APPENDIX A
METHODS FOR ESTIMATING COSTS AND LOAD REDUCTIONS FOR SIGNIFICANT POINT SOURCES

Under all of the nutrient credit trading scenarios evaluated in our study, we assumed that the 475 significant point sources (SigPSs) located in the watershed are faced with multiple options for reducing nitrogen and/or phosphorus concentrations in their wastewater effluent. To be as consistent as possible with the TMDL cost analysis being developed by CBPO (CBPO, 2012), we defined these options by specifying 16 discrete "tiers" of nutrient removal. Each tier represents a different combination of targeted nitrogen and phosphorus concentrations. For nitrogen, the options are below 8 mg/l, 5 mg/l, and 3 mg/l and for phosphorus they are below 1 mg/l, 0.5 mg/l, and 0.1 mg/l. In addition, each facility has the option to stay at its current (2010) concentration of nitrogen and/or phosphorus (i.e., no change in concentration).

To estimate the annual costs of the relevant technology options for each facility, we followed the following process.

First, we developed average "unit" cost estimates for each technology. These unit cost estimates are shown in Tables A-1 to A-4.[1] First, we developed separate estimates for capital and O&M costs. The unit costs for one-time capital expenditures are expressed in terms of average dollars per unit of wastewater treatment *capacity* (in gallons). The unit costs for O&M are expressed in terms of dollars per unit of treated wastewater *flow* (in millions of gallons). Second, we developed separate capital and O&M unit cost estimates for facilities requiring "expansion" and for those requiring "retrofit" technologies. The retrofit unit costs only applied to facilities with current concentrations of nitrogen below 8 mg/l *and* current concentrations of phosphorus below 1 mg/l (i.e., fewer than 20 significant municipal wastewater treatment facilities and none of the significant industrial facilities).

[1] No data were reported for a technology that combines TN<8 and TP<0.1 mg/l; therefore, we did not develop or include cost estimates for this one "tier" of nutrient removal.

Table A-1. Average Unit Capital Costs for Selected Tiers of Nutrient Removal Expansion Technologies (dollars per gallon of wastewater treatment capacity)

		Target Total Phosphorus (TP) Concentrations (mg/l)			
		No Change	to TP < 1	to TP < 0.5	to TP < 0.1
Target total nitrogen (TN) concentrations (mg/l)	No change	$0.00	$0.12[a]	$2.13[b]	$2.56[b]
	to TN < 8	$1.47[a]	$1.89[a]	$3.60[c]	n/a
	to TN < 5	$2.31[b]	$2.73[b]	$2.92[b]	$3.35[b]
	to TN < 3	$3.16[b]	$2.31[b]	$3.59[b]	$4.20[b]

[a] Based on average estimates reported in CBPO (2002).

[b] Based on regression analysis of estimates reported in EPA (2008).

[c] Approximated as the sum of TN < 8 and TP < 0.5 costs.

Table A-2. Average Unit O&M Costs for Selected Tiers of Nutrient Removal Expansion Technologies (dollars per million gallons of wastewater flow)

		Target Total Phosphorus (TP) Concentrations (mg/l)			
		No Change	to TP < 1	to TP < 0.5	to TP < 0.1
Target total nitrogen (TN) concentrations (mg/l)	No change	$0.00	$27.97[a]	$372.07[b]	$460.45[b]
	to TN < 8	$84.59[a]	$113.69[a]	$456.66[c]	n/a
	to TN < 5	$340.80[b]	$429.18[b]	$467.25[b]	$555.62[b]
	to TN < 3	$444.24[b]	$340.80[b]	$532.62[b]	$659.06[b]

[a] Based on average estimates reported in CBPO (2002).

[b] Based on regression analysis of estimates reported in EPA (2008).

[c] Approximated as the sum of TN < 8 and TP < 0.5 costs.

Table A-3. Average Unit Capital Costs for Selected Tiers of Nutrient Removal Retrofit Technologies (dollars per gallon of wastewater treatment capacity)

		Target Total Phosphorus (TP) Concentrations (mg/l)			
		No Change	to TP < 1	to TP < 0.5	to TP < 0.1
Target total nitrogen (TN) concentrations (mg/l)	No change	n/a	n/a	$0.86[a]	$1.28[a]
	to TN < 8	n/a	n/a	n/a	n/a
	to TN < 5	$1.03[a]	$1.46[a]	$1.64[a]	$2.07[a]
	to TN < 3	$1.88[a]	$1.03[a]	$2.31[a]	$2.92[a]

[a] Based on regression analysis of estimates reported in EPA (2008).

Table A-4. Average Unit O&M Costs for Selected Tiers of Nutrient Removal Retrofit Technologies ($ per million gallons of wastewater flow)

		Target Total Phosphorus (TP) Concentrations (mg/l)			
		No Change	**to TP < 1**	**to TP < 0.5**	**to TP < 0.1**
Target total nitrogen (TN) concentrations (mg/l)	**No change**	n/a	n/a	$110.59[a]	$198.96[a]
	to TN < 8	n/a	n/a	n/a	n/a
	to TN < 5	$79.32[a]	$167.70[a]	$205.76[a]	$294.14[a]
	to TN < 3	$182.76[a]	$79.32[a]	$271.14[a]	$397.58[a]

[a] Based on regression analysis of estimates reported in EPA (2008).

The unit cost estimates reported in Tables A-1 to A-4 were based on two main sources of data. For technologies involving TP < 8 and/or TP < 1, we relied on data reported in CBPO (2002) for 118 facilities in the watershed. The unit capital and O&M costs for these technologies are simply the average values reported in this source, updated to 2010 dollars using a construction cost index (CCI) (http://enr.construction.com/economics/current_costs/). For the other technologies, we relied on data reported in EPA (2008). In this case, the number of cost estimates available for each technology was limited; therefore, we used the data to estimate separate regression equations for capital and O&M costs. The regression results are reported in Tables A-5 and A-6.[1] The "Engineering Model Cost Estimate" variable is an indicator of whether the estimate was based on the CapdetWorks engineering cost model (=1) or a facility-specific estimate (=0). The engineering cost estimates for capital and O&M costs were both lower and statistically significantly lower for capital costs. The "Retrofit Cost Estimate" variable is an indicator of whether the estimate was based on a retrofit technology (=1) or an expansion technology (=0). The retrofit estimates statistically significantly lower for the capital and O&M costs. As expected, the capital and O&M costs are statistically significantly lower for higher target concentrations of nitrogen and phosphorus. The design capacity has a negative effect on unit capital and O&M costs (suggesting economies of scale in treatment technologies), but this effect is only statistically significant for O&M costs.

[1] These regression models excluded six outlier observations. These modeled estimates for technologies TN<3 TP<0.1 and TN<5 TP<0.1 had much lower costs than technology options will less nitrogen or phosphorus removal.

Table A-5. Ordinary Least Squares Regression for Capital Cost of Nutrient Treatment Technology

Dependent Variable: Capital Cost ($ per gallon of design capacity)		
Independent Variable	**Coefficient**	**t-ratio**
Intercept	5.45667	6.49
Engineering Model Cost Estimate (categorical variable)	−0.92252	−2.26
Retrofit Cost Estimate (categorical variable)	−1.27742	−3.66
Target Nitrogen Concentration (natural logarithm)	−0.26525	−2.04
Target Phosphorus Concentration (natural logarithm)	−1.66995	−3.34
Design Capacity (MGD)	−0.00345	−0.68
Number of Observations	38	
Adjusted R-square	0.372	

Table A-6. Ordinary Least Squares Regression for O&M Cost of Nutrient Treatment Technology

Dependent Variable: Capital Cost ($ per gallon of design capacity)		
Independent Variable	**Coefficient**	**t-ratio**
Intercept	821.20	7.00
Engineering Model Cost Estimate (categorical variable)	−62.00	−1.31
Retrofit Cost Estimate (categorical variable)	−261.49	−6.74
Target Nitrogen Concentration (natural logarithm)	−54.91	−3.72
Target Phosphorus Concentration (natural logarithm)	−202.49	−3.48
Design Capacity (MGD)	−6.61	−1.77
Number of Observations	34	

Adjusted R-square	0.659

Using these regression equations, we estimated the expected unit capital and O&M costs for the relevant technologies (based on the target nitrogen and phosphorus concentrations) reported in Tables A-1 through A-4. In each case, we set the engineering cost model variable equal to zero and the design capacity equal to 10 MGD. For the retrofit unit cost estimates, we set the retrofit variable equal to one and for the expansion unit cost estimates we set it equal to zero.

Second, to estimate the annual costs of the relevant technology options for each facility, we excluded the technology tiers that were not feasible options for each facility. In particular, facilities were not allowed to choose options with concentrations that are higher than their current concentration levels. For example, a facility with current concentrations of 6 mg/l of nitrogen and 0.6 mg/l of phosphorus does not have the option to choose the technology tiers resulting in 8 mg/l of nitrogen or 1 mg/l of phosphorus. Choosing these options would imply increasing their nutrient loads, which is not an allowable option.

Third, when cost estimates for specific technologies at a specific facility were reported in CBPO (2002), we used those cost estimates (updated to 2010 dollars) to represent the costs for the facility. To express capital costs in annual terms, we annualized the one-time costs based on a 20-year assumed lifetime and a 7% discount rate.

Fourth, when facility-specific cost data were not available, we applied the unit cost estimates for the technologies summarized in Tables A-1 to A-4 using the following equation:

$$\text{AnnTotCost}_{ij} = \text{AnnCapCost}_j * \text{DC}_i + \text{O\&MCost}_j * \text{AF}_i \qquad \text{(A.1)}$$

where

$AnnTotCost_i$ = total annual cost of technology *j* at facility *i* (in 2010 dollars)

$AnnCapCost_j$ = annualized unit capital cost (20 year lifetime and 7% discount rate) of technology *j* (in 2010 dollars per gallon of treatment capacity)

DC_i = design capacity of facility *i* (in gallons)

$O\&MCost_j$ = unit O&M cost of technology *j* (in 2010 dollars per million gallons)

AF_i = annual wastewater flow of facility *i* (in million gallons per year)

To estimate the annual *end-of-pipe* nutrient loads (at the point of discharge) for each relevant technology at each facility, we multiplied the facility's annual wastewater flow (in 2010) by the corresponding nutrient concentration. Under the no-trading scenario, facilities with current loads and concentrations that exceed their waste load allocations (and corresponding nitrogen and phosphorus concentration targets) were assumed to install the technology that would most closely meet their concentration targets without exceeding them. For example, if under the TMDL, a facility must reduce its TN concentration to at most 7 mg/l TN and 0.7 mg/l TP, then it was assumed that the facility would select the TN < 8 and TP < 1 technology. For these cases, the concentrations were assumed to equal the TMDL targets (i.e., 7 mg/l TN and 0.7 mg/l TP in the example).[1] Under the trading scenarios, we assumed that facilities also have the option to select other technologies and either sell or buy credits depending on whether they reduce loads by more or less than the TMDL (i.e., no trading) requirement. For these other technologies, we assumed that the achieved concentrations were equal to the specified upper limit. For example, we assumed that a facility choosing the technology combination TN < 5 and TP < 0.5 would achieve concentrations of TN = 5mg/l and TP = 0.5 mg/l. This assumption tends to understate the load reductions that could be achieved by these alternative technologies under the trading scenarios, which is consistent with our decision to be conservative in our analysis and guard against overstating the potential cost savings from trading.

To calculate the reduction in *delivered* loads to the Bay, we also accounted for the natural in-stream attenuation process between the point of discharge and the downstream tidal area of the Bay.

[1] For each facility, the TMDL concentration limits are the levels of nitrogen and phosphorus in wastewater discharges that would produce loads equal to the facility's WLA if it were operating at full capacity. Therefore, if a facility achieves these concentration levels while operating *below* capacity, it will generate loads that are also below its WLA. As a result, the load reductions achieved by SigPSs under the no-trading scenario—and therefore also the load reduction targets required under the trading scenarios—are greater than the difference between current loads and the WLAs for the SigPSs.

A.1 References

Chesapeake Bay Program Office (CBPO). 2002. *Nutrient Reduction Technology Cost Estimations for Point Sources in the Chesapeake Bay Watershed.* http://www.chesapeakebay.net/content/publications/cbp_13136.pdf.

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