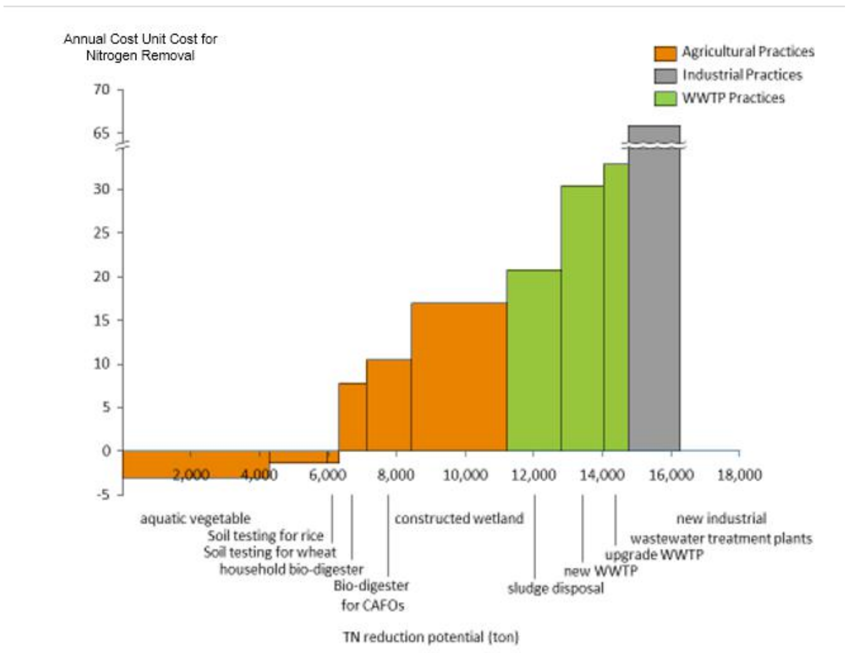

Pollution Reduction Opportunity Analysis

User's Guide

WORLD RESOURCES INSTITUTE

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Nutrient Pollution Reduction Opportunity Analysis
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I Introduction

The restoration of the ecological health and water quality of a river, lake, estuary, bay, or coastal area suffering from multiple sources of nutrient pollution nearly always requires a comprehensive management strategy. A holistic watershed approach that addresses all of the causes of the degradation is needed. The strategy must:

- Establish comprehensive water quality and pollutant loading monitoring programs;
- Identify all sources of harmful pollution;
- Quantify pollutant loads by source, sector, and location;
- Enable the development, calibration, and verification of watershed and water quality models;
- Assess the impacts of pollutant loads from all sources and sectors;
- Establish maximum allowable pollution loads to the water body for each important pollutant (a pollution budget or watershed cap);
- Develop and evaluate alternatives for reducing pollution loads; and
- Allocate allowable pollutant loads to sectors, regions, and sources.

All sources and sectors must be included in this analysis and accounted for under the loading caps. Otherwise, the caps would be meaningless. This does not mean however, that all sources must be assigned load reductions, they just have to be accounted for in the cap. As an example, runoff from forested lands frequently contributes nutrient loads to water bodies, albeit small ones, and they should be accounted for in the allocations. But it would make little sense to try and require load reductions from forested land.

Holistic watershed caps should be established and all sources and sectors should be included in the cap and assigned allocations. The sectors and sources can include wastewater effluent, untreated sewage, trash and garbage, urban runoff, direct and indirect industrial discharges, agriculture, atmospheric deposition, septic systems, phosphate detergents, marine vessels, and possibly other sources.

The allocation of allowable loads is not simply an *ad hoc* mathematical exercise, but rather a complex set of policy decisions on how to the distribute the cost of restoration to different sources. The role of science in the process is to identify the sources and loads and to determine if different control actions are equivalent, i.e. produce the same water-quality response and have the same degree of uncertainty. Following this comes the hard work of integrating all of the technical, social, and economic factors in the setting of the allocations and assigning responsibilities for controlling pollutant discharges.

Pollution Reduction Opportunity Analysis

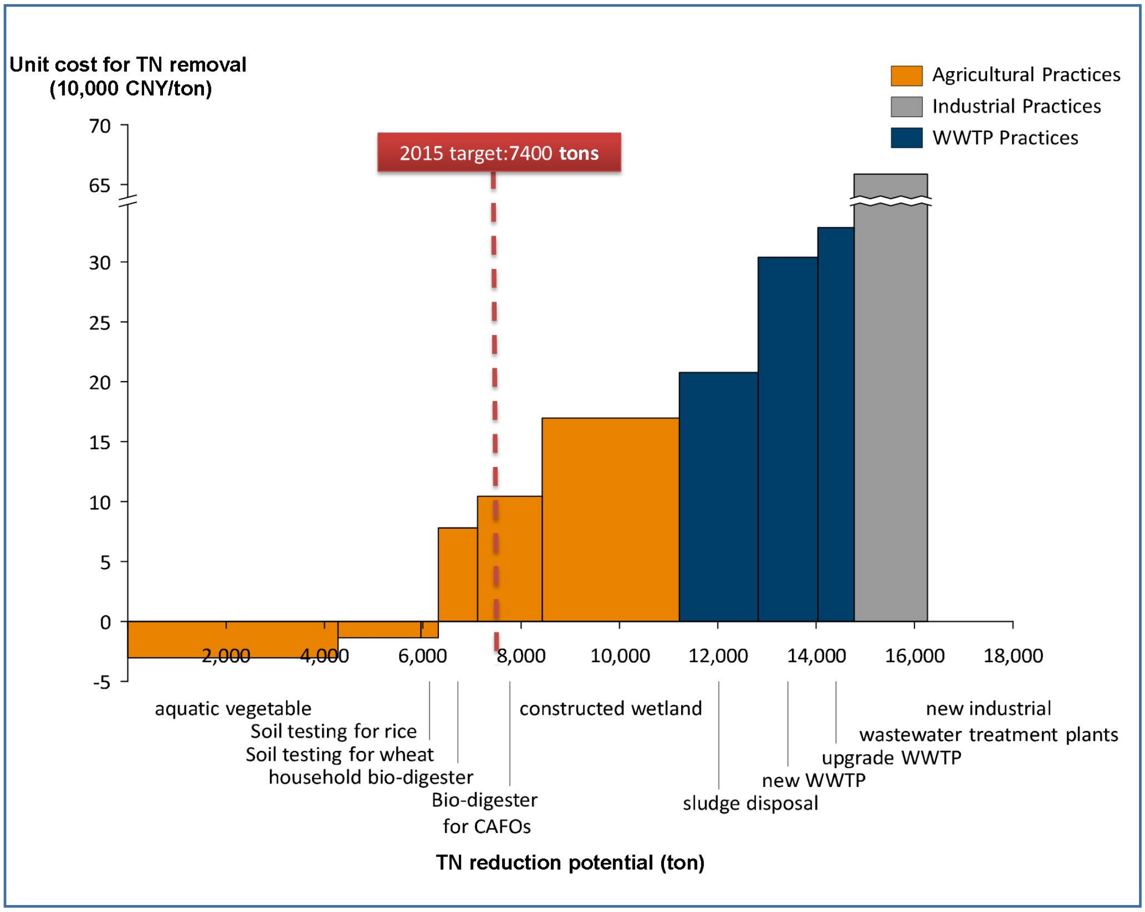
A major challenge arises when decisions must be made about the assignment of pollution-reduction responsibilities. Such decision-making becomes a political process at this point, one requiring decisions by policy makers and elected officials who are not well-versed in the science involved. A PROA is useful for two major reasons: it can help decision-makers better understand the biophysical links between changes in land-use, development and industrial activities, and the environment. And it also serves as a decision-support tool that can help identify the solutions that provide the greatest pollution reduction analyses at the lowest cost and for preparing policy recommendations on water quality restoration efforts.

The Pollution Reduction Opportunity Analysis (PROA) concept was developed by the World Resources Institute (WRI), in conjunction with Tsinghua University in Beijing, China. A PROA takes a holistic approach to watershed restoration through the following analytical steps:

1. All sources of the pollutant of concern are identified;
2. Pollutant loadings from each source and/or sector are estimated;
3. Methods of reducing the discharged loads from each source and/or sector are identified;
4. The load reduction potential of each source/sector is identified;
5. The cost of achieving load reductions for each source/sector is estimated on a per mass unit basis (cost per kg per year); and
6. The results are graphed in a manner that clearly shows the reduction potential and cost effectiveness for each method and sector.

An example of a PROA is shown in Figure 1. It was developed by WRI to analyze options for reducing total nitrogen discharges to Chao Lake from Lujiang County in the city of Hefei in Anhui Province, China. Results are graphed for all available reduction methods, color-coded by sector, and arranged from lowest to highest cost per ton for the reduction (the vertical axis). Each bar represents an method of reducing the discharged annual load. The horizontal axis units are tons per year and the width of each bar indicates the estimated total reduction potential for that method. Preliminary conclusions about what sources and/or sectors have the greatest potential for reductions as well as cost-effectiveness can quickly and easily be drawn.

Figure 1 Total Nitrogen PROA for Lujiang County Discharge to Chao Lake, China



Some interesting results from the PROA are worth noting. Lujiang County is largely agricultural, hence most of the reduction potential is found in that sector. The agricultural reduction methods are by far the most cost-effective ones. Some of the agricultural methods even have negative costs, for example, reducing fertilizer application rates. Upgrading wastewater treatment plants has far less potential and is less cost-effective.

A PROA graph can be a powerful communication tool. It can present the conclusion of the analysis in a simple and compelling way that is easily understandable by decision-makers, local governments and other stakeholders. A PROA should make it easier to reach consensus on a path forward.

II. Using the PROA Results

The PROA graph is a bar chart that clearly indicates two very important things, especially in the early stages of a watershed restoration effort. It reveals at a glance what the most cost-effective technologies for reducing pollution loads are, as well as the magnitude of the potential reductions that each could produce.

The Lujiang County total nitrogen PROA illustrates this. It allows several important conclusions to be immediately drawn:

- The largest potential TN load reductions are in the agriculture sector.
- The lowest cost load reductions are also in the agricultural sector;
- Some agricultural measures have negative costs, i.e. they would save farmers money;
- The measure with the most reduction potential, switching crops to aquatic vegetables such as lotus root, also has the lowest cost;
- Constructed wetlands have the second largest reduction potential but the highest unit costs of the agriculture options;
- Upgrading existing municipal wastewater treatment plants to reduce TN discharges has very little reduction potential but very high unit costs; and
- Building industrial wastewater treatment plants has low reduction potential but extremely high unit costs.

Conclusions such as these however, should not lead directly to policy decisions, especially in the early stages of the restoration effort. Identification of the most cost-effective alternatives by the PROA must then be followed by a more comprehensive evaluation. The PROA looks only at cost and reduction potential and not at other factors that would be critical to a sound decision about which ones to implement. These factors include such things as social impacts, indirect economic impacts, unintended environmental impacts, and implementability. Looking at the Lujiang County PROA again, the most promising alternative of changing crops to aquatic vegetables could potentially face some severe obstacles to its implementation, possibly including:

- Economic impact on farmers;
- Land and water requirements;
- Increased labor requirements for harvesting in the face of short labor supply in rural areas; and
- Farmer willingness to make the change.

All of the promising alternatives must be further evaluated in this manner.

III Refinement and Evolution of the PROA

A PROA should be considered the first step of might be a lengthy process for selecting actions to undertake. Its value in the early stages lies in pointing the restoration effort in the most promising directions. As the effort grows, matures, and comes closer to a preferred action plan, the PROA should change as well.

Refinement and evolution of the PROA is necessary and beneficial for the following reasons.

Initial Lack of Data—A lack of data specific to the watershed will almost always be a major concern in the early stages of a watershed restoration effort. It is likely that some of the desired data, including water quality data; sources, locations, and magnitudes of pollutants being discharged; and the cost of remedial actions, will not be available or even exist. Because of this, restoration efforts usually begin with establishment of water quality and pollutant loading monitoring programs. It takes time to identify all of the sources and quantify pollutant loads by source, sector, and location.

A PROA uses the best data that is available at the time it is created. It is likely that the first iteration of a PROA will rely heavily on literature and proxy values. Over time, the monitoring and data collections efforts will allow the replacement of the proxy and literature values with local data.

A reference database is provided along with the PROA model. It contains data on nutrient control technologies in use internationally, their efficiencies in reducing total nitrogen and total phosphorus discharges, capital costs, and operations and maintenance costs. Sectors covered are domestic and industrial wastewater, septics, urban stormwater, and agriculture. The data should be considered as literature values that can be replaced in the PROA over time as local data becomes available.

Initial Lack of Analytical Tools—Adequate analytical tools to assess the water body and its responses to pollutant loads are not likely to exist at the onset of the program. Pollutant loading and water quality response models are needed to support watershed management decisions, and the models cannot be developed without sufficient data from water quality and pollutant loading monitoring programs. As data is collected, scientific understanding of the watershed, pollutant loads and delivery factors, and water quality responses will steadily grow over time. The time frame for this process will likely be measured in years. Improvements in analytical tools could very likely result in changes to the PROA.

Available Alternatives Might Change—Some of the initial promising alternatives might not survive the follow-on analysis of implementability, and social, indirect economic, unintended environmental impacts. Also, new alternatives might emerge that can be added to the PROA.

The initial PROA should be is a very high-level, whole watershed analysis. As the restoration program progresses and comes closer to a preferred action plan, it may be useful undertake additional PROAs at the sub-watershed level. Identifying the most cost-effective measures in each sub-watershed could greatly increase

IV. Detailed Outline for Developing a PROA

Developing a PROA involves three overall steps: collecting and inputting necessary data and/or assumptions, performing calculations for pollutant load reductions and unit costs, and presenting the results in graphical form.

Following is a detailed list of actions needed to develop a PROA, initially applying it, and refining and improving it as additional data and information becomes available, and as lessons are learned.

A. Collect Data

To produce a nutrient PROA, data on nitrogen and phosphorus discharges by the following sectors are needed if they contribute loads to the water body:

- Sewage Collection;
- Wastewater treatment / Sludge Management;
- Urban stormwater;
- Direct industrial discharges;
- Agriculture;
- Aquaculture;
- Septic systems; and
- Atmospheric deposition;
- Septic systems.

Data needs by sector may include:

- Current annual discharged or runoff loads;
- Current treatment technologies and performance levels;
- Planned infrastructure and technology improvements;
- Load reductions expected from planned improvements;
- Other possible infrastructure and technology improvements or actions (e.g. policy changes) that could result in load reductions;
- Estimated unit costs for these reductions (e.g. 20 year life-cycle cost per kg of annual load reduction); and

Once contributing sectors have been identified, data is needed on the individual sources in the sectors. Aggregate data is preferred (such as the aggregate phosphorus load discharged by all of the municipal wastewater treatment plants in the watershed). If aggregate data is not available, data must be collected on all individual sources and then aggregated. Data needed on individual discharges can include

- Wastewater volumes discharged;
- Nitrogen and phosphorus effluent concentrations; and
- Location of discharges.

A database can be created for the collected data on nutrient sources and loads.

B. Inventory Current Pollution Control and Treatment Methods

Data should be collected on all sources that have the ability or potential to reduce of control their discharges. This includes both point sources, such as wastewater treatment plants and factories, and nonpoint sources such as agriculture. Desired data includes

- Treatment processes;
- Influent and effluent nutrient loads;
- Treatment efficiencies;
- Nutrient discharge limits;
- Agricultural Best Management Practices; and
- Nutrient reduction costs (capital and operating).

C. Use PROA Model to Evaluate Cost-effectiveness of Available Methodologies to Reduce Nutrient Discharges

Once the necessary data (or proxy data) have been gathered, it is entered into the PROA spreadsheet and the model automatically calculates the potential pollutant load reduction that each technology could produce and the annualized cost per kilogram of the reduction.

The results are put into the form of a bar chart cost-curve, using either Excel's graphing tools or Think-Cell, a commercial software program.

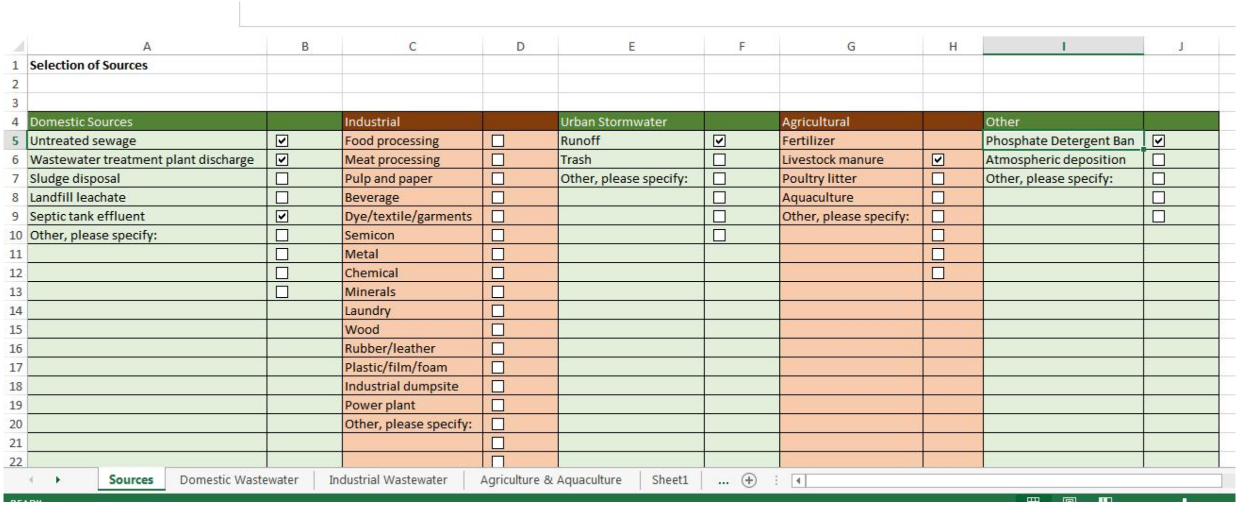
V. Creating a PROA—Step-by-Step Guidance

A PROA is an Excel spreadsheet model. Creating a PROA involves the following steps.

Step 1. Select Sources of Nutrient Pollution

Select the sources of nutrient pollution in the watershed by left-clicking in a check-box as shown in Figure 2. This will enter a check mark in the box. The check boxes do not affect anything else in the model; the purpose is merely to create a record of sources.

Figure 2 Selecting Nutrient Pollution Sources



	A	B	C	D	E	F	G	H	I	J
1	**Selection of Sources**									
2										
3										
4	Domestic Sources		Industrial		Urban Stormwater		Agricultural		Other	
5	Untreated sewage	☑	Food processing	☐	Runoff	☑	Fertilizer		Phosphate Detergent Ban	☑
6	Wastewater treatment plant discharge	☑	Meat processing	☐	Trash	☐	Livestock manure	☑	Atmospheric deposition	☐
7	Sludge disposal	☐	Pulp and paper	☐	Other, please specify:	☐	Poultry litter	☐	Other, please specify:	☐
8	Landfill leachate	☐	Beverage	☐		☐	Aquaculture	☐		☐
9	Septic tank effluent	☑	Dye/textile/garments	☐		☐	Other, please specify:	☐		☐
10	Other, please specify:	☐	Semicon	☐		☐		☐		
11		☐	Metal	☐				☐		
12		☐	Chemical	☐				☐		
13		☐	Minerals	☐						
14			Laundry	☐						
15			Wood	☐						
16			Rubber/leather	☐						
17			Plastic/film/foam	☐						
18			Industrial dumpsite	☐						
19			Power plant	☐						
20			Other, please specify:	☐						
21				☐						
22				☐						

Step 2. Select Technologies and Best Management Practices

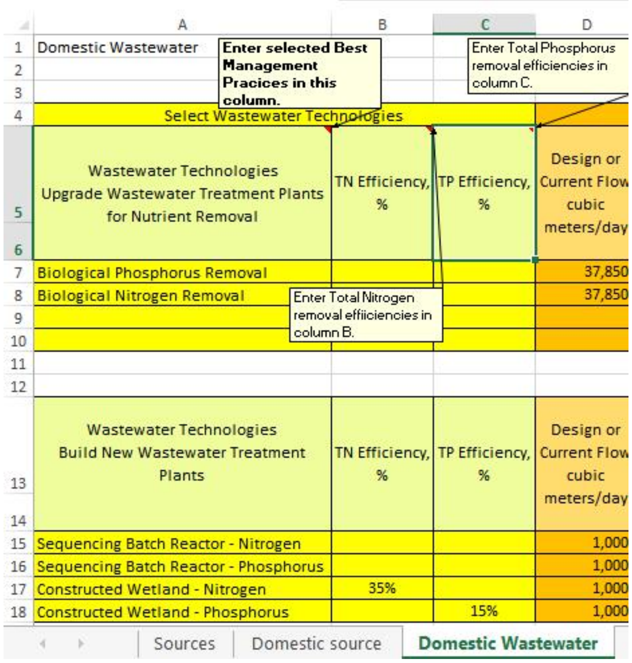
The PROA model has a tab for each of the source categories shown on the Sources tab—Domestic Wastewater, Industrial Wastewater, Urban Stormwater, Agriculture and Aquaculture, and Other. Appropriate technologies and best management practices (BMPs)for each category can be selected from the reference data base or other sources and added to the appropriate tab. Following is step-by-step guidance for each tab.

A. Domestic Wastewater Tab

Step 1) Enter selected technologies for domestic wastewater column in A and their nitrogen and phosphorus removal efficiencies, if known, in columns B and C as shown in Figure 3. The cells in these columns are formatted for percentage, so enter the efficiencies as whole numbers (e.g. 40 and 25).

All columns in the model that require user input are identified by a lighter fill color for the column heading, as well as a small red triangle in the upper right-hand corner. Rolling the mouse cursor over the cell with a triangle brings up a comment indicating what data should be entered in the column. Clicking SHOW ALL COMMENTS on the COMMENTS section of the Excel REVIEW menu will show all comments in the tab.

Figure 3



Enter selected Best Management Pracices in this column.

Enter Total Phosphorus removal efficiencies in column C.

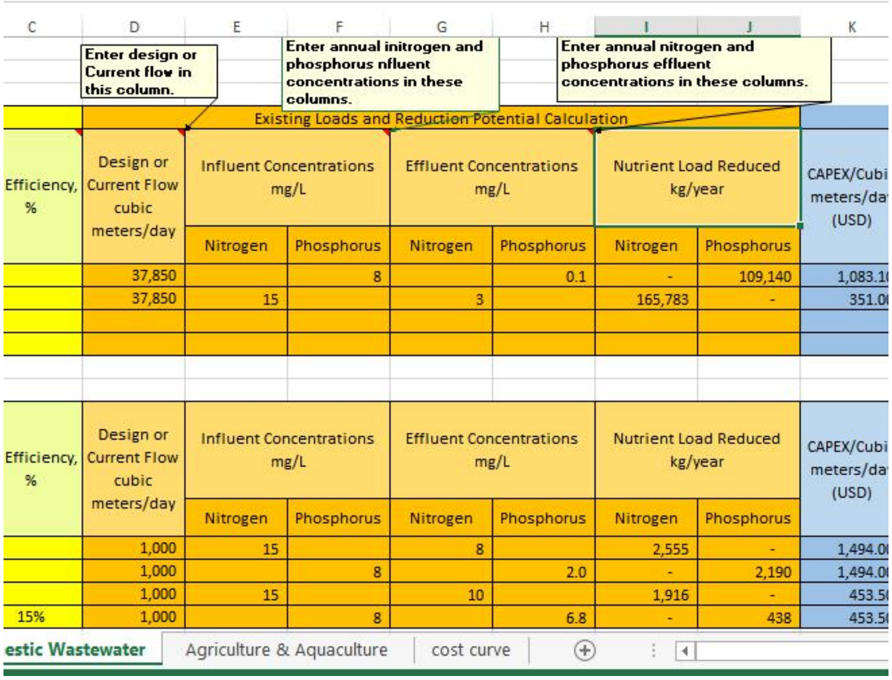
Enter Total Nitrogen removal effiiciencies in column B.

	A	B	C	D
1	Domestic Wastewater			
2				
3				
4	Select Wastewater Technologies			
5	Wastewater Technologies Upgrade Wastewater Treatment Plants for Nutrient Removal	TN Efficiency, %	TP Efficiency, %	Design or Current Flow cubic meters/day
6				
7	Biological Phosphorus Removal			37,850
8	Biological Nitrogen Removal			37,850
9				
10				
11				
12				
13	Wastewater Technologies Build New Wastewater Treatment Plants	TN Efficiency, %	TP Efficiency, %	Design or Current Flow cubic meters/day
14				
15	Sequencing Batch Reactor - Nitrogen			1,000
16	Sequencing Batch Reactor - Phosphorus			1,000
17	Constructed Wetland - Nitrogen	35%		1,000
18	Constructed Wetland - Phosphorus		15%	1,000

Step 2) Enter current or design flow in column D and expected influent and desired effluent nitrogen and phosphorus concentrations in columns E and F, as shown in Figure 4. Note that nitrogen and phosphorus costs are entered on separate rows. This is because all of the data in the reference database for upgrading wastewater treatment plants for nutrient removal has been reported this way. Data for new wastewater treatment plants is usually in the form of total capital cost, operation and maintenance cost, and nitrogen and phosphorus removal efficiencies. In this case, two rows are also used and the capital and O&M costs split between the two. Without more specific information about plant design, a 50-50 split should be assumed.

Once the current or design flows have been entered, annual nutrient load reductions are automatically calculated in columns I and J. See Figure 4.

Figure 4



Enter design or Current flow in this column.

Enter annual initrogen and phosphorus nfluent concentrations in these columns.

Enter annual nitrogen and phosphorus effluent concentrations in these columns.

C	D	E	F	G	H	I	J	K
	Existing Loads and Reduction Potential Calculation							
Efficiency, %	Design or Current Flow cubic meters/day	Influent Concentrations mg/L		Effluent Concentrations mg/L		Nutrient Load Reduced kg/year		CAPEX/Cubi meters/da (USD)
		Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus	
	37,850		8		0.1	-	109,140	1,083.1
	37,850	15		3		165,783	-	351.0

C	D	E	F	G	H	I	J	K
Efficiency, %	Design or Current Flow cubic meters/day	Influent Concentrations mg/L		Effluent Concentrations mg/L		Nutrient Load Reduced kg/year		CAPEX/Cubi meters/da (USD)
		Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus	
	1,000	15		8		2,555	-	1,494.0
	1,000		8		2.0	-	2,190	1,494.0
	1,000	15		10		1,916	-	453.5
15%	1,000		8		6.8	-	438	453.5

Step 3) Enter cost data.

There are three methods for entering cost data. The appropriate methods will depend on the nature of the cost data available.

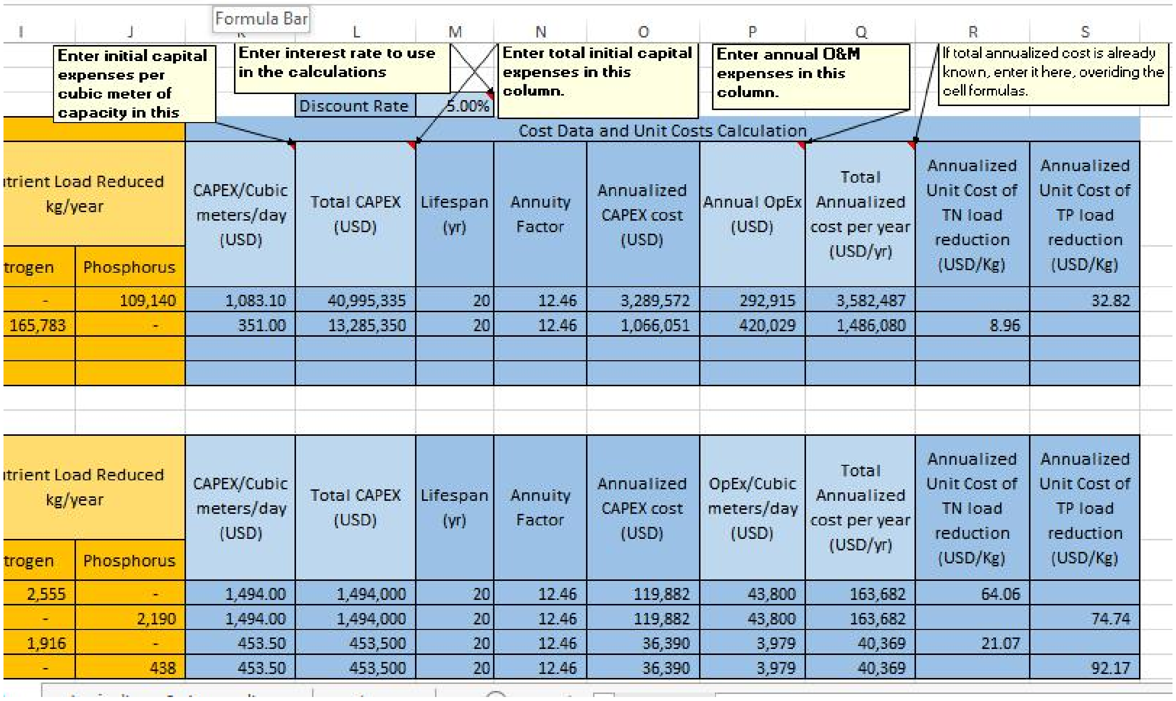
Case 1—If the data is in the form of initial capital cost, useful life, and annual operations & maintenance costs, enter this data in Columns L, M, and P. If only capital cost per cubic meter is available, enter it in column K. Column L will then calculate the total capital cost. If total capital cost is already known, it can be entered in column L, overwriting the formula.

Case 2—If the data is already in the form of total annualized cost, enter it in Column Q, overriding the cell formulas.

Case 3—If the data is in the form of total annualized cost per kg of nitrogen or phosphorus reduction, enter it in Columns R and S, overriding the cell formulas.

Enter the interest or discount rate to be used in the analysis in cell M3

Figure 4



Enter initial capital expenses per cubic meter of capacity in this

Enter interest rate to use in the calculations

Enter total initial capital expenses in this column.

Enter annual O&M expenses in this column.

If total annualized cost is already known, enter it here, overiding the cell formulas.

Discount Rate 5.00%

Cost Data and Unit Costs Calculation

itrient Load Reduced kg/year		CAPEX/Cubic meters/day (USD)	Total CAPEX (USD)	Lifespan (yr)	Annuity Factor	Annualized CAPEX cost (USD)	Annual OpEx (USD)	Total Annualized cost per year (USD/yr)	Annualized Unit Cost of TN load reduction (USD/Kg)	Annualized Unit Cost of TP load reduction (USD/Kg)
trogen	Phosphorus									
-	109,140	1,083.10	40,995,335	20	12.46	3,289,572	292,915	3,582,487		32.82
165,783	-	351.00	13,285,350	20	12.46	1,066,051	420,029	1,486,080	8.96	

itrient Load Reduced kg/year		CAPEX/Cubic meters/day (USD)	Total CAPEX (USD)	Lifespan (yr)	Annuity Factor	Annualized CAPEX cost (USD)	OpEx/Cubic meters/day (USD)	Total Annualized cost per year (USD/yr)	Annualized Unit Cost of TN load reduction (USD/Kg)	Annualized Unit Cost of TP load reduction (USD/Kg)
trogen	Phosphorus									
2,555	-	1,494.00	1,494,000	20	12.46	119,882	43,800	163,682	64.06	
-	2,190	1,494.00	1,494,000	20	12.46	119,882	43,800	163,682		74.74
1,916	-	453.50	453,500	20	12.46	36,390	3,979	40,369	21.07	
-	438	453.50	453,500	20	12.46	36,390	3,979	40,369		92.17

The cost calculations are performed as follows.

The total annualized cost is identical to equivalent annual cost (EAC). EAC is the total annual cost of constructing, operating and maintaining a facility over its useful lifespan. EAC's are usually used to explore the cost-effectiveness of alternatives with different costs and lifespans.

The EAC is equal to net present value (NPV) divided by an annuity factor, A(t,r). The annuity factor and EAC are calculated as follow:

Eq. 1 $A(t,r) = (1 - (1 / (1 + r)\ \hat{}\ t)) / r$

Eq. 2 $EAC = (\text{Initial Capital Cost}/A(t,r)) + \text{Annual Operation \& Maintenance Cost}$

t = lifespan in years, r = interest or discount rate

The annualized unit costs for nitrogen and phosphorus reductions are calculated by

Eq. 3 $\text{Unit Cost} = \text{EAC/nitrogen load reduction}$
$\text{Unit Cost} = \text{EAC/phosphorus load reduction}$

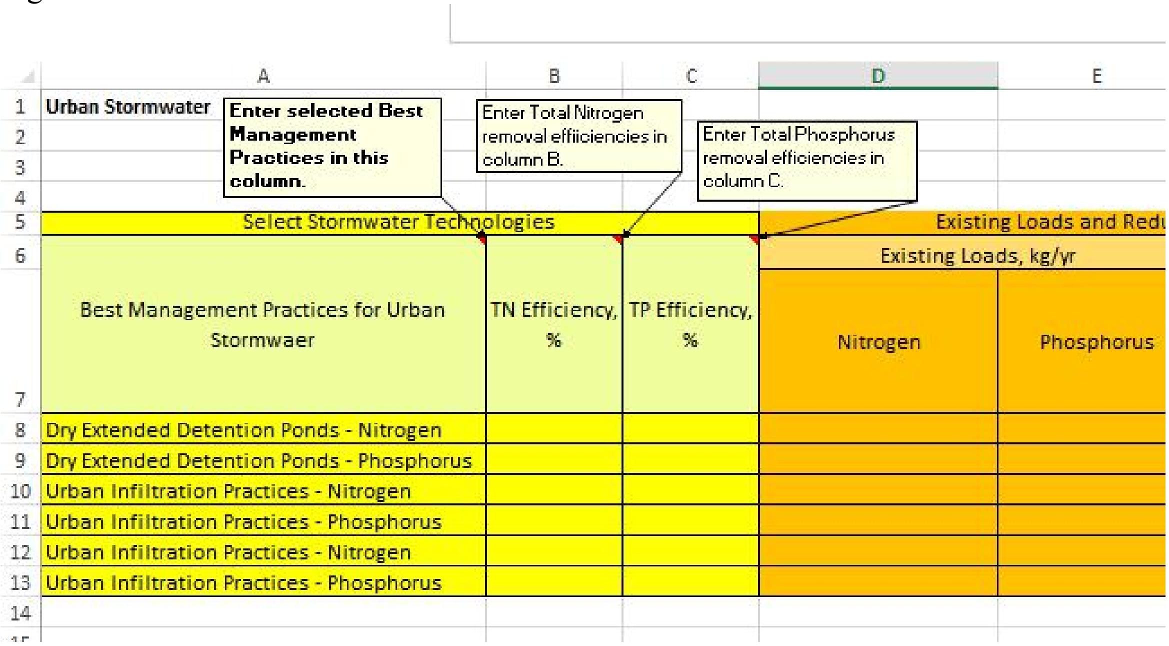
B. Industrial Wastewater Tab

The industrial wastewater tab is identical to the domestic wastewater tab. The treatment technologies are the same for both. However, industrial wastewater could have much higher concentrations of nitrogen and phosphorus, and higher capital and operating costs than those of the municipal WWTPs. There currently is no data on industrial costs in the reference database. If proxy data is needed, it is suggested that the municipal costs in the database be used, but increased by 20 percent.

C. Urban Stormwater Tab

Step 1) Enter selected Best Management Practices for urban stormwater in column A and their nitrogen and phosphorus removal efficiencies, if known, in columns B and C, as shown in Figure 5. The cells are formatted for percentage so enter the efficiencies as whole numbers.

Figure 6



Enter selected Best Management Practices in this column.

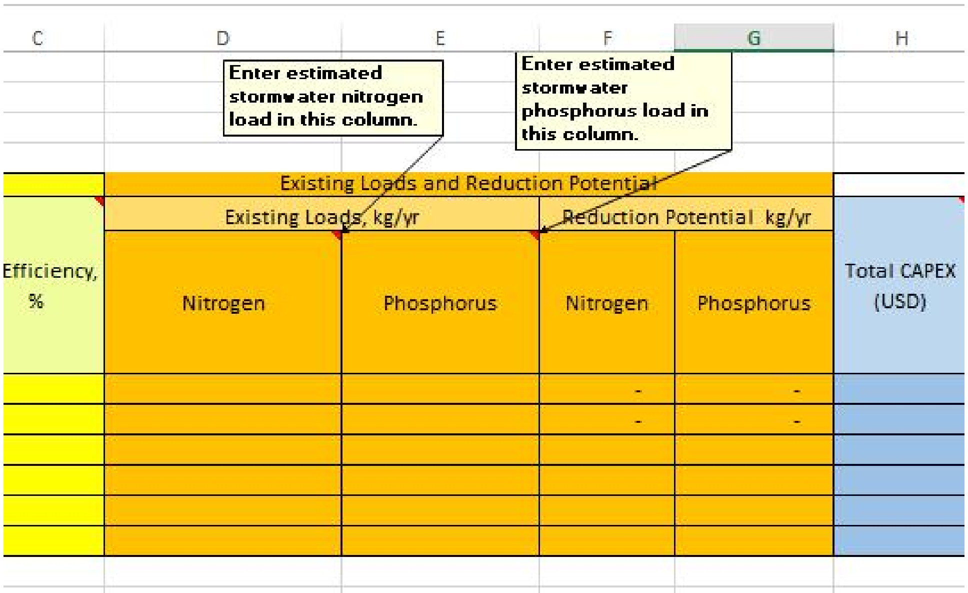
Enter Total Nitrogen removal effiiciencies in column B.

Enter Total Phosphorus removal efficiencies in column C.

	A	B	C	D	E
1	Urban Stormwater				
2					
3					
4					
5	Select Stormwater Technologies			Existing Loads and Redu	
6				Existing Loads, kg/yr	
7	Best Management Practices for Urban Stormwaer	TN Efficiency, %	TP Efficiency, %	Nitrogen	Phosphorus
8	Dry Extended Detention Ponds - Nitrogen				
9	Dry Extended Detention Ponds - Phosphorus				
10	Urban Infiltration Practices - Nitrogen				
11	Urban Infiltration Practices - Phosphorus				
12	Urban Infiltration Practices - Nitrogen				
13	Urban Infiltration Practices - Phosphorus				
14					

Step 2) Enter current estimated stormwater nitrogen and phosphorus loads in columns D and E. The input is in this form because it reflects all of the data in the reference database for stormwater BMPs. Once the efficiencies have been entered, annual nutrient load reductions are automatically calculated in columns F and G. See Figure 7.

Figure 7



Enter estimated stormwater nitrogen load in this column.

Enter estimated stormwater phosphorus load in this column.

C	D	E	F	G	H
	Existing Loads and Reduction Potential				
	Existing Loads, kg/yr		Reduction Potential kg/yr		
Efficiency, %	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Total CAPEX (USD)
			-	-	
			-	-	

Step 3) Enter cost data.

As with domestic wastewater, there are three methods for entering cost data. The appropriate methods will depend on the nature of the cost data available. All of the stormwater data in the reference database is in the form for case 3.

Case 1—If the data is in the form of initial capital cost, useful life, and annual operations & maintenance costs, enter this data in Columns H, I, and L.

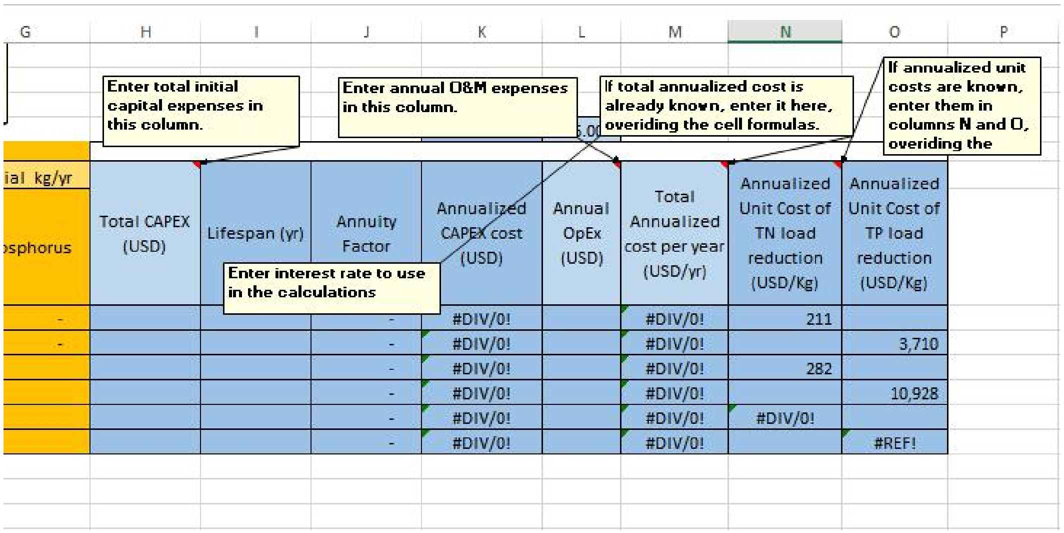
Case 2—If the data already is in the form of total annualized cost, enter it in Column M, overriding the cell formulas.

Case 3—If the data is in the form of total annualized cost per kg of nitrogen or phosphorus reduction, enter it data in Columns N and O, overriding the cell formulas.

Enter the interest or discount rate to be used in the analysis in cell M3

Once the cost data is entered, the unit cost calculations are identical to those for the domestic wastewater tab. Since only case 3 data is available, the unit costs are entered directly into columns.

Figure 8



Enter total initial capital expenses in this column.

Enter annual O&M expenses in this column.

If total annualized cost is already known, enter it here, overiding the cell formulas.

If annualized unit costs are known, enter them in columns N and O, overiding the

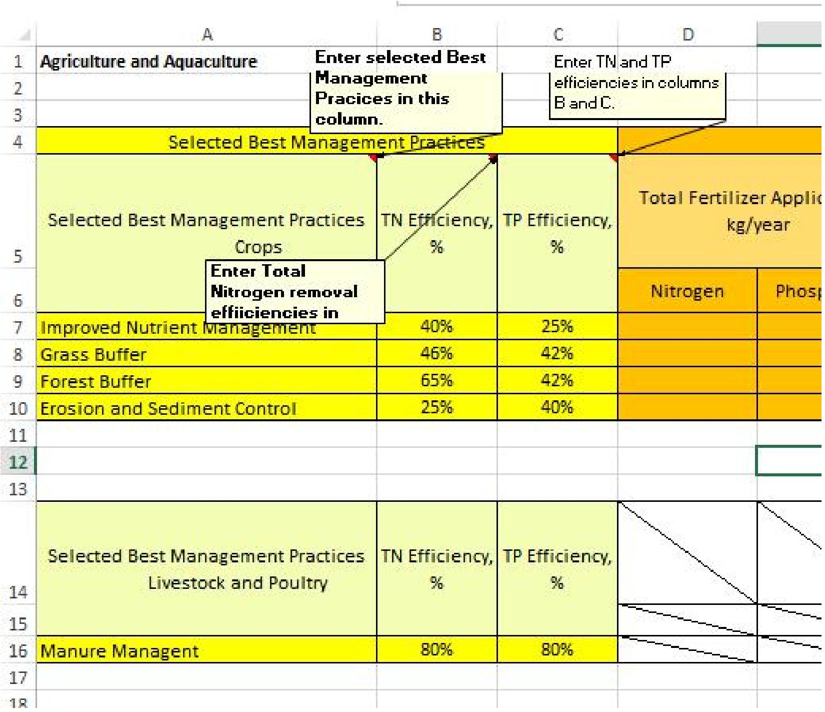
Enter interest rate to use in the calculations

G	H	I	J	K	L	M	N	O
ial kg/yr osphorus	Total CAPEX (USD)	Lifespan (yr)	Annuity Factor	Annualized CAPEX cost (USD)	Annual OpEx (USD)	Total Annualized cost per year (USD/yr)	Annualized Unit Cost of TN load reduction (USD/Kg)	Annualized Unit Cost of TP load reduction (USD/Kg)
-			-	#DIV/0!		#DIV/0!	211	
-			-	#DIV/0!		#DIV/0!		3,710
			-	#DIV/0!		#DIV/0!	282	
			-	#DIV/0!		#DIV/0!		10,928
			-	#DIV/0!		#DIV/0!	#DIV/0!	
			-	#DIV/0!		#DIV/0!		#REF!

D. Agriculture Tab

Step 1) Enter selected technologies for agriculture in column A and their nitrogen and phosphorus removal efficiencies, if known, in columns B and C, as shown in Figure 9. The cells are formatted for percentage so enter the efficiencies as whole numbers (e.g. 40 and 25).

Figure 9



Enter selected Best Management Pracices in this column.

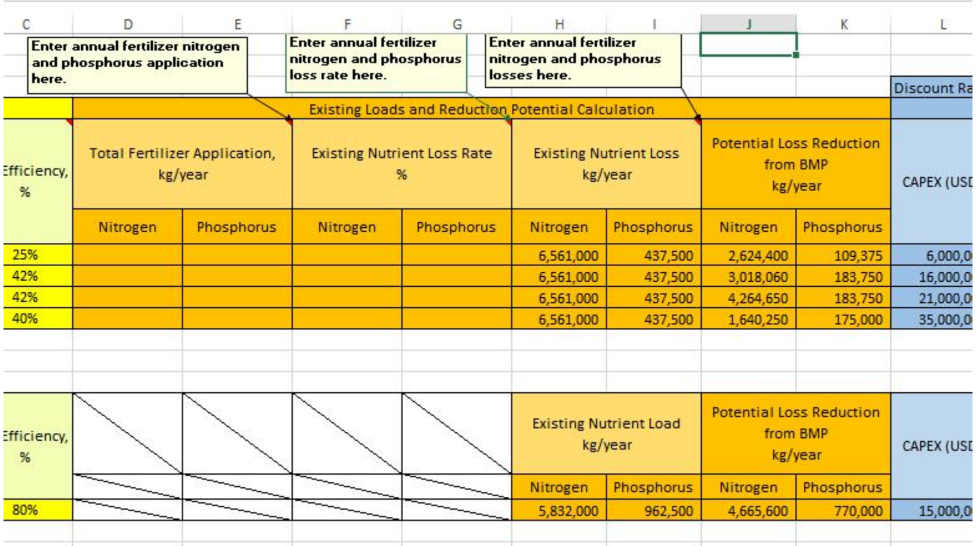
Enter TN and TP efficiencies in columns B and C.

Enter Total Nitrogen removal effiiciencies in

	A	B	C	D	
1	Agriculture and Aquaculture				
2					
3					
4	Selected Best Management Practices				
5	Selected Best Management Practices Crops	TN Efficiency, %	TP Efficiency, %	Total Fertilizer Applic kg/year	
6				Nitrogen	Phos
7	Improved Nutrient Management	40%	25%		
8	Grass Buffer	46%	42%		
9	Forest Buffer	65%	42%		
10	Erosion and Sediment Control	25%	40%		
11					
12					
13					
14	Selected Best Management Practices Livestock and Poultry	TN Efficiency, %	TP Efficiency, %		
15					
16	Manure Managent	80%	80%		
17					
18					

Step 2) Enter fertilizer data and calculate load reduction potential. There are two options for entering nitrogen and phosphorus fertilizer; the selection of which to use depends on the type of data available. If data on annual fertilizer nutrient application rates and losses are available, enter the data in columns D, E, F, and G. If the nutrient losses are known, enter the data in columns H and I. Columns J and K automatically select the correct input columns and calculate the load reduction potentials.

Figure 10



Enter annual fertilizer nitrogen and phosphorus application here.

Enter annual fertilizer nitrogen and phosphorus loss rate here.

Enter annual fertilizer nitrogen and phosphorus losses here.

C	D	E	F	G	H	I	J	K	L
									Discount Ra
	Existing Loads and Reduction Potential Calculation								
Efficiency, %	Total Fertilizer Application, kg/year		Existing Nutrient Loss Rate %		Existing Nutrient Loss kg/year		Potential Loss Reduction from BMP kg/year		CAPEX (USD
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus	
25%					6,561,000	437,500	2,624,400	109,375	6,000,0
42%					6,561,000	437,500	3,018,060	183,750	16,000,0
42%					6,561,000	437,500	4,264,650	183,750	21,000,0
40%					6,561,000	437,500	1,640,250	175,000	35,000,0

C	D	E	F	G	H	I	J	K	L
Efficiency, %					Existing Nutrient Load kg/year		Potential Loss Reduction from BMP kg/year		CAPEX (USD
					Nitrogen	Phosphorus	Nitrogen	Phosphorus	
80%					5,832,000	962,500	4,665,600	770,000	15,000,0

Step 4) Enter cost data

There are three options for entering cost data, the appropriate option will depend on the nature of the cost data available:

Case 1—The data is in the form of initial capital cost, annual operations & maintenance costs, and useful life, then enter this data in Columns L, M, and P.

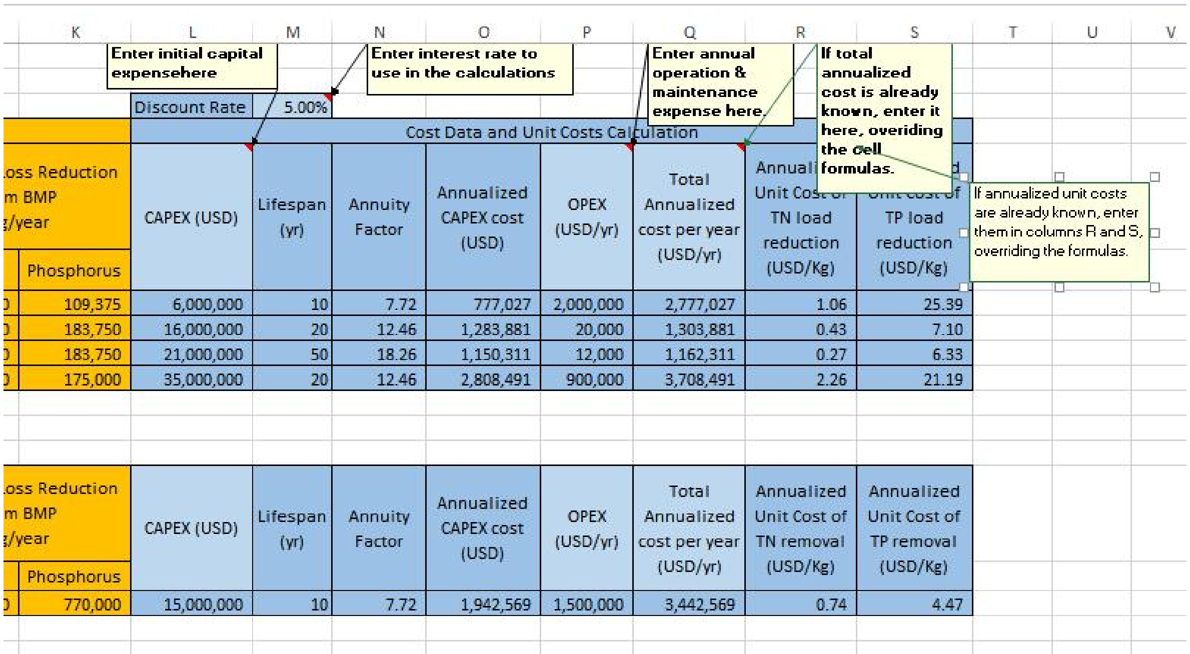
Case 2—If the data already is in the form of total annualized cost, enter it in Column Q, overriding the cell formulas.

Case 3—If the data is in the form of total annualized cost per kg of nitrogen or phosphorus, enter the data in Columns R and S, overriding the cell formulas.

As with stormwater, data in the reference database is largely in the form for case 3.

Once the data has been entered, the PROA calculates annualized unit costs The cost calculations are the same as on the domestic wastewater tab.

Figure 11



Enter initial capital expensehere

Enter interest rate to use in the calculations

Enter annual operation & maintenance expense here.

If total annualized cost is already known, enter it here, overiding the cell formulas.

If annualized unit costs are already known, enter them in columns R and S, overriding the formulas.

Discount Rate 5.00%

	Cost Data and Unit Costs Calculation							
oss Reduction m BMP g/year Phosphorus	CAPEX (USD)	Lifespan (yr)	Annuity Factor	Annualized CAPEX cost (USD)	OPEX (USD/yr)	Total Annualized cost per year (USD/yr)	Annuali Unit Cos TN load reduction (USD/Kg)	Unit cost of TP load reduction (USD/Kg)
109,375	6,000,000	10	7.72	777,027	2,000,000	2,777,027	1.06	25.39
183,750	16,000,000	20	12.46	1,283,881	20,000	1,303,881	0.43	7.10
183,750	21,000,000	50	18.26	1,150,311	12,000	1,162,311	0.27	6.33
175,000	35,000,000	20	12.46	2,808,491	900,000	3,708,491	2.26	21.19

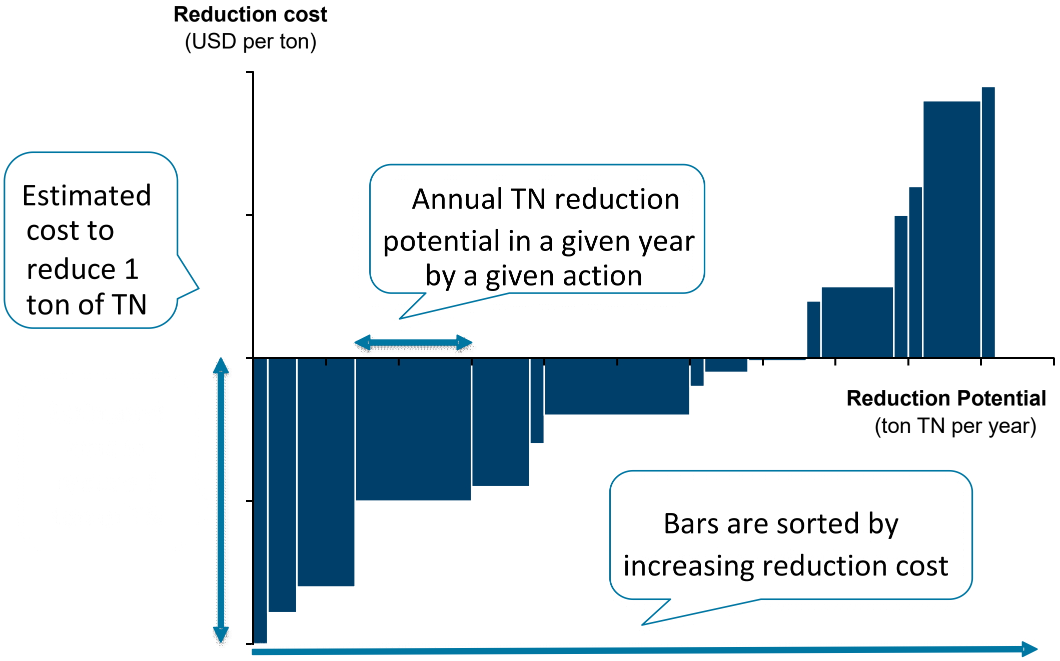
oss Reduction m BMP g/year Phosphorus	CAPEX (USD)	Lifespan (yr)	Annuity Factor	Annualized CAPEX cost (USD)	OPEX (USD/yr)	Total Annualized cost per year (USD/yr)	Annualized Unit Cost of TN removal (USD/Kg)	Annualized Unit Cost of TP removal (USD/Kg)
770,000	15,000,000	10	7.72	1,942,569	1,500,000	3,442,569	0.74	4.47

E. Data Visualization

The last step in creating a PROA is to visualize the otherwise abstruse cost-effectiveness analysis, presenting the result in a simple, straightforward manner that can be easily understood.

The two axes of a cost curve show the available pollution control measures, their nutrient reduction potentials and annualized costs, as shown in Figure 12.

Figure 12 An Illustrative Nitrogen Cost Curve


Reduction cost
(USD per ton)
Estimated cost to reduce 1 ton of TN
Annual TN reduction potential in a given year by a given action
Reduction Potential
(ton TN per year)
Bars are sorted by increasing reduction cost

Generating the cost curve—There are two recommended tools for creating the cost curves, a commercial software package called Think-cell and Excels graphing tools.

Using Think-cell—While there are many professional visualization tools available for economic graphs, Think-cell stands out for its efficiency, ease of use, quality and compatibility with the Microsoft Office suites.

Think-cell offers many economics chart types and graphical elements that are not included in Microsoft Excel. All the decorations – labels, connectors, arrows, and the like – are automated and placed precisely where they belong. The downside is its relatively high cost. The annual license fee for a single user is US$247.5. A 30-day free trial version is available to download at its official website.

Developing a cost curve with Think-cell is easy. After ensuring that Think-cell is properly installed, and Microsoft Excel and PowerPoint are working, follow the following three simple steps.

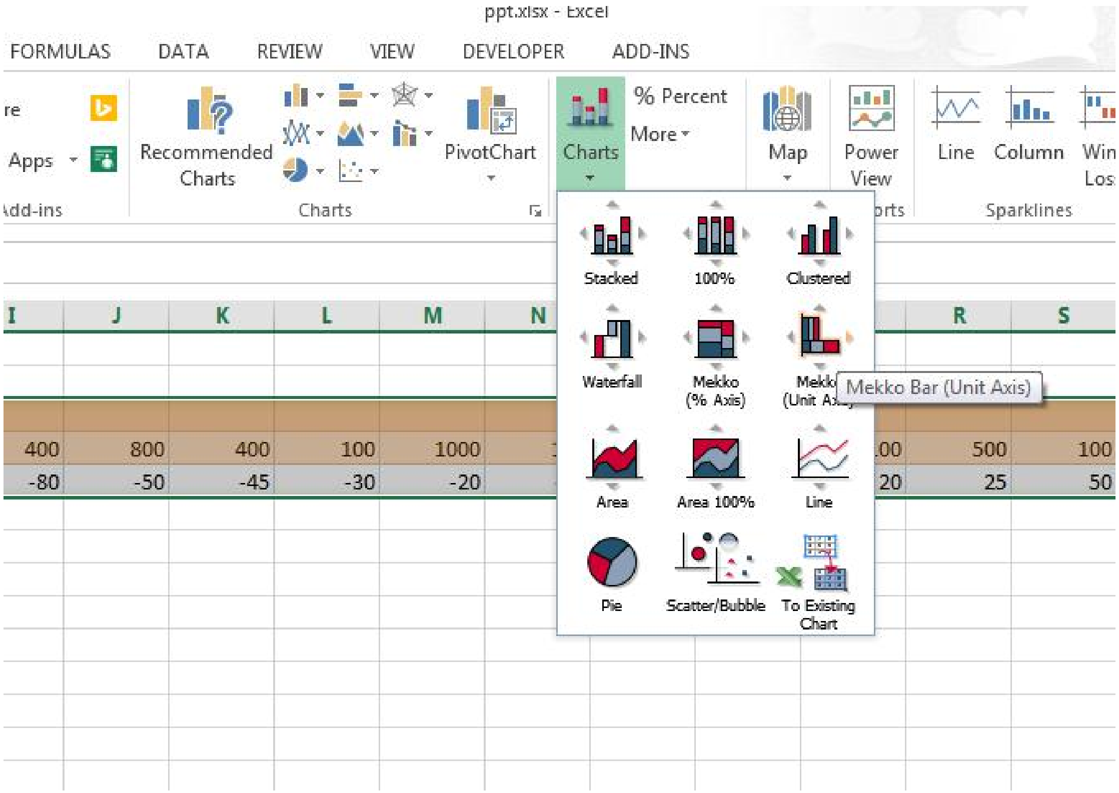
Step 1)—Create a new data sheet in the PROA model. Once abatement potential and annualized costs have all been calculated, copy and paste the results to the following template (Table 1). Options should be listed in order of least-cost to most-cost.

Table 1 Cost curve data template

	Option 1	Option 2	Option 3	Option 4	Option 5	……
Reduction potential (ton/year)						
Unit reduction cost (USD/ton)						

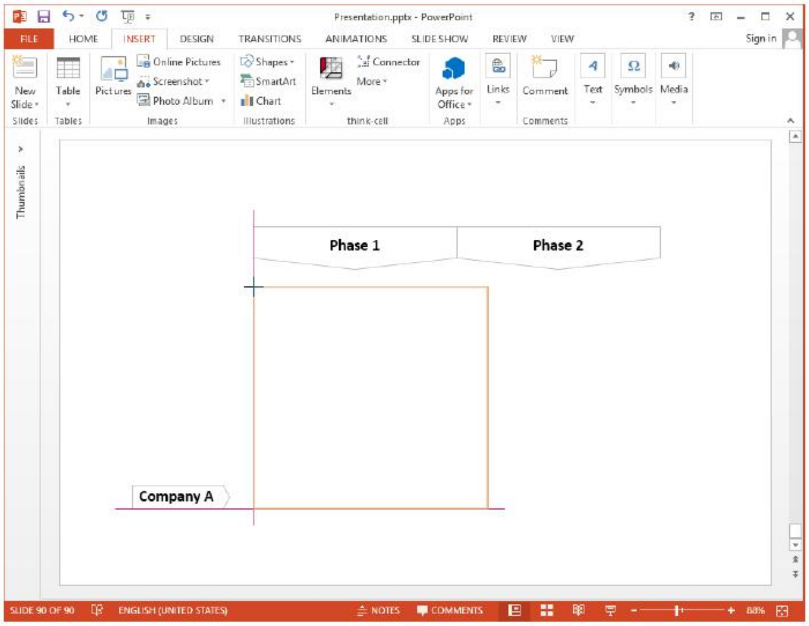
Step 2)—Select the data and click CHARTS under the INSERT tab. Then choose "Mekko Bar (Unit Axis)".

Figure 13. Selecting Cost Curve in Think-cell


ppt.xlsx - Excel
FORMULAS
DATA
REVIEW
VIEW
DEVELOPER
ADD-INS
re
Apps
Recommended Charts
PivotChart
Charts
% Percent
More
Map
Power View
Line
Column
Win Los
Add-ins
Charts
orts
Sparklines
Stacked
100%
Clustered
Waterfall
Mekko (% Axis)
Mekko (Unit Axis)
Mekko Bar (Unit Axis)
Area
Area 100%
Line
Pie
Scatter/Bubble
To Existing Chart
I
J
K
L
M
N
R
S
400
800
400
100
1000
00
500
100
-80
-50
-45
-30
-20
20
25
50

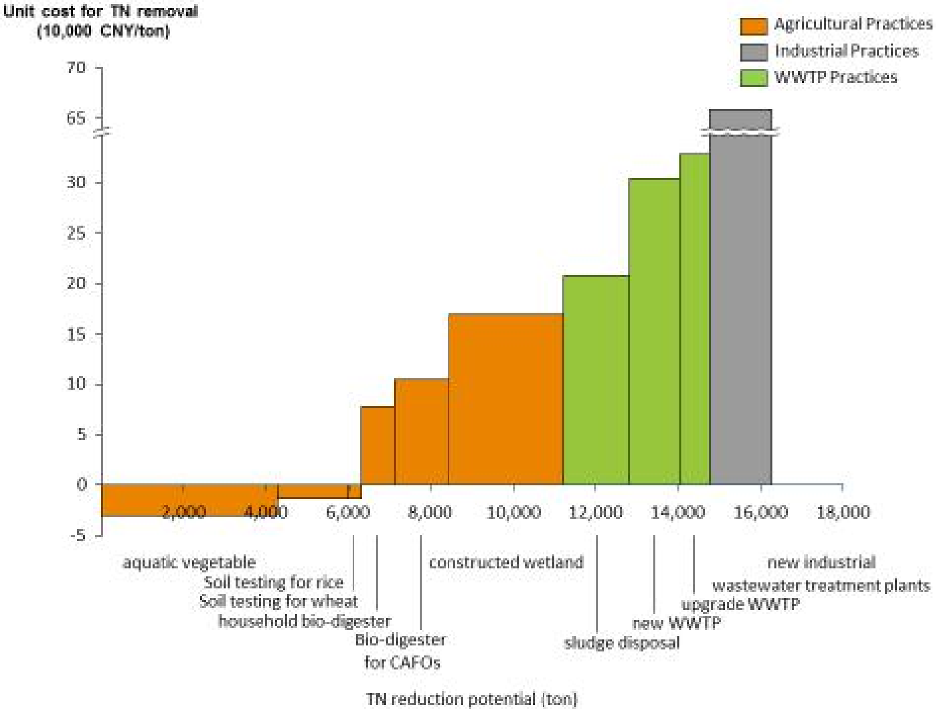
Step 3—Microsoft PowerPoint will be automatically activated. A rectangle will appear with the mouse pointer, indicating where the graph will be inserted on the slide. Just click the left mouse button to place it with the default width and height.

Figure 14. Creating the Cost Curve in PowerPoint


Presentation.pptx - PowerPoint
FILE
HOME
INSERT
DESIGN
TRANSITIONS
ANIMATIONS
SLIDE SHOW
REVIEW
VIEW
Sign in
New Slide
Table
Pictures
Online Pictures
Screenshot
Photo Album
Shapes
SmartArt
Chart
Elements
Connector
More
Apps for Office
Links
Comment
Text
Symbols
Media
Slides
Tables
Images
Illustrations
think-cell
Apps
Comments
Thumbnails
Phase 1
Phase 2
Company A
SLIDE 90 OF 90
ENGLISH (UNITED STATES)
NOTES
COMMENTS
88%

The cost curve will be developed automatically. Adjust the size, add labels and legend as needed.

Figure 15 Illustrative Cost Curve

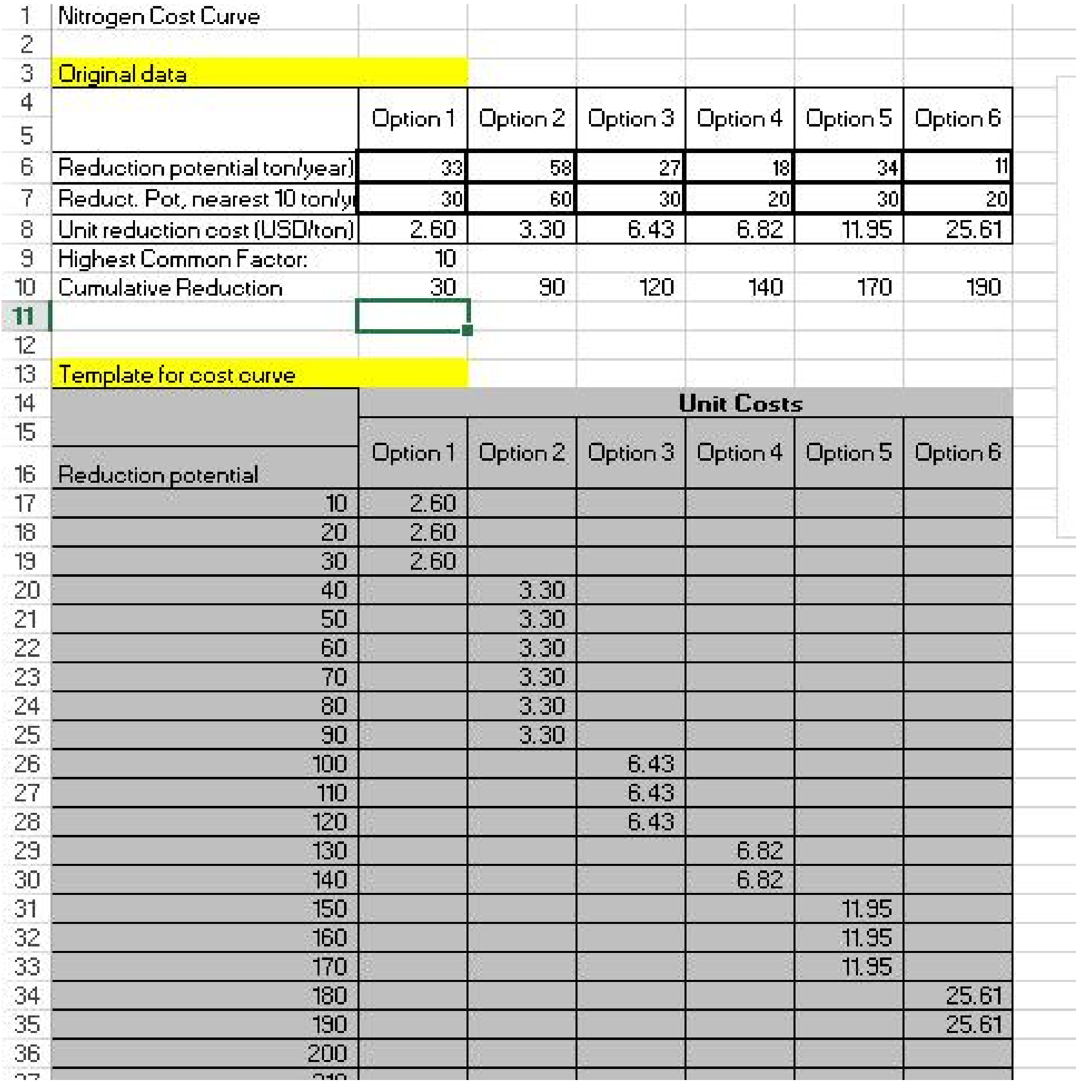


Using Excel—A cost curve is presented by a Mekko chart, which is essentially a two-dimensional stacked column chart. In addition to the varying segment heights of a regular stacked chart, a Mekko chart also has varying column widths. Column widths are scaled such that the total width matches the desired chart width. Since the Mekko chart is not available in Excel, the solution is to arrange the data in a format that can use Excel's standard clustered column chart to manually achieve a similar result. The process for doing so is as follows.

Step 1) Create a table showing the options, reduction potentials, and unit costs, as shown in Figure 16 Rows 3-10. Row 7 is used if it is necessary to round the reduction potential to avoid having an excessively large number of rows in the template section, shown in gray in Figure 16. (For example, if the cumulative load reduction were 1,247 tons per year and no rounding was done, the HCF would probably be 1 and 1,247 rows would be required for the data in the template. Rounding only marginally affects the width of the bars in the graph and the unrounded Row 6 values are shown on the X axis.

The model automatically calculates the HFC and uses it to populate the first column in the template section.

Figure 16

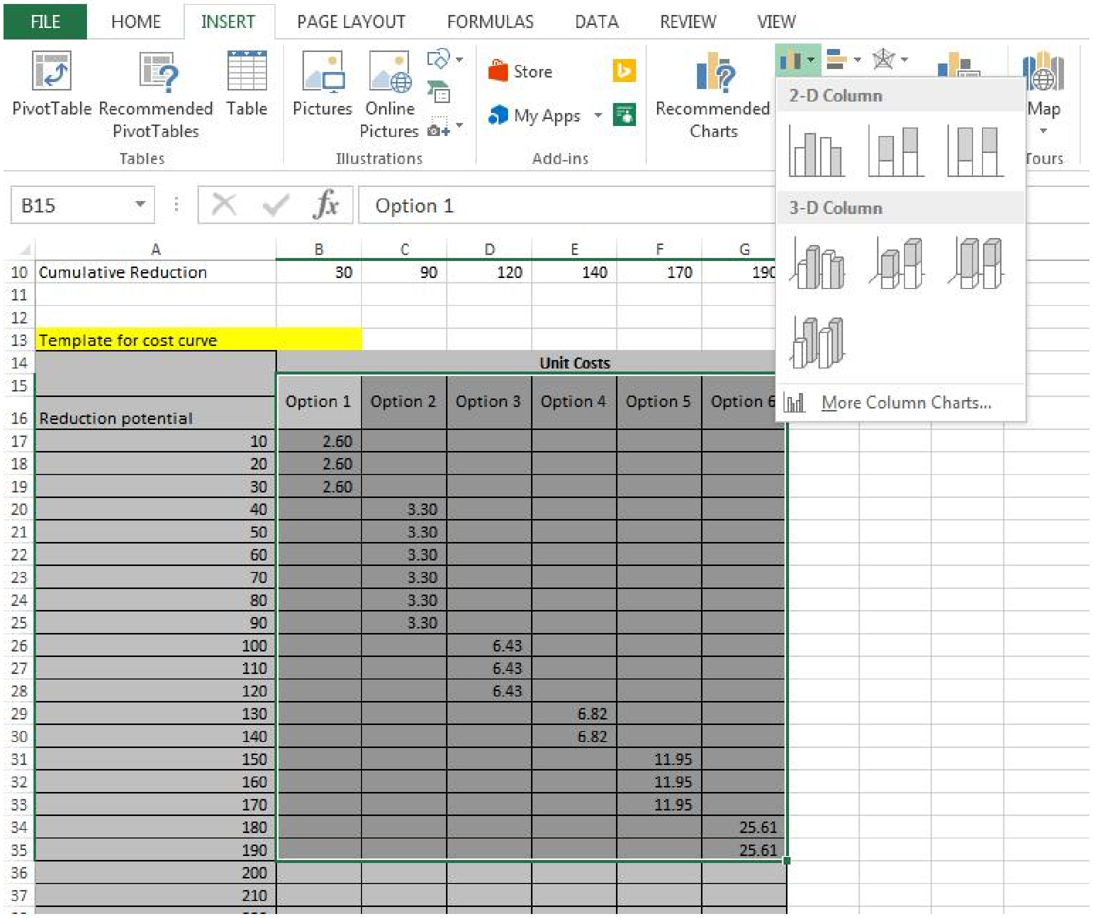


1	Nitrogen Cost Curve						
2							
3	Original data						
4		Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
5							
6	Reduction potential ton/year)	33	58	27	18	34	11
7	Reduct. Pot, nearest 10 ton/y	30	60	30	20	30	20
8	Unit reduction cost (USD/ton)	2.60	3.30	6.43	6.82	11.95	25.61
9	Highest Common Factor:	10					
10	Cumulative Reduction	30	90	120	140	170	190
11							
12							
13	Template for cost curve						
14		Unit Costs					
15							
16	Reduction potential	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
17	10	2.60					
18	20	2.60					
19	30	2.60					
20	40		3.30				
21	50		3.30				
22	60		3.30				
23	70		3.30				
24	80		3.30				
25	90		3.30				
26	100			6.43			
27	110			6.43			
28	120			6.43			
29	130				6.82		
30	140				6.82		
31	150					11.95	
32	160					11.95	
33	170					11.95	
34	180						25.61
35	190						25.61
36	200						

Step 2) Enter unit cost data. The unit costs of each option are then entered in the template section. Option 1's rounded reduction potential is 30 tons/yr, so its unit cost of $2.60 is entered in the first three rows of the data range under Option 1, rows 17-19. Option 2's unit cost of 3.30 is entered in rows 20-27 and so on until the total cumulative reduction potential of 190 tons is reached on row 35. Entering the data in this manner serves to establish the correct bar width for each option.

Step 3) Select the appropriate data range in the template (Cell range B15 to G35 in this example) and select the standard Stacked Column chart type (the first to left button under "2-D Column") as shown in Figure 17.

Figure 17.


FILE
HOME
INSERT
PAGE LAYOUT
FORMULAS
DATA
REVIEW
VIEW
PivotTable
Recommended PivotTables
Table
Tables
Pictures
Online Pictures
Illustrations
Store
My Apps
Add-ins
Recommended Charts
2-D Column
3-D Column
More Column Charts...
Map
Tours
B15
Option 1

	A	B	C	D	E	F	G
10	Cumulative Reduction	30	90	120	140	170	190
11							
12							
13	Template for cost curve						
14		Unit Costs					
15		Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
16	Reduction potential						
17	10	2.60					
18	20	2.60					
19	30	2.60					
20	40		3.30				
21	50		3.30				
22	60		3.30				
23	70		3.30				
24	80		3.30				
25	90		3.30				
26	100			6.43			
27	110			6.43			
28	120			6.43			
29	130				6.82		
30	140				6.82		
31	150					11.95	
32	160					11.95	
33	170					11.95	
34	180						25.61
35	190						25.61
36	200						
37	210						

Excel will treat each row in the selected data range as a separate bar, generating this this chart:

Figure 18

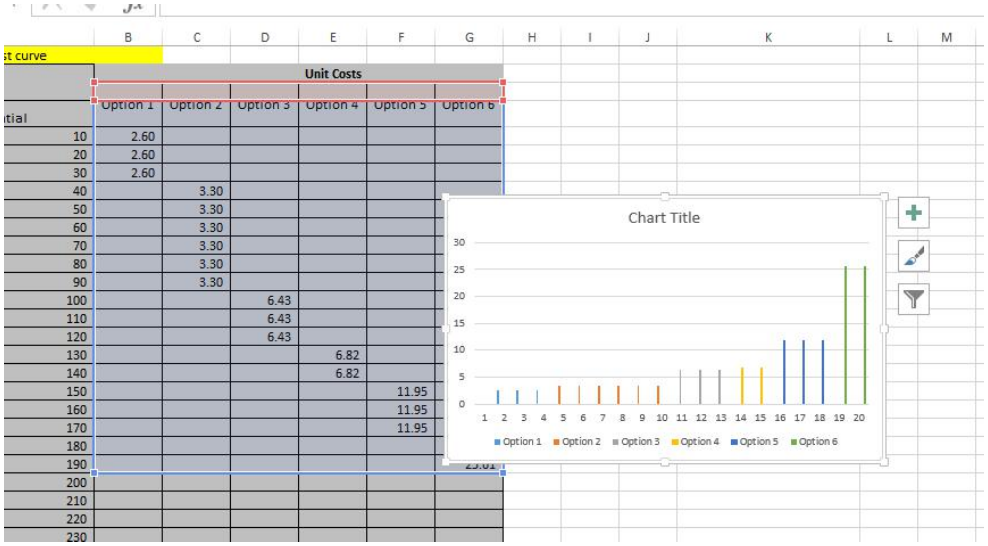


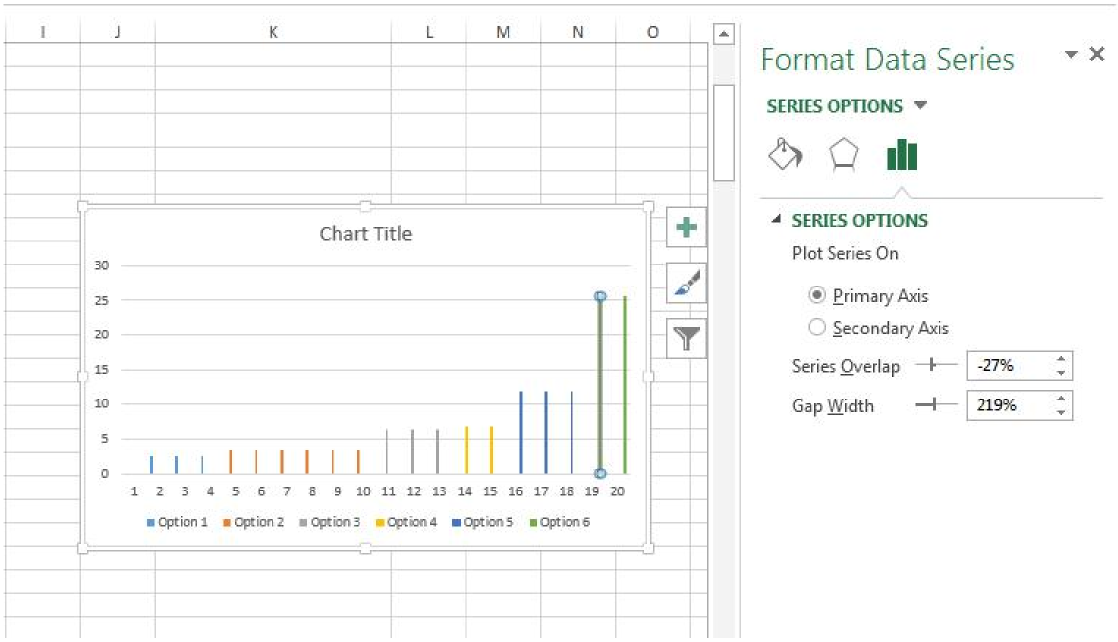
Chart Title
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
■ Option 1
■ Option 2
■ Option 3
■ Option 4
■ Option 5
■ Option 6

	B	C	D	E	F	G
st curve						
	Unit Costs					
tial	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
10	2.60					
20	2.60					
30	2.60					
40		3.30				
50		3.30				
60		3.30				
70		3.30				
80		3.30				
90		3.30				
100			6.43			
110			6.43			
120			6.43			
130				6.82		
140				6.82		
150					11.95	
160					11.95	
170					11.95	
180						
190						
200						
210						
220						
230						

Step 4) Format the Graph

Right-click any bar in the graph and select "Format Data Series". Set Series Overlap to 100% and Gap Width to 0%. In this way, columns representing the same option will be combined so that they appear as a single bar with the correct width.

Figure 19



Format Data Series

SERIES OPTIONS

SERIES OPTIONS

Plot Series On

● Primary Axis

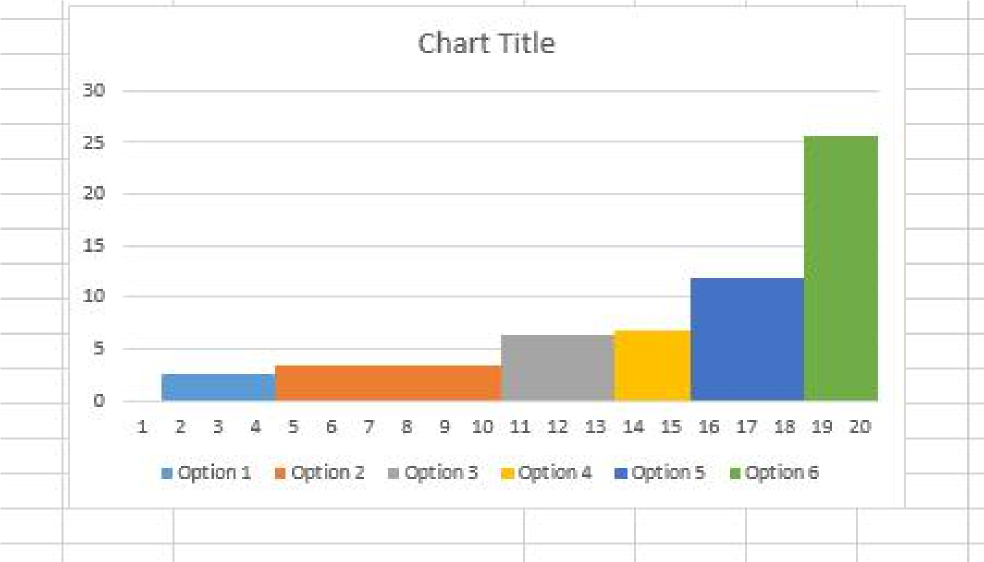
○ Secondary Axis

Series Overlap -27%

Gap Width 219%

I
J
K
L
M
N
O
Chart Title
30
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Option 1
Option 2
Option 3
Option 4
Option 5
Option 6

Figure 20



Right-click on Chart Title and select what elements to include in the chart. Left-clicking on the triangle to the right of each option brings up a submenu for that option. It is recommended that the Primary Horizontal Axis not be selected because Excel would use bar numbers (1 through 17 in this example) instead of the desired values. Each chart element can then be edited or moved as desired.

Figure 21

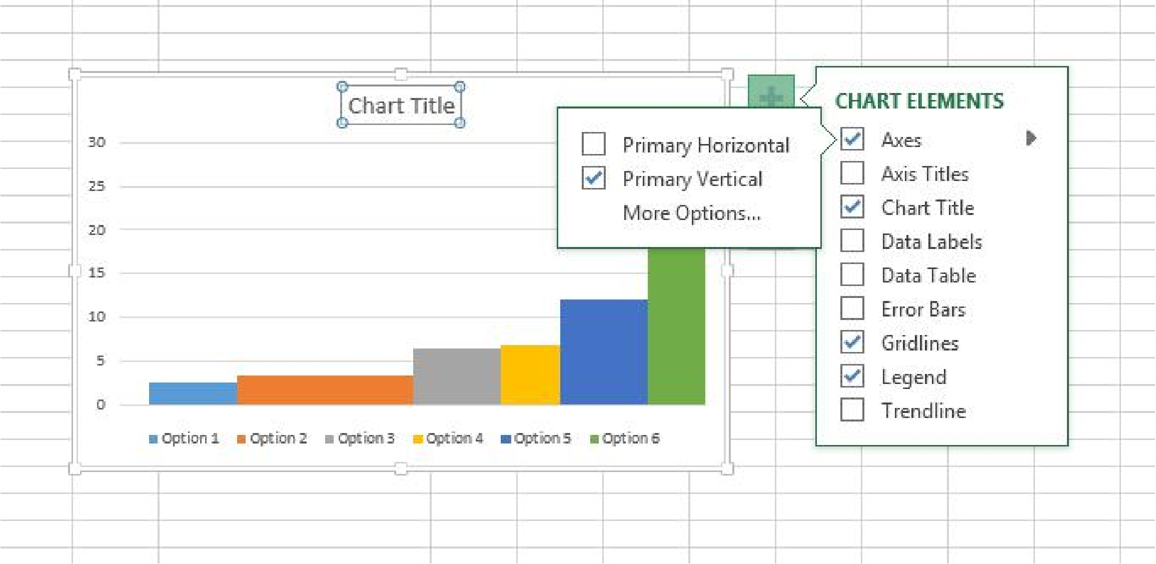
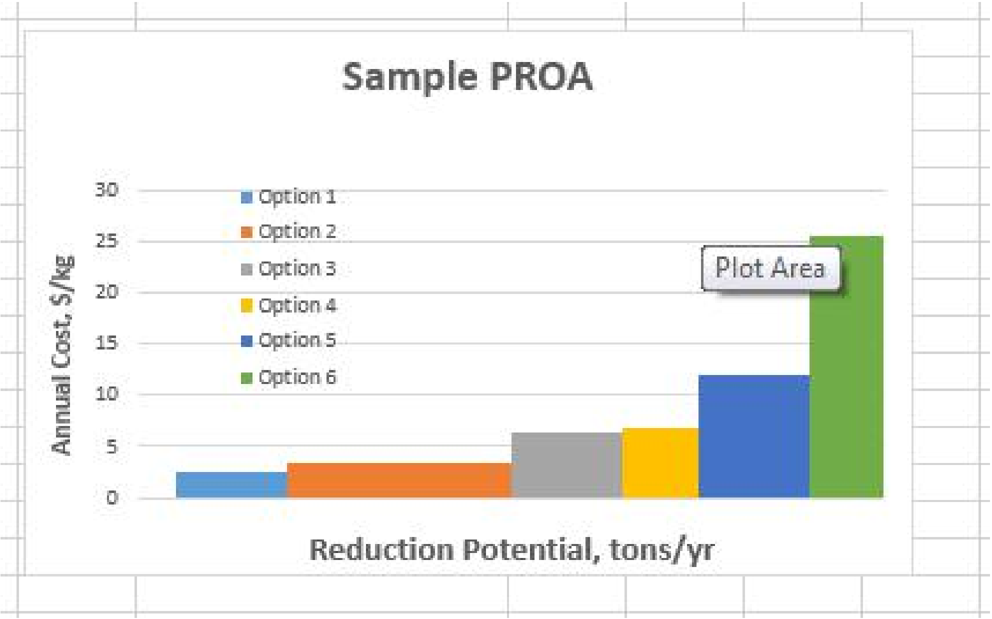


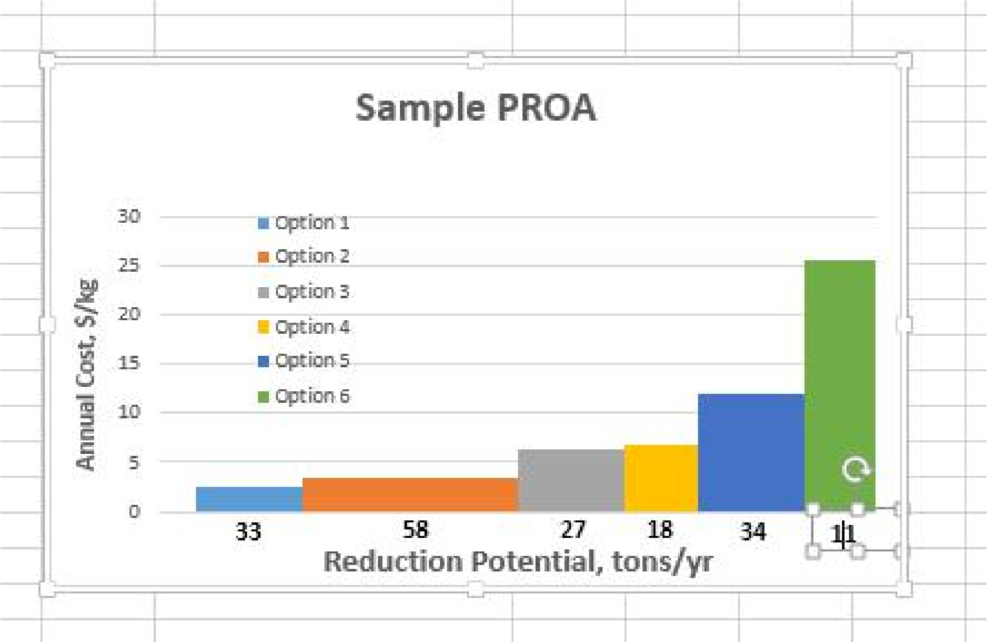
Chart Title
30
25
20
15
10
5
0
Option 1
Option 2
Option 3
Option 4
Option 5
Option 6
☐ Primary Horizontal
☑ Primary Vertical
More Options...
CHART ELEMENTS
☑ Axes ▸
☐ Axis Titles
☑ Chart Title
☐ Data Labels
☐ Data Table
☐ Error Bars
☑ Gridlines
☑ Legend
☐ Trendline

Figure 22



Finally, insert text boxes to show the reduction potential for each bar.

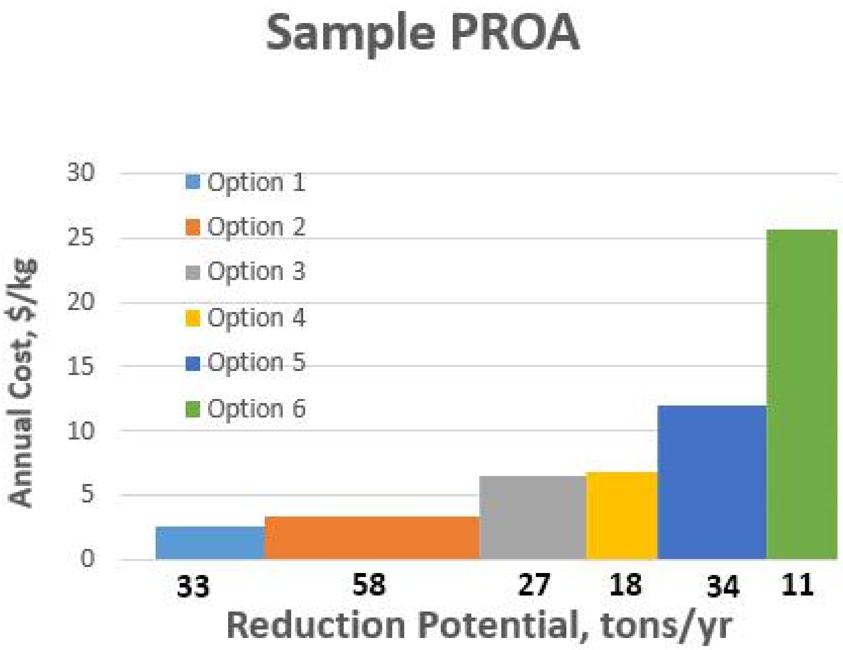
Figure 23



Step 5) Modifying the data. If changes are made to data values in the selected range, Excel will automatically adjust the bar widths and heights but the data values in the text boxes would have to be manually changed. If the data range is changed, the data must be reselected. Right-click on any bar in the graph, left-click on “Select Data“ and select the new range. Then edit the text boxes to show the new values.

The PROA chart is complete.

Figure 24


Sample PROA

Option 1
Option 2
Option 3
Option 4
Option 5
Option 6
Annual Cost, $/kg
30
25
20
15
10
5
0
33
58
27
18
34
11
Reduction Potential, tons/yr