrient reduction. The cost effectiveness approach is useful in identifying tradeoffs that exist between program cost and program thrusts.

GETTING STARTED

The CEA model requires an IBM compatible personal computer with sufficient processor speed and RAM to run Microsoft's Access and Excel simultaneously. The model has successfully run on a Pentium-166 MHz class PC with 32 Mb RAM.

System Requirements

Microsoft Windows 95

Microsoft Access and Excel 97

What's Best! version 3.0

By Lindo Systems Inc.
P.O. Box 148231
Chicago IL 60614

Phone: (312)871-2524
Web: http:\\www.lindo.com

Hard drive space 5.5 MB

Installation and Setup

There are three files distributed on the Cost Effectiveness disks: two application files (Shortcuts.EXE, Cost Effective.EXE) and a text file (Setup.TXT). The text file contains a document that explains how to set up the cost

effectiveness analysis. The user is given the following instructions:

1. Run the setup of What's Best!, and it will be added as an add-in in Excel.
2. Set two options in the options dialog box in the WB! Menu in Excel.

   Numeric Cells: 25,000

   Max Solver Memory: 250

   The solver will not run if these parameters are not set.

3. Close Excel and place Disk 1 in the floppy drive (A).
4. Run Cost Effective.EXE. This will set up the needed files into C:\Cost Effectiveness.
5. Run Shortcuts.EXE (this will set up the program group from which the user will run the model).
6. Open "Open CEA Model From Beginning" under the "Cost Effectiveness Analysis" program group. To view the help file run "Help With CEA" that is in the same program group.

Windows Help File

Once the model is installed, a file named CEAhelp.hlp will be listed in the folder C:\Cost Effectiveness. This file can be opened from the program file called "CEA Help File" in the Cost Effectiveness Analysis program group. This file contains indexed information on the model that provides a description of the model's dialog boxes, worksheets, modules, terminology, and a discussion of results from four scenarios based on the default data in the model.

SYSTEM OVERVIEW

Description of What's Best!

What's Best! is an all-purpose optimization solver add-on for spreadsheets that can use linear or nonlinear variables to find a solution to a problem. Depending on the problem, optimization helps find a solution that yields the most desirable output. What's Best! also allows the user to restrict values to be integers or binary integers.

What's Best! uses three steps in setting up a model. First, the user determines adjustable cells or variables that can be adjusted during the model run when finding a solution. Second, the user defines a goal (Define Best) of the solution such as "maximize reductions" or "minimize costs." Third, the user specifies constraints or limitations on the model.

Use of MS-Access and MS-Excel

Both Access and Excel were used in the design of the CEA model. Access addresses the data storage needs while Excel contains the What's Best! add-in.

Within Access, there are two databases that store the data used in the CEA model; both are found in C:\Cost Effectiveness:

<u>CEA Base Data.mdb</u> saves all the default data to the model. This database is saved as read-only to prevent incidental changes to the default data. The only time this database should be opened and modified is to permanently change the default data set.

<u>Cost Effectiveness Analysis.mdb</u> is the working database that is used by the CEA model. This database allows the user the flexibility to import the default data, then to modify the data to fit the particular needs of the scenario to be analyzed.

Excel is the host application for running the CEA model. The optimization software, What's Best! version 3.0, is the add-on program within Excel. The file Cost Effective Analysis.xls

contains the worksheets and formulas that are necessary to run the optimization. This file also is password-protected and is saved with a read-only recommendation. When opened as read only, the model can be run to its full extent. If the user wants to make permanent changes to this file, the password is CEA. If the user wants to make permanent changes to the data, the data should be changed in the Access file, CEA Base Data.mdb.

Program/Model Flow

The design of the model and data flow between Access and Excel are illustrated in Plate 1. The documentation of the flow diagram (numbers correspond to those on Plate 1) is explained below.

MS Access

1. Open MS Access. MS Access is the application that stores all of the information needed to run the Cost Effectiveness Analysis. The database is found in C:\Cost Effectiveness\Cost Effectiveness Analysis.mdb.

2. Import. When this database is opened, the user will be presented options for using the default data set, or using the latest edited data set. If the user chooses to use the latest edited data, the control of the program is directed to the main menu of the Cost Effectiveness Analysis database where the user can view, edit, or print the data. If the user chooses to use the default data set, the program imports new data tables from a protected database in C:\Cost Effectiveness\CEA Base Data.mdb. After the data are imported from the protected database, control is directed to the main menu of the Cost Effectiveness Analysis database where the user can view, edit, or print the data.

3. Main Menu. **View, Edit, Print**, and **Other Options**. At the top of the main menu in Access, the user will see **Option** tabs titled.

   3.1 View Data. This option allows the user to only view the data in the Access Database.

   3.2 Edit Data. This option allows the user to change any of the numbers in the database. Note that the numbers are saved in this database until a user imports the default data set. When the default data set is imported, the edited data are lost.

   3.3 View and Print Data. This option allows the user to print the data currently in the database and allows the user to view the data in a report format. When a button on the **Print Data** page is selected, the data in that particular table are printed in the report format.

4. Other Options. The **Other Options** page of the main menu allows the user to close the main menu so that the interior structure of the database can be viewed and/or changed. The **Other** button on the **Other Options** page allows the user to open C:\Cost Effectiveness\Cost Eff Analysis.xls and automatically activate MS Excel to the main menu in this file.

5. MS Excel. The **Open Excel to Continue With CEA Model** button simply activates MS Excel and opens the Cost Effective Analysis.xls file in Excel so that the user can continue proceeding through the steps needed to run an optimization scenario.

MS Excel

6. MS Excel. MS Excel opens the Main Menu and allows the user to determine which steps in the program have been executed and which need to be executed to run an optimization scenario. When the user opens Excel to the Main Menu, these relevant steps are indicated by "lights." The user must view all of the dialog boxes that allow for customization of the model to meet particular needs.

7. Nonpoint Options. This allows the user to choose if Nutrient Management Legislation is to be used in the model. There is also the option to use additional BMPs in the model run. The purpose of this option is to allow the user to add three additional BMPs to each of the eight landuse classifications. The phosphorus and nitrogen reduction values as well as the cost for each of the BMPs have to be defined in Access. Once the numbers have been entered in Access, the user must tell the model to incorporate these additional options to run the model.

8. Additional BMPs. This is shown if the user checks the **Additional BMP** box in the preceding dialog box. This allows the user to verify the particular BMPs that have been defined in Access.

9. Point Source Options. This allows the user to decide which point source data to select for the base year in the model. In the **Point Source** dialog box, there is also the option to use an additional retrofit option in the model.

10. Additional Retrofit Options. This allows the user to use an additional customized retrofit option in the model. Once again, the parameters–such as costs–to be used in the model have to be defined and set up in Access. Additionally, the user must define the effluent limits and the threshold values in the two following dialog boxes.

11. Point Source Effluent Limits. This allows the user to enter the effluent limit for both nitrogen and phosphorus for each individual retrofit option including an additional user defined retrofit. These values represent the concentrations of nutrients leaving the plant. The annual load in pounds of nutrients reaching the bay from each plant is the product of the effluent limit (concentration), a constant, flow and the transport factor.

12. Point Source Threshold Values. This allows the user to set the "trigger" value for each of the point source retrofits. The threshold value must be greater than or equal to the effluent limit for each of the retrofits; otherwise, the model cannot be solved, and will prompt the user to correct this problem.

13. Discount Rate and Period. This allows the user to set the discount rate, as a decimal, and the period, in years. The default settings for these values are a discount rate of 10 percent (0.10) for a period of 20 years.

14. Data Import. This is a very important function of this model. When the user chooses to import, the model performs many functions not apparent to the user, including: (1) checking all the effluent limits and threshold values to ensure that the effluent limits are all less than or equal to the threshold values; (2) checking if all of the information needed to run the model has been entered by verifying that all the appropriate "lights" are green. If all lights are not green then the model prompts the user to enter the appropriate information. Once the user enters the information, the model continues performing its functions, including: (1) copying the information from Access into the model (The point source data are copied according to the year of data that has been chosen in the point source dialog box. If Nutrient Management Legislation is to be used in the model, those numbers are accounted for by subtracting the reductions from the total reduction targets.); (2) calculating the cost equations for the point source retrofits for each retrofit and for each plant; and (3) copying and pasting as values the sheets that contain formulas related to point source reductions as well as the cost equations in other sheets in the program. This last step in the import process is necessary because the What's Best! software application cannot optimize using cells with these formulas in them.

15. Type of Optimization. There are two options for defining the optimization scenario that the user wants to run: (1) four built-in scenarios, and (2) a customizable option.

16. Built-in Optimization Scenario. This includes **Minimum Costs, BNR Only**, **Phosphorus Only**, and a **BNR/Phos Reduction** run. The minimum cost run is an optimization that has two constraints: (1) the nitrogen and phosphorus reductions have to reach the defined reduction target (the boxes for entering the target values are at the top of the built-in optimization dialog box); and (2) the reduction target must be completed at a minimum cost. The BNR run is somewhat different in that the goal of this run is to reach the maximum reduction in both point and nonpoint nitrogen and phosphorus while using only BNR retrofits on the point source end of the model. Like the BNR scenario, the phosphorus only scenario goal is to maximize both nitrogen and phosphorus but this is to be done using only the two phosphorus only retrofits on the point source end. The BNR/Phos Reduction run maximizes both point and nonpoint phosphorus reductions while using all available point source retrofits. When the user exits the dialog box, the menu display is updated to reflect the choices made in the dialog box.

17. Custom Optimization Scenarios. This allows the user great flexibility in setting up and running a scenario. The options include the option to set the nitrogen and phosphorus reduction target values. The user can choose: (1) which source to use in the model (i.e. point source, nonpoint, or both); (2) which nutrients to use as target values (i.e. nitrogen, phosphorus, or both); and (3) the goal of the optimization (i.e. maximize reduction or minimize costs). When the user exits the dialog box, the menu display is updated to reflect the choices made in the dialog box.

18. Solve the Model. When the user chooses to solve a scenario, the model verifies that all the appropriate information has been entered into the program, and the effluent limits and the threshold values are all applicable. If the model is ready to run, it shifts control to What's Best!, and the model begins an optimization run. When the model is finished, the program returns to the output sheet in Excel.

19. Output Sheet. The model gives the user four choices for printing the data: the nonpoint summary, the nonpoint details, the point source results, and the whole output sheet.

CEA MODEL OPERATION

Starting the Model

To start the CEA model: (1) move the cursor to the "Start" button on the menu bar and press; (2) move to the **Programs** folder to open the program menu; (3) move the cursor to the **Cost Effectiveness Analysis** group folder; and (4) click on **Open CEA Model From Beginning**. The program will start MS-Access and the Import Screen will appear.

MS-Access

Import screen

The **Import Screen** is the starting point for the CEA model. The user must define the data set before running the MS-Excel portion of the model. One of two options can be selected: **Import** or **Continue**. The **Import** button allows the user to start out with the default data set. The default data set in CEA Base Data.mdb is copied to the file Cost Effectiveness Analysis.mdb where the latter file is used by the model. The **Continue** button uses the existing data set in the file Cost Effectiveness Analysis.mdb. First-time model users should select the **Import** button.

Once the user selects the **Import** or **Continue** option, control is directed to the main menu form in MS-Access.

Access main menu

The main menu in MS-Access allows the user to view or modify the data set for nonpoint and point source loads and costs. There are four tabs in the upper left corner of the menu that allow the user to **View**, **Edit**, **Print**, and **Start Excel** (additional options). When the user selects the tab, the text in the form buttons changes color.

View form

The **View Form** tab allows the user to look at all the data in the Access database without changing any of these data. The text in each form button is blue. An example of the information in one of the Access forms is the **BMP Costs** form. The BMP costs are organized such that the model segments are the data fields and the BMP Type is the record. To scroll through the information contained in the form, use the scroll buttons at the bottom left corner of the form.

Edit data

The **Edit Form** tab allows the user to modify any of the data directly in the Access form. The text in each form button is green. The user should use these forms to add, delete, or change the data in the model. The changes made to these data will be saved in Access. The next time the user opens the program and selects the **Continue** button at the **Import** screen, the latest data and not the imported data will be used in the model.

Print data

The **Print Data** tab allows the user to obtain a hard copy of the data in any of the tables listed. The text in each button is magenta. The data for each table are printed from the report format in Access and displayed for the user to view. To obtain a hard copy, select the file drop down menu from the menu bar and select print.

Additional options

The **Additional Options** tab allows the user to view the Access database window or to continue with the model.

To view the database, the user selects the **Close Switchboard and View Database Window** button. This allows the user to see all the tables, forms, report, macros, and modules in the Access database. The table window contains a brief comment of where the data were obtained and when the data were reviewed. To use the model after viewing the database window, the user needs to reopen the file Cost Effective Analysis.mdb. This brings the user back to the **Import** screen.

To continue with the model, select the **Open Excel to Continue With CEA Model** button. This transfers model flow to Excel and activates the Cost Eff Analysis.xls file.

MS-Excel

Main menu

The **Main Menu** in Excel is the user interface that runs the optimization model. This menu gives the user the flexibility to change some of the parameters that are used in the model and to customize the type of scenario that is necessary for a given situation.

The user should be familiar with several areas on the **Main Menu**: model overview, status display, scenario summary, and the buttons.

Model overview

The model overview contains a brief statement of purpose and a help button at the end of the paragraph. The **Help** button opens a help file index that explains the screens, terms, definitions, and worksheets used in the model.

Status display

The **Main Menu** has several status display components to update the user on the progress made in setting up the model. On the left side of the menu is a series of boxes or lights that change from red to green. Red indicates information that needs to be entered before the model can be run. Conversely, green signifies information already entered. The menu displays the overall status of the model in the center. The “ready” or “not

ready" prompt is self-explanatory. The right side of the **Main Menu** also displays the summary of the optimization scenario.

Scenario summary

As the user sets up the model, the Summary of Optimization Scenario cells display a detailed summary of the scenario's components. This information allows the user to review the particular scenario without accessing each particular dialog box. This summary is also on each page of the output sheets after the model runs.

Buttons

Model setup begins when the user answers specific questions about the scenario being constructed. Each button has a small red triangle near the upper right corner of the button. When the user moves the mouse cursor over this red triangle, a small message will appear describing the button functions.

The simplest way to start is by selecting the **Begin Stepping Through Model** button. This button guides the user through the steps needed to run the optimization scenario. The user will go through several dialog boxes: **Nonpoint #1**, **Point #1**, **Effluent Limits**, **Threshold Values**, and **Discount and Period**.

Nonpoint #1 (nonpoint source options): The **Nonpoint Options** dialog box gives the user the option to use Nutrient Management Legislation (NML), which will remove the acres designated for the NML BMP from the acres available for the other BMPs. NML has cost and reduction in nitrogen and phosphorus loads associated with the implementation.

The user has the option to define three extra BMPs for each land use in the model. The values associated with these BMPs must be defined in Access, but the user must also activate the BMP by selecting that option in the nonpoint dialog box. When the user checks the **Extra BMP** box and the **OK** button, the **Additional BMP** dialog box is displayed for user input. The user should check the appropriate boxes to the BMPs defined by the user in Access.

Point #1 (point source options): The point source data in the program consist of data from 1985, 1994, and projected data for year 2000. The user selects which set of data to use as the base year for the model. For the projected terminus of the program, the model uses year 2000 data. The base year data are compared to the year 2000 data to evaluate the improvement or degradation due to the projection of concentration and flows at each plant before a retrofit is implemented.

The **Additional Retrofit** check box allows the user to activate an additional retrofit, which the user defined in Ms Access (cost variables). The user then defines the effluent limit and the threshold value for this retrofit in the effluent limits and threshold value dialog boxes that follow in the **Stepping-Through Model** sequence.

Effluent limits (point effluent limits): This dialog box defines the nitrogen and phosphorus effluent limits (concentration in mg/L) specific to each type of retrofit. A user-defined retrofit also is available as an additional retrofit option.

Threshold values (point thresholds): The threshold values dialog box is used to define the threshold or "trigger" value for the effluent discharge from a facility. This threshold value set for a retrofit can be used to allow a "buffer" between the effluent limit and the effluent that is feasible for treatment. For example, if the effluent limit is set at 10 mg/L it may not be feasible to treat the effluent until it reaches a value of 12 mg/L. In other words, the cost of obtaining the 2 mg/L of reduction outweighs the gain.

The default for the model is to have the effluent limit equal to the threshold value.

Discount and period (cost equation variables): The discount rate and period are used in cost equations to calculate the cost of implementation (capital costs) and

maintenance of a retrofit on a facility. The cost equation for the BNR retrofits is different than the phosphorus only retrofits, but both types of retrofits use the same discount rate and period values.

The default values for this model are a discount rate of 10 percent (0.10) over a period of 20 years.

After the user answers the information in the dialog boxes, data automatically are imported from Access. At any time, the user may go back and change options by selecting the appropriate button. When all the information is complete, the status bar displays the **Ready** prompt and the model is ready to run. Once the data are imported and the status is **Ready**, the user must define an optimization scenario from the **Built-in Scenario** or **Custom Scenario** buttons.

Built-in scenario (built-in optimization options): The **Built-in Scenario** dialog box allows the user to run the model with a choice of four built-in scenarios: **Minimum Costs**; **BNR Only**; **Phosphorus Reduction Only**; or **Both BNR and Phosphorus Reduction**. The model presents defaults for the nitrogen and phosphorus reduction target values in the dialog box. There will be a decrease in the reduction target if NML is implemented as well as a point source "reduction credit" if the user selects to use the 1985 or 1994 point source data. The nitrogen and phosphorus target values are needed when the user selects the minimum cost scenario. Where the goal is to maximize nutrient load reductions, the target values are not used in the remaining three scenarios.

1. Minimum Costs:
   The model uses both point source retrofits and nonpoint source BMPs to meet or exceed the reduction target values at the absolute minimum cost.

2. BNR Only:
   In the model, there are five BNR retrofits, two Phosphorus Only retrofits and the possibility of one user defined retrofit. This scenario disregards reduction target values, and the model maximizes nitrogen and phosphorus reductions using nonpoint BMPs and the five BNR retrofit options with no regard to cost.

3. Phosphorus Reduction:
   As with the BNR only, this scenario disregards reduction targets or costs. This scenario will maximize reduction in nitrogen and phosphorus using all the nonpoint BMPs, but it only uses the Phosphorus Only retrofits on the point source side.

4. BNR/Phosphorus Reduction:
   This scenario uses all nonpoint BMPs and all point source retrofits to achieve the maximum reduction possible with no regard to reduction targets or costs.

Custom scenario (customizable optimization options): The custom scenario dialog box permits the user to tailor a scenario to meet specific constraints by varying the reduction targets, selecting the source for the reduction, and selecting the type of nutrient reduction. The user has the following options:

1. Nitrogen and phosphorus reduction target values:
   When using the model to minimize costs, the user must set reduction target values. When maximizing nutrient reductions, the model does not require the target values. The model runs fine with these values in place regardless of the goal.

2. Sources to be used:
   The user selects from three options: use **only point sources**, use **only nonpoint sources**, or use **both point and nonpoint sources**.

3. Type of reduction:
   The user selects from three options: use **only nitrogen**, use **only**

phosphorus, or use **both nitrogen and phosphorus**.

4. Optimization goal:
   The user selects to either **minimize costs** while reaching the reduction target (be it nitrogen reduction, phosphorus reduction, or both), or to **maximize the reduction** of the nutrient(s).

Solving the scenario

When the user selects to solve the scenario (selecting the **Run Optimization** button), the model verifies that all of the information entered into the program is valid. If all of this information is satisfactory, control is directed to What's Best!. The process that What's Best! uses to optimize is outlined in the user's guide included with the program. If the optimization scenario is feasible, the program returns to Ms Excel at the output worksheet within the Cost Effectiveness Analysis. If the scenario is not feasible, What's Best! will display an error page describing the possible causes of the error.

Output sheet

When the model solves the scenario, the results are transferred to the output worksheet in Excel. The output worksheet contains three sections: (1) a summary of the nonpoint source information section, (2) a detailed nonpoint information section; and (3) a point source information section. A small pop-up dialog box on the output worksheet that allows the user to select any of the three sections or all three sections to print.

Nonpoint summary. The nonpoint summary section contains information on loads, acres, reductions, and costs for nitrogen and phosphorus BMPs on the various land uses and gives the user a good overall synopsis of the nonpoint results. The box in the upper right of the worksheet is the optimization scenario summary similar to that found on the main menu of the model. The second box gives the overall totals for loads, reductions and costs. The third and largest box summarizes the acres available for treatment, loads, reductions and costs by each land use and the BMP type on each of the land uses.

Nonpoint details. The nonpoint details section provides a further breakdown of the acres treated, reductions and costs by each land use and the BMP type for each of the watershed model segments. This section gives the user a better idea of the area in the watershed where a single type of BMP is being used or not being used.

Point source. The point source section contains a summary and a detail area of the point source retrofit results along with the optimization scenario summary.

The first set contains a point source summary listing nine retrofit options and the number of plants associated with the retrofit and the pre-retrofit, no action, and post-retrofit loads. The point source details present the same information but itemized by each facility and its associated NPDES number.

The second set contains a point source summary listing nine retrofit options and the number of plants associated with each retrofit. However, the additional information includes load reductions due to the retrofit along with any reduction credits and the cost of the retrofit. The point source details present the same information but itemized by each facility and its associated NPDES number.

Data Model Worksheets

Menu

The *Menu* worksheet is the user interface to the CEA model. This menu also is called the CEA menu.

Output sheet

The *Output Sheet* worksheet contains the results of the optimization scenario run. Results include the nonpoint and point source summaries and details for loads, reductions and costs.

Point source loading

The *Point Source Loading* worksheet is a pre-processor of the point source data and optimization scenario results for the output sheet.

Optimization dialog

The *Optimization Dialog* worksheet contains the graphic of the model optimization options dialog box listing optimization scenarios.

Nonpoint options

The *Nonpoint Options* worksheet contains the graphic of the nonpoint source options dialog box.

Point source options

The *Point Source Options* worksheet contains the graphic of the point source options dialog box.

Added BMPs

The *Added BMPs* worksheet contains the graphic of the addition BMP options dialog box that the user defines.

Return values

The *Return Values* worksheet contains the user's responses to the questions posed in the CEA menu of the program. The optimization scenario uses these responses or values that the user defines.

Acres by land use

The land use acres on the *Acres by Land Use* worksheet are based on the Chesapeake Bay Program's Watershed Model Application To Calculate Bay Nutrient Loads Appendix E: Land Use and Selected Parameter Values (EPA, 1995). The model defines land use into seven types (A21:A28) and distributes them over nineteen Phase II CBP watershed model segments (B21:T21). Since there is a different segmentation scheme design based on the Phase IV CBP watershed model, the model adds the additional segments to this worksheet (U21:Z21) to allow for expansion when needed. If the user needs the Phase IV data, the MS-Access database should be updated.

Areas of the worksheet are defined as the Adjusted Land Use (A1:T10), percent in State Adjustment (A15:T16), Urban Distribution (A18:T19), Original Land Use (A21:T28), and Nutrient Mgmt Leg (A34:T38).

The model imports land use acres from MS-Access and writes to the area defined as Original Land Use. The original acreage is adjusted before use in the CEA model to account for model segment area in Pennsylvania and distribution of urban land into pervious and impervious areas. If the user wants the model to consider Pennsylvania's Nutrient Management Legislation, the acreages are copied from (A35:T38) to the area (A11:T14) where CVT, CST, HAY and AWA are treated. Nutrient Management Legislation acres were determined from spreadsheets obtained from Pa. DEP.

For the Adjusted Land Use area, a series of equations adjusts the acreage for each segment and land use field (i.e. B2). Using segment 10 as an example:

CVT = (B22*B$16)-B11
CST = (B23*B$16)-B12
HAY = (B24*B$16)-B13
PAS = B25*B$16
AWA = (B26*B$16)-B14
URP = (B27*B$16)-B8
URI = B27*B$16*B19
FOR = B28*B$16

Nitrogen loading

The model saves the nitrogen loading rates for each land use by watershed model segments in the *Nitrogen Loading* worksheet. The loading rates are in the units of pounds per acre per year and obtained from Chesapeake Bay Program's Watershed Model Application To Calculate Bay Nutrient Loads Appendix E: Land use and Selected Parameter Values (EPA, 1995).

The loading rate table is defined in the area (A1:Z9). Land use is defined into seven types

(A2:A9) and distributed over nineteen Phase II CBP watershed model segments (B2:T9).

Nitrogen transport

The model saves the nitrogen transport factors for each watershed model segment in the *Nitrogen Transport* worksheet. The transport factors account for losses in nitrogen as nitrogen is delivered from each watershed model segment to the Chesapeake Bay. Transport factors were obtained from Chesapeake Bay Program's Watershed Model Application To Calculate Bay Nutrient Loads Appendix E: Land use and Selected Parameter Values (EPA, 1995).

Phosphorus loading

The model saves the phosphorus loading rates for each land use by watershed model segments in the *Phosphorus Loading* worksheet. The loading rates are in the units of pounds per acre per year and were obtained from Chesapeake Bay Program's Watershed Model Application To Calculate Bay Nutrient Loads Appendix E: Land Use and Selected Parameter Values (EPA, 1995).

The loading rate table is defined in the area (A1:Z9). Land use is defined into seven types (A2:A9) and distributed over nineteen Phase II CBP watershed model segments (B2:T9).

Phosphorus transport

The model saves the phosphorus transport factors for each watershed model segment in the *Phosphorus Transport* worksheet. The transport factors account for losses in phosphorus as phosphorus is delivered from each watershed model segment to the Chesapeake Bay. Transport factors were obtained from Chesapeake Bay Program's Watershed Model Application To Calculate Bay Nutrient Loads Appendix E: Land Use and Selected Parameter Values (EPA, 1995).

Nitrogen reduction efficiency

The model saves the nitrogen load reductions due to an implemented BMP in the *Nitrogen Reduction Eff* worksheet defining the area (A1:Z56). CBP Phase II reduction efficiencies were obtained from two documents: (1) Pennsylvania Nutrient Reduction Strategy, Summary of Nutrient Reduction Factors and Nutrient Reduction Calculations, and (2) Matrix of BMP Efficiencies Determined by the Tributary Strategy Workgroup, Table 1. BMP Efficiency Matrix (Appendix A).

The reduction efficiency is expressed as the ratio between the pre- and post-BMP load. For example, CVT.CON for model segment 10 is 0.169. This means that when this BMP is applied, the user can expect a nitrogen load reduction of 16.9 percent. Efficiencies can vary by watershed model segment for the same BMP. A three-letter prefix, a period, and a three-letter suffix (ABC.DEF) represent the BMP types listed in column (A) of the worksheet. The three-letter prefix defines the land use type on which the BMP is applied while the three-letter suffix defines the BMP. For example, CVT.FPL would represent conventional tillage with a farm plan.

There are three different categories of BMP types within each land use: (1) a default required for the CEA model; (2) CBP defined BMP; and (3) optional user defined BMPs. These categories repeat for each land use. Using the land use CVT as an example:

- Category 1: CVT.CVT in cell (A2) and data in cells (B2:T2). No BMP is applied; therefore the efficiency is zero.

- Category 2: CVT.CON, CVT.NUT, CVT.FPL, CVT.HEL, CVT.CTN, CVT.CTF, CVT.CNF in cells (A3:A10). Data in cells (B3:T10) were obtained from two documents: (1) Pennsylvania Nutrient Reduction Strategy, Summary of Nutrient Reduction Factors and Nutrient Reduction Calculations; and (2) Matrix of BMP Efficiencies Determined by the Tributary Strategy Workgroup, Table 1, BMP Efficiency Matrix (Appendix A).

- Category 3: CVT.001, CVT.002, CVT.003 in cells (A11:A13) and data in cells (B11:T13) are defined by the user. If the user does not define additional BMPs, then the efficiency will be zero.

The BMP types are a "supply list" of options that the CEA model can select during optimization. When the CEA model uses a particular BMP and applies that BMP to a select number of acres, the model removes the selected acres from the acres available for BMP implementation.

Phosphorus reduction efficiency

The model saves the phosphorus load reductions due to an implemented BMP in the *Phosphorus Reduction Eff* worksheet defining the area (A1:Z56). CBP Phase II reduction efficiencies were obtained from two documents: (1) Pennsylvania Nutrient Reduction Strategy, Summary of Nutrient Reduction Factors and Nutrient Reduction Calculations, and (2) Matrix of BMP Efficiencies Determined by the Tributary Strategy Workgroup, Table 1. BMP Efficiency Matrix (Appendix A).

A more detailed description of the reduction efficiency worksheet can be found in the previous section: Nitrogen Reduction Efficiency.

BMP costs

The model saves the costs associated with an implemented BMP in the *BMP Costs* worksheet defined in the area (A1:Z56). Costs are included for both the Phase II and Phase IV model segments and were obtained from Seay (1995) and Camacho (1992). Streambank fencing costs were determined from several sources that are summarized in the document, "Pennsylvania DEP Streambank Fencing Program," November 1996, Kenn Pattison Memo 3/20/97 and referenced in Tech Memo #5 (Appendix A).

The BMP cost is expressed in dollars per acre. A three-letter prefix, a period, and a three-letter suffix (ABC.DEF) represent the BMP types listed in column (A) of the worksheet. The three-letter prefix defines the land use type on which the BMP is applied while the three-letter suffix defines the BMP. For example, CVT.FPL would represent conventional tillage with a farm plan.

There are three different cost categories of BMP types within each land use: (1) a default required for the CEA model; (2) CBP defined BMPs; and (3) optional user defined BMPs. These categories repeat for each land use. Using the land use CVT as an example:

- Category 1: CVT.CVT in cell (A2) and data in cells (B2:T2). No BMP is applied; therefore the efficiency is zero.

- Category 2: CVT.CON, CVT.NUT, CVT.FPL, CVT.HEL, CVT.CTN, CVT.CTF, CVT.CNF in cells (A3:A10) and data in cells (B3:T10).

- Category 3: CVT.001, CVT.002, CVT.003 in cells (A11:A13) and data in cells (B11:T13) are defined by the user. If the user does not define additional BMPs, then the efficiency will be zero.

The BMP types are a "supply list" of options that the CEA model can choose during optimization. When the CEA model uses a particular BMP and applies that BMP to a select number of acres, it removes the selected acres from the acres available for BMP implementation.

HEL and SBF acres

Highly Erodible Land (HEL) acreages were obtained from the Natural Resources Conservation Service database (Kenn Pattison oral comm. and written comm. 3/5/97). The HEL in each watershed model segment was aggregated from county-level data and proportionally assigned to the land use categories of CVT, CST, and HAY. When BMPs are being applied to CVT, CST, and HAY land uses with the optimization model, the model is forced to use the three land uses on HEL acres first before using non-HEL acre CVT, CST, and HAY. HEL acreage is listed in the worksheet *HEL and SBF Acres* in cells (A1:T5) for watershed model phase II segments.

Streambank Fencing (SBF) acreages were based on one mile of fence treating 58.8 acres of pasture land. The total acres available are based on the stream miles available for streambank fencing in each model segment (Kenn Pattison, written comm. 3/20/97). SBF acreage is listed in

the worksheet *HEL and SBF Acres* in cells (A10:T12) for watershed model phase II segments.

Base point loads TB

Before the optimization model runs, the model lists point source loads in the worksheet *Base Point Loads TB*. This worksheet calculates the nitrogen and phosphorus load reductions from the base year (user defined as year 1985, 1994 or 2000) and the year 2000. These reductions are counted as a credit towards Pennsylvania's Nutrient Reduction Strategy targets for nitrogen and phosphorus. By default, the user determines the loads for each cell when selecting pre-processing options under the optimization model's CEA Menu.

Definition of the columns and data sources in the worksheet *Base Point Loads TB* are defined as follows:

Column A is the Facility Name of the point source. Point sources are listed alphabetically from cells A2:A150. Cells A151:A175 are defined for additional point sources. Facility names are copied from the worksheet *Point Source Data,* column A.

Column B is the permit number of the point source facility and is copied from the worksheet *Point Source Data,* column B.

Column C is the delivered total phosphorus load for the base year. The load equals plant_flow * TP_USED * 8.34 * 365 * TFP.

Column D is the delivered total nitrogen load for the base year. The load equals plant_flow * TN_USED * 8.34 * 365 * TFN.

Column E is the delivered total phosphorus load for the year 2000. The load equals plant_2000FLOW * Plant_2000P * 8.34 * 365 * TFN.

Column F is the delivered total nitrogen load for the year 2000. The load equals plant_2000FLOW * Plant_2000N * 8.34 * 365 * TFN.

For Columns C, D, E and F:

Plant_flow is the point source discharge in millions of gallons per day from worksheet *Point Source Data,* column R.

Plant_2000FLOW is the point source discharge in millions of gallons per day from worksheet *Point Source Data,* column O.

TP_USED is the total phosphorus concentration in mg/L from worksheet *Point Source Data,* column T.

Plant_2000P is the total phosphorus concentration in mg/L from worksheet *Point Source Data,* column Q.

TN_USED is the total nitrogen concentration in mg/L from worksheet *Point Source Data,* column S.

Plant_2000N is the total nitrogen concentration in mg/L from worksheet *Point Source Data,* column P.

TFP is the transport factor for phosphorus in the watershed model segment where the facility is located from worksheet *Pt Phos Red Sheet,* column E.

TFN is the transport factor for nitrogen in the watershed model segment where the facility is located from worksheet *Pt Nit Red Sheet,* column E.

The constant 8.34 is the conversion factor for pounds per day.

The constant 365 is the conversion factor from daily load to annual load.

Column G is the total phosphorus load reduction (credit) in the year 2000 defined as the difference between column E and C (Year 2000 load – Base year load). If the difference is greater than zero, then the reduction is considered zero.

Column H is the total nitrogen load reduction (credit) in the year 2000 defined as the difference between column F and D (Year 2000 load – Base year load). If the difference is greater than zero, then the reduction is considered zero.

Cell J2 is the sum of the total phosphorus reductions (credits) from cells G2:G175 due to the change in point source phosphorus from the base year to the year 2000.

Cell K2 is the sum of the total nitrogen reductions (credits) from cells H2:H175 due to the change in point source nitrogen from the base year to the year 2000.

Base nonpoint loads TB

The delivered nonpoint loads for nitrogen and phosphorus by phase II watershed model segment for each land use are listed in the worksheet *Base Nonpoint Loads TB*. The determination of load in this worksheet is based on data copied in from other worksheets: *Acres by Land Use*, *Nitrogen Loading*, *Nitrogen Transport*, *Phosphorus Loading*, and *Phosphorus Transport*.

Nitrogen loads are in the cells A1:T9 with the calculated total delivered nonpoint nitrogen load in cell AB2. The total delivered point source load is provided in cell AC2. The sum of the nonpoint and point source total delivered nitrogen load is provided in cell AA2.

Phosphorus loads are in the cells AD1:AW9 with the calculated total delivered nonpoint phosphorus load in cell BE2. The total delivered point source load is provided in cell BF2. The sum of the nonpoint and point source total delivered nitrogen load is provided in cell BD2.

The total delivered load is the product of acres, loading rate, and transport factor, which are obtained from different worksheets. As an example, the delivered nitrogen and phosphorus loads for CVT in segment 10 are defined as follows:

For nitrogen, cell B2:
(*Acres by Landuse*,B2 + *Acres by Landuse*,B11) * *Nitrogen Loading*,B2 * *Nitrogen Transport*,B$2

For phosphorus, cell AE2:
(*Acres by Landuse*,B2 +*Acres by Landuse*,B11) * *Phosphorus Loading*,B2 * *Phosphorus Transport*,B$2

The sum of (*Acres by Landuse*,B2 + *Acres by Landuse*,B11) equals the total acres in the model segment. The total number of acres are subdivided into two categories: (1) total acres that can receive NML, and (2) total acres that cannot receive NML. The acreage numbers for these two categories are used in other parts of the model.

Phosphorus loads after

The worksheet *Phosphorus Loads After* contains the nonpoint source loads apportioned to each BMP type by model segment. When the optimization model has completed a run, the post-processed information on loads is calculated based on post-processed information in other worksheets: *Land Use After Optimization*, *Phosphorus Loading*, *Phosphorus Reduction Eff*, and *Phosphorus Transport*.

The loads are provided in the cells defined by the area A1:T56 for phase II watershed model segments. Using the CVT.CON BMP type on watershed model segment 10 as an example, the phosphorus load is calculated as:

'Land Use After Optimization'!B3 * *'Phosphorus Loading'*!B$2 * (1-*'Phosphorus Reduction Eff'*!B3) * *'Phosphorus Transport'*!B$2

Nitrogen loads after

The worksheet *Nitrogen Loads After* contains the nonpoint source loads apportioned to each BMP type by model segment. When the optimization model completes a run, it calculates the post-processed information on loads based on post-processed information in other worksheets: *Land Use After Optimization*, *Nitrogen Loading*, *Nitrogen Reduction Eff*, and *Nitrogen Transport*.

The loads are provided in the cells defined by the area A1:T56 for phase II watershed model segments. Using the CVT.CON BMP type on watershed model segment 10 as an example, the phosphorus load is calculated as:

'Land Use After Optimization'!B3 * *'Nitrogen Loading'*!B$2 * (1-*'Nitrogen Reduction Eff'*!B3) * *'Nitrogen Transport'*!B$2

Land use after optimization

The worksheet *Land Use After Optimization* contains the adjustable cells as defined by What's Best! for the BMP types in each phase II watershed model segment and the constraint cells on what land use acres are available.

The adjustable cells defined for the BMP type (A1:T56) are the BMP options available to the optimization model. These cells are colored blue, while the non-adjustable cells are colored black. The non-adjustable cells are the extra BMP types available to the user. When the user defines an additional BMP for a particular land use, the cell will be considered adjustable (blue).

The constraint cells (AA1:BL9) are the total land use acres of all the BMP types (A1:T56) applied to the land uses in each watershed model segment. For example, the constraint in cell AB2 states that the number returned in cell AA2 must equal the total land use acres of CVT for watershed model segment 10. Cell AA2 is the sum of BMP types for CVT in watershed model segment 10. The forms of the equations using watershed model segment 10 as an example are:

Cell AB2 = WB(AA2,"=",*'Acres by Landuse'*!B2)
Cell AA2 = SUM($B$2:$B$13)

The constraint cells (AB10:AT13) are based on the land uses in HEL where the total BMP type in HEL must be less than or equal to (cannot exceed) the total HEL acres available in the selected watershed model segment for the land uses of CVT, CON, and HAY. Cells (AB11:AT11) are for CVT, cells (AB12:AT12) are for CON, and cells (AB13:AT13) are for HAY. The forms of the equations using watershed model segment 10 as an example are:

Cell AB11 (CVT) = WB(B6,"<=",*'HEL and SBF Acres'*!B3)
Cell AB12 (CON) = WB(B17,"<=",*'HEL and SBF Acres'*!B4)
Cell AB13 (HAY) = WB(B25,"<=",*'HEL and SBF Acres'*!B5)

The constraint cells (AB16:AT16) are based on the PAS land use in SBF where the total BMP types in SBF must be less than or equal to (cannot exceed) the total acres available for SBF in the selected watershed model segment. The form of the equation using watershed model segment 10 as an example is:

Cell AB16 (SBF) =
WB(SUM(B32:B33),"<=",'HEL and SBF Acres'!B12)

Costs

The worksheet *Costs* contains the nonpoint source cost apportioned to each BMP type by model segment. When the optimization model completes a run, it calculates the post-processed information on cost based on post-processed information from other worksheets: *BMP Costs* and *Land Use After Optimization.*

The worksheet provides costs in the cells defined by the area A1:T56 for phase II watershed model segments. Using the CVT.CON BMP type on watershed model segment 10 as an example, the cost for implementing the BMP is calculated as:

'BMP Costs'!B3**'Land Use After Optimization'*!B3

The model totals the nonpoint source costs in cell AA1, and totals the costs associated with point source retrofits and NML in this worksheet in cells AB2 and AD2, respectively.

Phosphorus reduction results

The worksheet *Phosphorus Reduction Results* contains the load reduction due to nonpoint phosphorus BMPs. Cells (A1:T56) contain the reductions for phase II watershed model segments based on post-processed information from other worksheets: *Land Use After Optimization, Phosphorus Loading, Phosphorus Reduction Eff,* and *Phosphorus Transport.*

Using the CVT.CON BMP type on watershed model segment 10 as an example, the phosphorus reduction is calculated as:

*'Landuse After Optimization'!B3 *'Phosphorous Loading'!B$2*(1-'Phosphorous Reduction Eff'!B3) *'Phosphorous Transport'!B$2*

Cells (AA2:AK2) contain a series of nutrient load and reduction data needed to run the optimization model. These cells are:

AA2 (Nonpoint) = (SUM(B2:T56)); defined as the total nonpoint phosphorus reduction after optimization in pounds.

AB2 (Point) = ('Point Phos Reduction After'!N2); defined as the total point source phosphorus reduction due to a retrofit after optimization in pounds.

AC2 (Total Phos) = SUM(AA2:AB2); defined as the total of the nonpoint and point source phosphorus reduction after optimization in pounds.

AD2 (Constraint) = WB(AC2,">=",AE2); defined as the constraint that the total phosphorus reduction must equal or exceed the phosphorus reduction target in pounds.

AE2 (Reduction Target) = AG2-AF2-AK2; defined as the phosphorus reduction target adjusted for the point source phosphorus credit and NML reductions in pounds.

AF2 (Reduction Due to NML) = defined as the phosphorus reduction when NML is implemented in pounds.

AG2 (Phosphorus Target) = defined as the base phosphorus reduction target before adjustments in pounds.

AH2 (Nonpoint both N&P) = AA2+'Nitrogen Reduction Results'!AA2; defined as the total nonpoint source nutrient reduction in pounds.

AI2 (Point N&P) = AB2+'Nitrogen Reduction Results'!AB2; defined as the total point source nutrient reduction in pounds.

AJ2 (Both Point and Nonpoint Both N & P) = AC2+'Nitrogen Reduction Results'!AC2; defined as the total nonpoint and point source nutrient reduction in pounds.

AK2 (Reduction due to yr. change) = defined as the reduction credit of a point source facility from a change in load of the user defined base year to the year 2000.

Nitrogen reduction results

The worksheet *Nitrogen Reduction Results* contains the load reduction due to nonpoint nitrogen BMPs. The reductions are provided in the cells (A1:T56) for phase II watershed model segments and are based on post-processed information from other worksheets: *Land Use After Optimization, Nitrogen Loading, Nitrogen Reduction Eff,* and *Nitrogen Transport*.

Using the CVT.CON BMP type on watershed model segment 10 as an example, the nitrogen reduction is calculated as:

'Landuse After Optimization'!B3**'Nitrogen Loading'*!B$2*(*1-'Nitrogen Reduction Eff'*!B3)**'Nitrogen Transport'*!B$2

Cells (AA2:AK2) contain a series of nutrient load and reduction data needed to run the optimization model. These cells are:

AA2 (Nonpoint) = (SUM(B2:T56)); defined as the total nonpoint nitrogen reduction after optimization in pounds.

AB2 (Point) = ('Point Nitrogen Reduction After'!N2); defined as the total point source nitrogen reduction due to a retrofit after optimization in pounds.

AC2 (Total Nitrogen) = SUM(AA2:AB2); defined as the total of the nonpoint and point source nitrogen reduction after optimization in pounds.

AD2 (Constraint) = WB(AC2,">=",AE2); defined as the constraint that the total nitrogen reduction must equal or exceed the nitrogen reduction target in pounds.

AE2 (Reduction Target) = AG2-AF2-AK2; defined as the nitrogen reduction target adjusted for the point source nitrogen credit and NML reductions in pounds.

AF2 (Reduction Due to NML) = Defined as the nitrogen reduction when NML is implemented in pounds.

AG2 (Nitrogen Target) = Defined as the base nitrogen reduction target before adjustments in pounds.

AH2 (Nonpoint both N&P) = AA2+'Phosphorus Reduction Results'!AA2; defined as the total nonpoint source nutrient reduction in pounds.

AI2 (Point N&P) = AB2+' Phosphorus Reduction Results'!AB2; defined as the total point source nutrient reduction in pounds.

AJ2 (Both Point and Nonpoint Both N & P) = AC2+' Phosphorus Reduction Results'!AC2; defined as the total nonpoint and point source nutrient reduction in pounds.

AK2 (Reduction due to yr. change) = Defined as the reduction credit of a point source facility from a change in load of the user defined base year to the year 2000.

Point source data

The worksheet *Point Source Data* contains all the facility data needed to calculate loads for point sources and the plant type information needed for retrofit options. Cells (A1:Q150) contain the point source data. Cells (A151:Q175) are blank and available for additional facilities. Cells (R1:T175) are reserved for the user-defined facility data needed to calculate loads. When the user defines the point source data set needed under the CEA Menu, the model copies the appropriate data to cells (R1:T175). This area is blank before the user runs the optimization model.

The worksheet contains the following data:

Column A (Facility Name) = Alphabetical listing of the point source.

Column B (NPDES) = National Permit Discharge Elimination System number.

Column C (Stream Code) = Pennsylvania's five-digit number that identifies the stream receiving the facility discharge.

Column D (River Mile Index) = Location of the discharge point in miles upstream of the mouth to which the facility discharges.

Column E (Latitude) = Latitude of the discharge point.

Column F (Longitude) = Longitude of the discharge point.

Column G (Plant Type) = Level and type of treatment.

AS = Activated Sludge
ASE = Activated Sludge/Extended Aeration
ASPF = Activated Sludge/Plug Flow
ASOD = Activated Sludge/Oxidation Ditch
ASCS = Activated Sludge/Contact Stabilization
ASTF = Activated Sludge/Trickling Filter
ASN = Activated Sludge with Nitrification
ASCM = Activated Sludge/Complete Mix
ASP = Activated Sludge/Phosphorus Removal
CC = Chemical Coagulation
LA = Lagoon
RBC = Rotation Biological Contactors
TF = Trickling Filter
FF = Fixed Film
I = Industrial
OD = Oxidation Ditch
SBR = Sequencing Batch Reactors
P = Primary

Column H (Seg#) = Watershed model segment number.

Column I (1985 Flow (mgd)) = The 1985 average daily discharge in millions of gallons per day.

Column J (1985 TN (mg/L)) = The 1985 average total nitrogen concentration of the discharge in milligrams per liter.

Column K (1985 TP (mg/L)) = The 1985 average total phosphorus concentration of the discharge in milligrams per liter.

Column L (1994 Flow (mgd)) = The 1994 average daily discharge in millions of gallons per day.

Column M (1994 TN (mg/L)) = The 1994 average total nitrogen concentration of the discharge in milligrams per liter.

Column N (1994 TP (mg/L)) = The 1994 average total phosphorus concentration of the discharge in milligrams per liter.

Column O (2000 Flow (mgd)) = The 2000 average daily discharge in millions of gallons per day.

Column P (2000 TN (mg/L)) = The 2000 average total nitrogen concentration of the discharge in milligrams per liter.

Column Q (2000 TP (mg/L)) = The 2000 average total phosphorus concentration of the discharge in milligrams per liter.

Column R = User defined facility data for flow.

Column S = User defined facility data for total nitrogen concentration.

Column T = User defined facility data for total phosphorus concentration.

Point source costs per retrofit

The worksheet *Point Source Costs Per Retrofit* is a copy of the values only from the worksheet *Pt Costs Sheet.* This is done because the software What's Best! has trouble using data in cells containing a function. For a description of point source costs, see the description under the Pt Costs Sheet section.

Point nitrogen reduction

The worksheet *Point Nitrogen Reduction* is a copy of the values only of the worksheet *Pt Nit Red Sheet.* This is done because the software What's Best! has trouble using data in cells containing a function. For a description of point source nitrogen reductions, see the description under the Pt Nit Red Sheet section.

Point phosphorus reduction

The worksheet *Point Phosphorus Reduction* is a copy of the values only of the worksheet *Pt Phos Red Sheet.* This is done because the software What's Best! has trouble using data in cells containing a function. For a description of point source phosphorus reductions, see the description under the Pt Phos Red Sheet section.

Point adjustables

The worksheet *Point Adjustables* contains the adjustable cells for all available retrofits. The retrofit options are defined in the area (E1:M175) and the constraint cells are defined in cells (N1:N175). This worksheet is used to force the optimization model to use only one retrofit per facility.

Point costs after optimization

The worksheet *Point Costs After Optimization* presents the cost of the selected retrofit for each facility after optimization. This worksheet is the product of the *Point Adjustables* and *Point Source Costs per Retrofit* worksheets. The total annual cost of all retrofits selected is saved in cell (N2).

Point nitrogen reduction after

The worksheet *Point Nitrogen Reduction After* presents the point source nitrogen reduction due to the retrofit selected at each facility. This worksheet is the product of the *Point Adjustables* and *Point Nitrogen Reduction* worksheets. The total nitrogen reduced from all retrofits selected is saved in cell (N2).

Point phosphorus reduction after

The worksheet *Point Phosphorus Reduction After* presents the point source Phosphorus reduction due to the retrofit selected at each facility. This worksheet is the product of the *Point Adjustables* and *Point Phosphorus Reduction* worksheets. The total Phosphorus reduced from all retrofits selected is saved in cell (N2).

Pt phos red sheet

The worksheet *Pt Phos Red Sheet* presents the phosphorus load reduction for each type of retrofit option available at a facility. This worksheet uses information from the worksheets *Returned Values* and *Point Source Data*. Load reductions due to retrofits are located in cells (F1:M175).

A retrofit is considered an available option if the effluent limit (phosphorus concentration) of the retrofit is less than the year 2000 effluent limit of the facility. The difference in the year 2000 effluent limit and that of the retrofit is the load reduction. If the effluent limit associated with a particular retrofit is greater than the effluent limit of the facility, the retrofit is not considered an option and the load reduction is set to zero.

Pt nit red sheet

The worksheet *Pt Nit Red Sheet* presents the nitrogen load reduction for each type of retrofit option available at a facility. This worksheet uses information from the worksheets *Returned Values* and *Point Source Data*. Load reductions due to retrofits are located in cells (F1:M175).

A retrofit is considered an available option if the effluent limit (nitrogen concentration) of the retrofit is less than the year 2000 effluent limit of the facility. The difference in the year 2000 effluent limit and that of the retrofit is the load reduction. If the effluent limit associated with a particular retrofit is greater than the effluent limit of the facility, the retrofit is not considered an option and the load reduction is set to zero.

Pt costs sheet

The worksheet *Point Source Costs Per Retrofit* contains the annual costs for eight retrofit types based on characteristics of the facility. The function procedure "cost_equation" is used to calculate annual costs for each retrofit type at each facility.

A report by Camacho (1992) is the primary source of information on retrofit costs (based on 1990 dollars), which he determined by equations developed from costs of retrofit types, the type of facility, and design flows. Coefficients and exponents were given for two sets of equations for capital costs and operation and maintenance costs. These equations are of the form:

$$\text{Capital} = a(\text{Flow})^b \quad \text{and} \quad \text{O\&M} = c(\text{Flow})^d$$

Where, Capital = Capital costs
O&M = Operation and maintenance costs
Flow = Flow in million of gallons per day
a,b,c,d = Regression coefficients and exponents

The model saves the regression coefficients and exponents in the worksheet *Retrofit Cap&O&M Cost Parameters*, applicable to six retrofit types: three-stage seasonal; three-stage annual; five-stage seasonal; five-stage annual; limit of technology; and a user-defined. Within each of the six retrofit types, the model further subdivides the regression parameters into four plant types: extended aeration; activated sludge; activated sludge with nitrification; and fix film. These four types are finally subdivided into two flow regimes: between 0.5 and 5.0 mgd; and between 5.0 and 30 mgd. For the phosphorus only #1 and phosphorus only #2 retrofits, the worksheet uses and lists separate cost parameters. The phosphorus only retrofit costs are based on effluent limit concentrations and designed flows.

Annual costs of the retrofit were determined using the results of the capital and operation and maintenance costs and applying a discount rate and term. The model prompts the user to define the discount rate and term. The current default is

set at a discount rate of 10 percent and a term of 20 years.

Retrofit Cap&O&M cost parameters

The worksheet *Retrofit CAP&O&M Cost Parameters* contains the coefficients and exponents needed to calculate costs of retrofits. For three-stage seasonal (C1:F10), three-stage annual (G1:J10), five-stage seasonal (K1:N10), five-stage annual (O1:R10), the cost data were obtained from Camacho's (1992) report presented in Appendix I. Data for the limit of technology (S1:V10) were not available, so the coefficient and exponent parameters were set to cause the costs to be extremely high. These numbers can be changed when better information is available.

The phosphorus retrofit cost data were obtained from tables 3.11 and 3.12 on page 89 of Camacho's (1992) report. The phosphorus only operation and maintenance costs are saved in cells (113:B18) and are based on the phosphorus effluent concentration. The capital costs are saved in cells (A21:E26) and are based on the phosphorus effluent concentration and plant flow.

Macro 1

The *Macro 1* worksheet is used to create dialog boxes for the retrofit effluent limits and threshold values. These dialog boxes differ from the worksheets containing the graphic dialog boxes (optimization dialog, nonpoint option dialog, point source option dialog, and added BMPs dialog) in that a user response returns a value. The graphic dialog boxes, found in the other worksheets, are what Excel terms "user forms" where a user response returns a text response (e.g. True/False or Yes/No).

DEFINITION OF TERMS

Acres Available: Total acres available for each land use before implementation of BMPs and NML. (See heading on output sheet.)

Adjusted Reduction Target: New reduction target load in pounds to account for point source credits and NML. (See heading on output sheet.)

AWA: Animal waste acres.

AWT: Animal waste treatment.

BMP: Best Management Practice.

BMP Costs: Nonpoint source costs related to the implementation of control programs on a cost per acre basis. Costs vary based on management measures applied to a particular land use type and the watershed model location (segment).

CST: Conservation tillage land use.

CTF: Conservation tillage with farm plan.

CTN: Conservation tillage with nutrient management.

CVT: Conventional tillage land use.

Controllable Load: Nutrient loads that are the difference between the 1985 baseline and the all-forested scenario determined by the Chesapeake Bay Program Watershed Model in a watershed made up of only the Chesapeake Bay Program signatory states. Non-controllable loads include atmospheric deposition, loadings from non-signatory states, loadings from forest, and that part of existing land use loading that would be contributed by forest.

Delivered Load: That portion of the edge of field load that is transported to the Chesapeake Bay. A transport factor is applied to the edge of field load to obtain the delivered load.

Edge of Field Load: The total load generated from all nonpoint and point sources within a watershed model segment before being transported to the next watershed model segment. (See delivered load.)

FPL: Farm plan.

FOR: Forest land use.

HAY: Hay land use.

HEL: Highly Erodible Land.

Highly Erodible Land Acres: The Natural Resource Conservation Service determined county land areas that were susceptible to high erosion rates. For the purpose of the CEA model, these HEL acres are apportioned to the land uses of conventional tillage, conservation tillage, and hayland land uses. Land that is designated as HEL is eligible for special BMPs.

Nitrogen Loading Rate: A quantity of nitrogen transported from a unit area. The loading rate used in the CEA model varies by land use and model segment and is expressed as an annual rate in pounds per acre.

Nitrogen Reduction Efficiency: Nonpoint source nitrogen load reduction efficiency of a BMP installed at a site expressed as one minus ratio of post-BMP nitrogen load and the pre-BMP nitrogen load calculated as (1-post BMP/pre-BMP).

Nitrogen Transport Factor: The factor applied to the total edge-of-stream nitrogen load in each watershed model segment that results in the total nitrogen load that is delivered to the Chesapeake Bay. The factor is a number from 0 to 1.

NMF: Nutrient management with farm plan.

NML: Nutrient Management Legislation.

Nutrient Management Legislation: Pennsylvania regulations establishing minimum criteria for nutrient management plans required of farms with over 2,000 pounds of livestock or poultry per acre.

NML Acre: Acres that are removed from the acres available for potential BMP installation because of activities due to NML.

NUT: Nutrient Management.

Original Land Use Acres: The number of acres of a land use type in each model segment as defined by the Chesapeake Bay Program Watershed Model before adjustments are made in the Cost Effectiveness Analysis Model.

PAS: Pasture land use.

Phos. Only Capital Costs: Point source phosphorus only retrofit annual capital costs based on plant flows in millions of gallons per day and level of treatment in phosphorus concentrations of 2, 1, 0.5, and 0.2 milligrams per liter.

Phosphorus Loading Rate: A quantity of phosphorus transported from a unit area. The loading rate used in the CEA model varies by land use and model segment and is expressed as an annual rate in pounds per acre.

Phosphorus Reduction Efficiency: Nonpoint source phosphorus load reduction efficiency of a BMP installed at a site expressed as one minus ratio of post-BMP phosphorus load and the pre-BMP phosphorus load calculated as (1-post BMP/pre-BMP).

Phosphorus Transport Factor: The factor applied to the total edge-of-stream phosphorus load in each watershed model segment that results in the total phosphorus load that is delivered to the Chesapeake Bay. The factor is a number from 0 to 1.

Point Source Credit: Nutrient load reductions that occur at a point source facility as a result of no action. This could occur if a facility experiences a decrease in flows and/or nutrient concentration for reasons other than a retrofit.

Post-BMP Load: Total delivered load from all acres treated by a particular BMP. (See heading on output sheet.)

Reduction Target Load: The total amount of delivered load reduction needed to meet the 40 percent nutrient goal. (See heading on output sheet.)

Retrofit Cap&O&M Costs: Point source retrofit costs due to capital investment and operation and maintenance costs of a biological nutrient removal retrofit. Costs are a function of plant type, flow, retrofit options, and coefficients provided by Camacho (1992).

SBF: Streambank Fencing.

SBF1: Streambank fencing funded by the Pennsylvania Department of Environmental Protection.

SBF2: Streambank fencing funded by the Pennsylvania Game Commission.

SBF Acres: Acres available in each model segment for the installation of fencing along the streambank.

Total Available Load: The total delivered load from all nonpoint and point sources before the implementation of BMPs and retrofits. (See heading on output sheet.)

URI: Impervious urban land use.

URP: Previous urban land use.

Watershed Model Segment: Defined watershed areas within the Chesapeake Bay Basin that are used to calculate nutrient loads in the Chesapeake Bay Program's watershed model.

MODEL SCENARIOS

The four built-in scenarios in the CEA model were run with the default data sets. The starting assumptions for the four scenarios are described below with summary results presented in Table 1. Detailed results for each scenario are presented in the output sheets in Appendix B.

Scenario 1 – Minimized Costs

All nonpoint source BMPs and all point source retrofits are available as options to meet the target reductions for nitrogen and phosphorus. Nutrient management legislation is implemented and point source reductions due to changes in flow or concentration from 1985 to 2000 are credited toward the targeted reductions. The objective is to minimize costs while meeting or exceeding the reduction targets for nitrogen and phosphorus.

Scenario 2 – BNR Only

All nonpoint source BMPs and biological nutrient removal point source retrofits (5 options) are available as options for nutrient reduction. Nutrient management legislation is implemented and point source reductions due to changes in flow or concentration from 1985 to 2000 are credited toward the targeted reductions. The objective is to maximize reductions.

Scenario 3 – Phos. Only

All nonpoint source BMPs and phosphorus reduction only point source retrofits (2 options) are available as options for nutrient reduction. Nutrient management legislation is implemented and point source reductions due to changes in flow or concentration from 1985 to 2000 are credited toward the targeted reductions. The objective is to maximize reductions.

Scenario 4 – BNR & Phosphorus Reduction

All nonpoint source BMPs and all point source retrofits are available as options for nutrient reduction. Nutrient management legislation is implemented and point source reductions due to changes in flow or concentration from 1985 to 2000 are credited toward the targeted reductions. The objective is to maximize reductions.

Results

Scenario 1 represents the minimum cost to implement nonpoint and point source controls to meet the Chesapeake Bay Program and Pennsylvania goal of a 40 percent reduction in controllable nutrient load. Scenarios 2, 3, and 4 differ from scenario 1 in that cost is no longer a constraint (scenario 1 = minimized cost) and load reductions don't meet a target (scenarios 2, 3, and 4 = maximize reductions). The objective of scenarios 2, 3, and 4 is to evaluate the changes of point source loadings and costs for 174 facilities when changing the starting point source assumptions.

Because scenarios 2, 3, and 4 keep the starting nonpoint source assumptions constant and vary the point source assumptions, one would expect the nonpoint source results to be the same. However, an exception for the nonpoint results

Table 1. Cost Effectiveness Analysis Summary Results for Four Built-in Scenarios

Load Reductions (lb) and Costs ($)	Scenario 1 Min. Costs	Scenario 2 BNR Only	Scenario 3 Phos Only	Scenario 4 BNR & Phos.
Point Source Credit Reduction				
Nitrogen	2,362,665	2,362,665	2,362,665	2,362,665
Phosphorus	735,832	735,832	735,832	735,832
Point Source Retrofit Reduction				
Nitrogen	2,795,860	8,453,633	0	8,453,633
Phosphorus	662,587	763,873	687,586	763,873
Nonpoint Source NML Reduction				
Nitrogen	2,822,546	2,822,546	2,822,546	2,822,546
Phosphorus	450,000	450,000	450,000	450,000
Nonpoint Source BMP Reduction				
Nitrogen	14,760,929	34,041,179	34,041,179	34,041,179
Phosphorus	1,286,581	1,703,351	1,703,351	1,703,351
Total Point Source Reduction				
Nitrogen	5,158,525	10,816,298	2,362,665	10,816,298
Phosphorus	1,398,419	1,499,705	1,423,418	1,499,705
Total Point Source Cost	10,475,445	$4{,}502 \times 10^9$	3,277,503	$4{,}502 \times 10^9$
Total Nonpoint Source Reduction				
Nitrogen	17,583,475	36,863,725	36,863,725	36,863,725
Phosphorus	1,736,581	2,153,351	2,153,351	2,153,351
Total Nonpoint Source Cost	174,364,049	1,928,608,648	1,943,460,543	1,928,608,648
Total Reduction				
Nitrogen	22,742,000	47,680,022	39,226,390	47,680,022
Phosphorus	3,135,000	3,653,056	3,576,769	3,653,056
Total Cost	184,839,494	$4{,}504 \times 10^9$	1,946,738,046	$4{,}504 \times 10^9$

occurred in the costs where scenario 3 differed from the equal costs in scenarios 2 and 4. While the total load reduction (maximized reductions) remained the same for nonpoint sources in scenarios 2, 3, and 4, scenario 3 used both streambank fencing options (PAS.SBF1 and PAS.SBF2) instead of just the one streambank fencing option (PAS.SBF2) used in scenario 2 and 4 The first option, PAS.SBF1, is more expensive than the second option, PAS.SBF2; thus the increased change in cost while maintaining a consistent total load reduction. Since scenarios 2, 3, and 4 are not concerned with costs but only with maximizing reductions, both streambank fencing options are equally available to the model because the load reduction efficiencies for nitrogen and phosphorus are the same in each option.

For point source loads, the credit reductions remain constant across all four scenarios and any changes that occur in load depend on the retrofit options selected by the model. The point source reductions that occurred in nitrogen and phosphorus were the same for scenarios 2 and 4. These reductions were attributed to 141 LOT retrofits and 27 three-stage seasonal retrofits while 6 facilities received no retrofits. In scenario 3, by definition, all retrofit reductions occurred in phosphorus and were attributed to 84 phosphorus only #1 retrofits and 77 phosphorus only #2

retrofits while 13 facilities received no retrofits. The total phosphorus retrofit reduction in scenario 3 is 10 percent less than that found in scenarios 2 and 4. Although costs may be higher, this suggests that BNR retrofits are better in maximizing reductions in phosphorus than the reductions for phosphorus only retrofits.

In scenario 1, costs for point source retrofits influenced the type of retrofit selected for a facility. Of the 174 point source facilities available, 116 received phosphorus only retrofits while 45 received BNR retrofits. The total point source phosphorus load reduced in scenario 1 differed from scenario 3 by 25,000 pounds. Scenarios 2 and 4 showed an additional 100,000 pound reduction in phosphorus when compared to scenario 1. This suggests that point source retrofits to control phosphorus are close to being exhausted as an option and nonpoint source solutions should be explored. If one seeks to increase phosphorus reductions from point sources, additional point source phosphorus reductions would be achieved by: (1) reducing the input load to the treatment facility such as was done with a phosphate detergent ban, and (2) exploring more efficient phosphorus reduction technologies.

Although point source phosphorus reductions are nearing limits imposed by available technology, there is a lot of room for increased point source nitrogen reductions. For scenario 1, the point source nitrogen reduction is limited to 2.8 million pounds as a share in meeting the 40 percent reduction target. However, an additional 5.6 million pounds could be reduced if cost is not an issue.

SUMMARY

The cost effectiveness analysis model is useful in identifying the relative costs and nutrient load reductions based on a mix of nonpoint source BMPs and point source retrofits. The user should not consider the cost estimates as absolute but as a relative measure between different scenarios. The total point source costs reflect an annual cost for a period of 20 years for the four scenarios. The nonpoint source costs reflect a one time total cost.

The four scenarios revealed some interesting load reduction and cost results:

The greatest reductions occurred from nonpoint source BMPs as compared to point source retrofits. For every pound reduced from point source retrofits, 3.4 and 1.2 pounds of nitrogen and phosphorus, respectively, were reduced from nonpoint source BMPs.

- The HEL nonpoint source BMP appears to be among the most cost effective BMPs.
- Urban and forest BMPs were not considered as a cost effective option.
- The phosphorus only point source scenario appears to be the most cost effective of the three point source scenarios investigated.
- Although more costly, BNR retrofits appear to be better in maximizing point source phosphorus reductions than the phosphorus only retrofits.
- Streambank fencing as a cost effective BMP occurred only in model segments 120 and 140 using the Game Commission's streambank fencing program. The Pa. DEPs streambank fencing program was not selected by the model.

The cost effectiveness analysis does not provide a discrete decision rule for implementation, but an evaluation of the types of information needed to provide for better management decisions. These decisions must also consider funding, practicality and political will in implementing strategies to achieve nutrient reduction goals.

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Appendixes only available in hard copy.