Analysis of Nutrient Removal Costs in the Chesapeake Bay Program and Implications for the Mississippi-Atchafalaya River Basin

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Stephen R. Harper, Ph.D., PE (corresponding author)
Daniel Coleman, PE
Daniel Tobocman, PE
Dan Wilkinson, PE
Leigh-Ann Bender

Abstract

This paper examines construction-level costs in 2006/2007 dollars for fifty wastewater nutrient removal projects constructed or under construction in Virginia and Maryland. The costs analysis reveals what many in the industry have felt in terms of accelerating treatment costs and explores contributing factors. Treatment costs are also parsed using using an Improvement Factor concept that tallies the extent of flow expansions and technical modifications being undertaken to allow generalization of cost envelopes for various project types. The generalized costs from the CB were applied to goals in the USEPA's recent Science Advisory Board Report on The Gulf of Mexico Hypoxic Zone to frame the potential costs of nutrient removal facing the Mississisppi-Atchafalaya River Basin covering 31 states and 41% of the US population.

Summary and Recommendations

The major points developed and supported in this paper are:

- On a total project basis, costs for nutrient removal upgrade projects in the CB averaged of $8.20/GPD of new design capacity. Approximately half of these costs were specifically for nutrient removal components, the other half to equally modernize other components of the treatment plants.

- Nearly 2/3 of all projects in the CB required near this level of effort to reach the ENR levels of performance. Approximately 1/6th of CB communities needed new plants or near-replacement. These communities paid nearly twice the average amount to implement nutrient reduction, $15/GPD and higher.

- 1/5th of CB communities were ahead of the curve with sound equipment and wastewater treatment plant designs directly amenable to nutrient removal upgrades. For these proactive or foresighted communities, recent upgrade costs have been more favorable, at 1 to 5 $/GPD.

- Total costs for POTW treatment in the MARB were developed based on the average CB cost figure of $8.20/GPD. Meeting the recommended numerical limits and point source reduction strategy outlined in the Draft could yield point source treatment costs of $130 Billion or more in the MARB. (Annual operating costs examined in a companion paper on nutrient trading typically exceed the annual cost of capital)

- Given these impending burdens that represent only a fraction of the total nutrient reduction goal looming in the MARB, we recommend careful consideration of materials and construction market factors when implementing timetables for point source treatment projects. In a tight global materials market, extra care must be exercised not to over-constrain specialized bidders or limited bids can translate into higher project delivery costs.

- For a variety of reasons discussed in a companion paper on nutrient trading[1], we join a chorus of recommendations to develop nutrient credit trading programs that draw agricultural discharges into the reduction mix while not over-regulating or distracting from like-minded conservation efforts. Excellent examples of creative programs for overcoming obstacles to PS-NPS trading and capturing the more cost-effective and sustainable nutrient removal from agricultural and other non-point loads can be found in US EPA's Water Quality Trading Toolkit for Permit Writers.[2]

- The MARB and CB share many similarities and also many distinctions, but above all they are vastly different in:
    1. The degree involvement of the Federal Government in the structure and ownership of the Mississippi and Atchafalaya Rivers vs. CB rivers,
    2. The scale of socioeconomic benefits gained by the government's involvement and ownership of these MARB Rivers, and
    3. The number of States and communities once or twice removed from the coastal States, and the affected coastal water (also much farther afield in the MARB than in the CB)

  These major differences and others suggest that Gulf hypoxia is a national rather than a regional issue. Hence we encourage the pursuit of new Federal construction grants for point source nutrient removal projects, in the MARB as well as nationwide. .

Introduction

Prior to describing and providing data on the costs of recent nutrient removal projects in the CB, a few paragraphs are devoted to the observation of sharply increased construction costs in the US and other countries over the last several years. While the US economy

[1] Wilkinson, et al. A Comparison of Nutrient Trading Program Structure and Costs with Considerations for Optimizing Nutrient Reduction in the Mississippi-Atchafalaya River Basin (submitted to WEFTEC 2008)
[2] http://www.epa.gov/owow/watershed/trading/WQTToolkit.html USEPA 833-R-07-004 August 2007

overall has appeared recently to grow at single-digit rates, infrastructure projects were experiencing double digit growth in many areas and mid-teen growth rates in many raw materials costs. Projects nationwide were chronically coming in significantly over preliminary estimates and initial bids.

Construction Cost Indices (CCIs) supplied by the Engineering News Record (and others[3]), widely used in cost estimating to adjust costs year-to-year and by location, were yielding exceptionally poor results. The wastewater treatment industry did not escape this consternation.

Nor were these problems restricted to the US. For example, a May 2007 study by the Regional Municipality of Waterloo, Ontario[4] cited the following observations regarding water and sewage infrastructure:

- From 1999 to 2003, construction costs increased at a rate of 3% per year
- From 2003 to 2005, the rate of increase jumped to 8 to 10% per year
- From 2005 to 2007, rates leveled off back to pre-2003 levels.

Regarding material costs increases, the Waterloo memo noted:

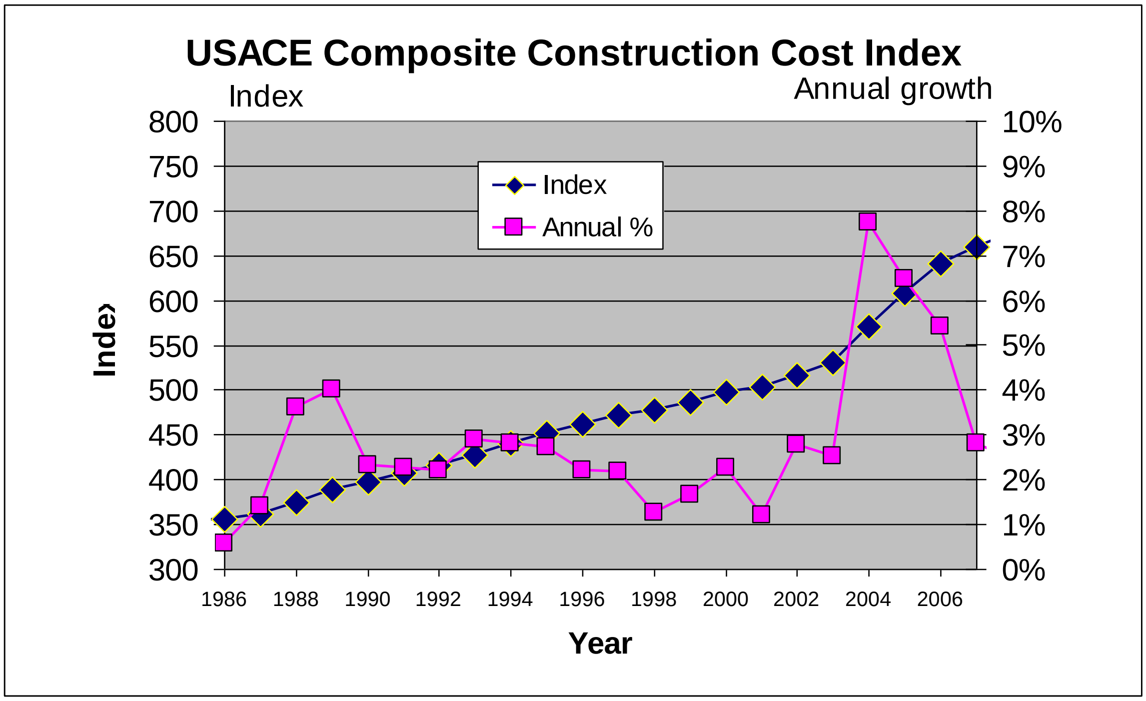
- From 2003 to 2006 tendered prices for a 300 mm watermain increased 29 % compared to an ENR CCI increase of 15% over the same period

Similar trends are noted in the US Army Corps of Engineers May 2007 Civil Works Construction Cost Index System, depicted in Figure 1. A rapid increase in construction cost growth rates is noted from 2003 to 2005, with a retreat in 2006 and the first quarter of 2007.

Figure 1. Corps of Engineers Construction Cost Index

[3] http://www.fhwa.dot.gov/programadmin/contracts/price.cfm

[4] Region Of Waterloo, Water Supply Strategy Update, Supplementary Tech Memo: Update Cost Estimates http://www.region.waterloo.on.ca/web/region.nsf/97dfc347666efede85256e590071a3d4/CAD9CE327D8C534A85257288004E9142/$file/TM%20Supplementary-VF.pdf?openelement



In contrast, costs specific to the transportation sector continued to increase at a double-digit pace straight through the first half of 2007, with no sign of relent, as shown in recent reports by Washington State DOT[5] and other state (and Federal) transportation agencies. For example, WSDOT shows prevailing rapid increases in structural concrete since 2004, with increases as follows:

- A 26 % jump 04 to 05,
- A 17% from 05 to 06, and
- A 19% in the first half of 2007 alone.

A survey of State Transportation Agencies conducted by AASHTO and FHWA[6] increases found only a weak association in 45 States between lower numbers of bid and higher costs, but a significant association was illustrated with raw material costs, which had increased 17 to 26 % across the board.

Material costs, and hence project costs remain a rapidly moving target. Sixteen States responded that they had inserted new price adjustment clauses into contracts in 2006. 20 % of States reported unusual problems with delays in receiving raw materials that impacted project delivery costs.

Finally, while some construction sectors, such as housing, have relented from double digit growth, others that are heavily reliant on large quantities of materials, such as transportation, have not. Construction rate increases for wastewater treatment plants have not relented.

[5] http://www.wsdot.wa.gov/biz/Construction/CostIndex/CostIndexPdf/StructuralConcrete.pdf
[6] http://www.fhwa.dot.gov/programadmin/contracts/price.cfm

The bottom line is that construction costs have increased sharply in many areas including wastewater treatment. Cost estimating has become difficult as materials prices remain unsettled. Just as the cost information in this communication may "update" or "correct" past generalizations, its own relevancy will have a very short life expectancy.

Observing and Understanding Current Nutrient Removal Costs in the Chesapeake Bay

In broad economic terms, numerous factors caused recent increases in prices of materials - energy, hurricanes, business consolidations, and explosive demand in China and India, Iraq. The wastewater treatment industry has not evaded these increases by any means. Worse, numerous simultaneous opportunities for a limited number of qualified contractors in the CB, under a limited timeframe, resulted in what some characterized as a bidder's market for construction of treatment plants. Some projects bid over the past 3 years have has as few as two bidders, and in at least 2 cases, a single bidder.

With the looming compliance deadline of January 1, 2011[7], communities were left with a limited number of options:

- Rebid the project with the hope that additional competition will emerge and drive the cost down, (at the cost of project scheduling)
- Award the project at what may be elevated prices, with a resultant unplanned rate increase, but less impact on schedule, or
- Utilize nutrient trading programs that have been developed in the Chesapeake Bay. *However, many communities were in positions where decisions needed to be made on how they would comply prior to the existence and maturation of the trading programs. Hence we recommend continued early development of trading programs in the CB.*

For example, at the Blue Plains Plant in the CB, cost estimates for new anaerobic digesters (a huge 10-yr project) increased from $148 Million in 2000 to $350 million in 2006 and to $600 million only a year later.[8] Based on this final estimate, the project was postponed, and the schedule will be compromised while the authority awaits a better economic outlook.

In Virginia, the Water Quality Improvement Fund is proposing new steps to qualify for and maintain grant funding – steps directed at forcing additional value engineering and obtaining more bids, and bid transparency. The WQIF proposals are still in a public comment period and can viewed at http://www.deq.state.va.us/bay/wqifdown.html.

The bottom line is that nutrient removal has been tossed around by local and much larger global forces. The number and types of reasons for cost increases have been as varied as the configurations of the treatment processes being built. Hence for years engineers and

[7] Chesapeake 2000 Preamble at ChesapeakeBay.net/agreement.htm
Program Compliance Deadline in the Chesapeake Bay Interstate Agreement

[8] http://www.dcwasa.com/site_archive/news/press_release265.cfm

economists in the CB strained at development of cost curves or cost factors for the construction of nutrient removal plants.

A brief history of these efforts is provided and followed by our own analysis of the CB data using construction-level information from 2006/2007. Perhaps these comments and the information they are structured around can help the MARB avoid some of the cost turmoil experienced in the CB, by better matching and timing of priority nutrient removal opportunities with the availability of qualified resources in the local or imported marketplace.

Historical Review of Nutrient Removal Cost Estimates –

This analysis also builds on the previous work of others. The first significant effort was led by Virginia Tech[9] and summarized 1999 estimates of costs for upgrading CB POTWs from secondary treatment (ammonia limits or monitor only) to BNR levels (effluent TN of 8 mg/L) and to ENR levels (3 mg/L).

Costs estimated for CB nitrogen removal upgrades in 1999 averaged 18 cents/GPD for the BNR upgrades and 50 cents from BNR to ENR, with most upgrades listed between $0.25 and 0.90 per GPD (1999 dollars). These capital costs were combined with estimated operating cost increases to project 20-year per-pound costs of TN removal of 94 cents/ GPD and 2.98 per pound of N. Based on high divergences in the data set Randall and co-workers identified strata of costs and separated State-based tables into "High-Cost" and "other" categories. While this was a first step at segregating costs into groups or types of treatments, the estimates proved to be optimistically low.

This approach was expanded on in 2002 by the development of both capital and operating cost curves for varying Tiers of service, and incremental estimation of TN and TP costs separately, by the Chesapeake Bay Program's Nutrient Reduction Technology Cost Task Force[10]. This effort developed cost curves for four levels of treatment:

- TN only to 8 mg/L
- TN to 8 with TP to 1 mg/L
- TN to 5 with TP to 0.5
- TN to 3 with TP to 0.3

Cost curves were developed within Tiers for TN and TP removal. The cost curves were then combined with a survey of POTW flows in the CB Watersheds to project total loads, load reductions, and per-pound costs. As shown in Figure 2, these curves also were low in today's market, and adjustment via CCI Indexing is not accurate.

The PA Municipal Authorities Association and PA DEP convened Point Source Workgroup and Wasteload Allocation Steering Committee meetings in 2006. These groups considered survey data from 25 POTWs in PA and determined per-plant average

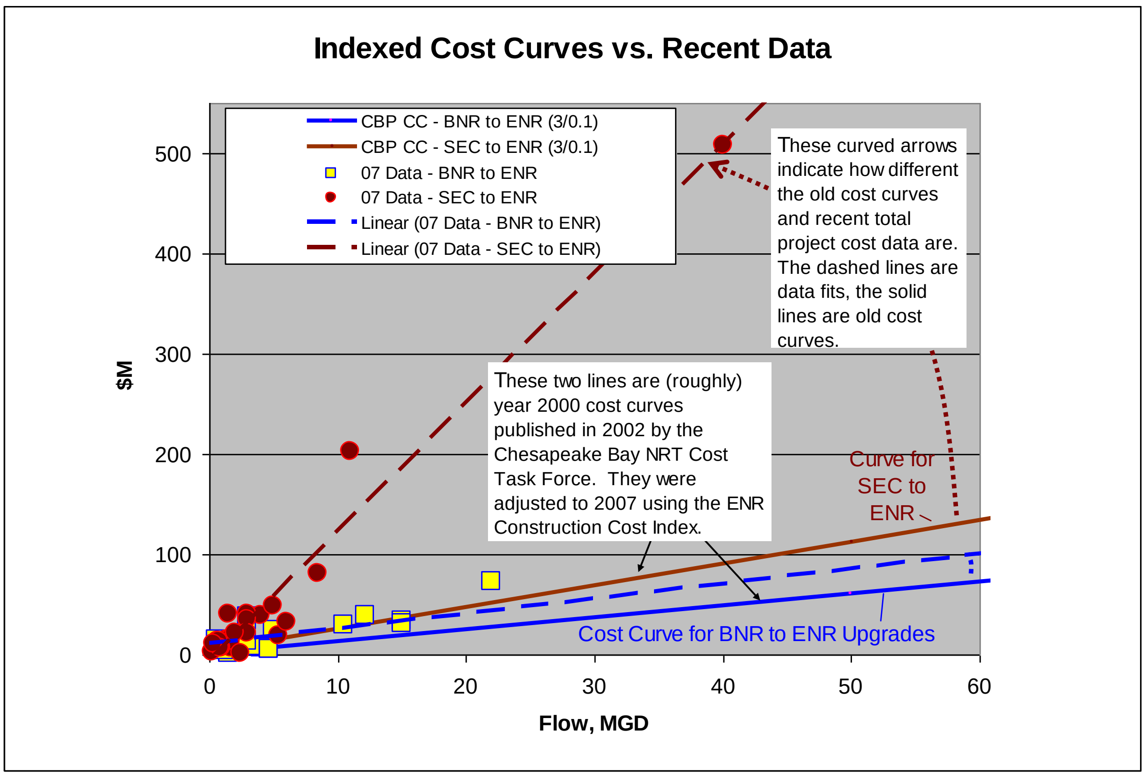
[9] Randall, CW, Copithorn, R. and Young, T. An Evaluation of the Cost of Point Source Nitrogen Limits of Treatment Implementation in the Chesapeake Bay Watershed.
[10] http://www.efc.umd.edu/pdf/TechnologyCostEstimations.pdf

cost of $7 million to $9 Million or $1.25/GPD for the nutrient removal portions of projects. Most of the information was from preliminary estimates. Cost curves were also developed based on 2002 design flows.

Attempts to bring the cost curves or cost developed by others forward in time with Engineering News Record CCIs or Army Corps of Engineers CCIs were not successful (Figure 2). Hence the entire database was re-examined using a new Tiered or service-level concept similar to that used by others, as described in the remainder of this communication.

New this time was the addition of two new dimensions that distinguish 1) degree of flow expansion as well as the degree of performance upgrade, and 2) the selection of one or both nutrients.

Figure 2. Comparison of 2000 Cost Curves (Updated to 2007) vs. Recent Cost Data



2006/2007 Nutrient Removal Cost Database and Analysis

Adding to the problem described by the foregoing discussion were the different funding approaches undertaken by MD, VA, and PA. While Maryland's Bay Restoration Fund established mechanisms to fund entire projects, VA's Water Quality Improvement Fund and PA's PENNVEST grants fund only "nutrient removal portions". This approach led to the publication of separate "nutrient removal" costs from "total project costs" and created new metrics with similar names as the existing ones, adding confusion.

For the present analysis, where the objective is to apply data from the CB to the MARB, we have adopted the following "design philosophies" that helped bring some clarity.

<u>Nutrient Removal Project - Cost Considerations, Analysis Philosophy</u>

Nutrient removal at the POTW cannot be done in a vacuum. To achieve high levels of treatment, all parts of the plant, not just nutrient removal processes, need to work well. Hence in this analysis, the focus is on **total project cost** rather than just the nutrient removal portion.

Furthermore, POTWs are most often upgraded based on their 5-year permits cycles, and at these designated "opportunities":

1. An "upgrade" (e.g., providing capability for better nutrient removal) may also, but not always, trigger an "expansion" (e.g., creation of larger flow capacity, ability to serve more persons)
2. An "expansion" almost always triggers an "upgrade", but the "upgrade" might be of different degrees, such as:
    a. Complete replacement of the plant with advanced technology. This happens when a plant is not configured with tanks that can be reused or most of the equipment is at its life expectancy.
    b. Adding new technologies to remove just more TN. This can happen when an existing system has tankage that can be reconfigured and utilized in different ways.
    c. Adding new technologies to remove just more TP. This is usually very possible with existing tankage, but there are also several ways to accomplish P removal.
    d. Adding new technologies to remove both more TN and more TP.
3. Additionally, an "expansion project" may (often) include one or more high cost items not explicitly associated with removal of a particular contaminant (say N or P), but needed to allow the entire process to work at a higher level, for example:
    a. New lift stations or conveyance infrastructure
    b. New solids handling (digestion or dewatering) or dewatering centrate treatment systems
    c. New headworks or odor controls
    d. Elimination or treatment of stormwater flows
    e. New monitoring systems and electronic controls

The following analysis is built upon a database of 50-plus case studies from MD and VA projects that have either recently completed construction, are under construction, or have construction bids in hand. Table 1 was developed by collecting information from:

- Maryland Department of the Environment (website, phone, email collaboration)
- Virginia Department of Environmental Quality (website, phone, email collaboration)
- O'Brien & Gere Project Files (seven of 50 projects are direct information)

Noise was minimized by removing any preliminary or study estimates. Graphing data based on an "improvement factor" concept, where the shotgun blast of cost data from the entire database (Figure 3) was segregated into meaningful generalizations, as shown in Figure 4.

The Improvement Factor on the X axis of Figure 4 is described on the plot. Generally, it is proportional to the percent of flow expansion, plus the degree of removal, plus the number of nutrients being removed. The more elements included in a project, the greater the 'Improvement Factor".

Based on the groupings and distinctions identified in Figure 4, flow-based cost envelopes were also developed as shown in Figure 5. These envelopes show a range of cost for a given type of project at its design flowrate.

Figure 3. All Wastewater Treatment Plant Construction Cost Data in Database

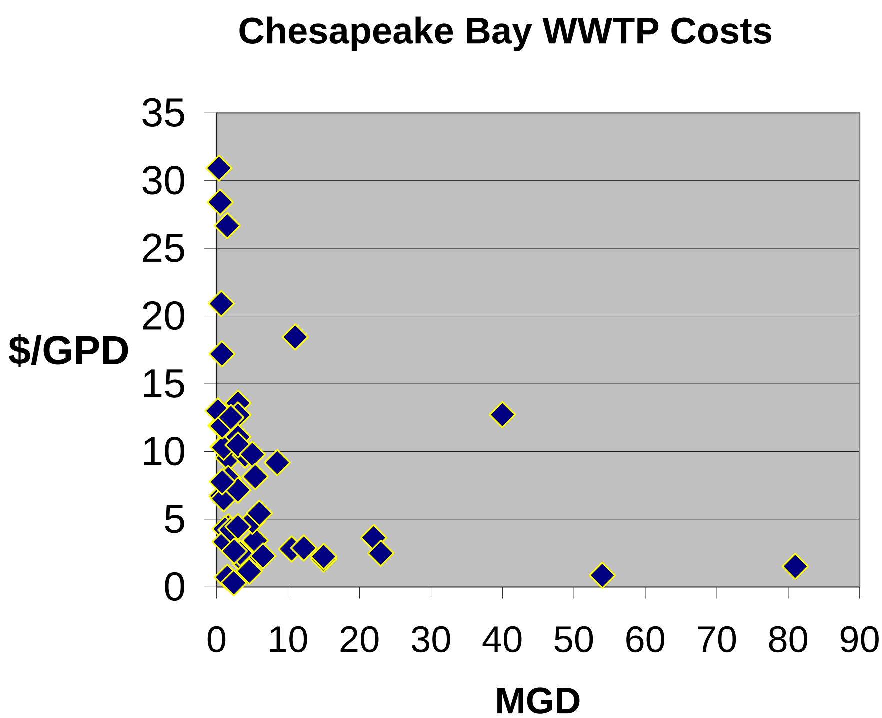


Figure 4.

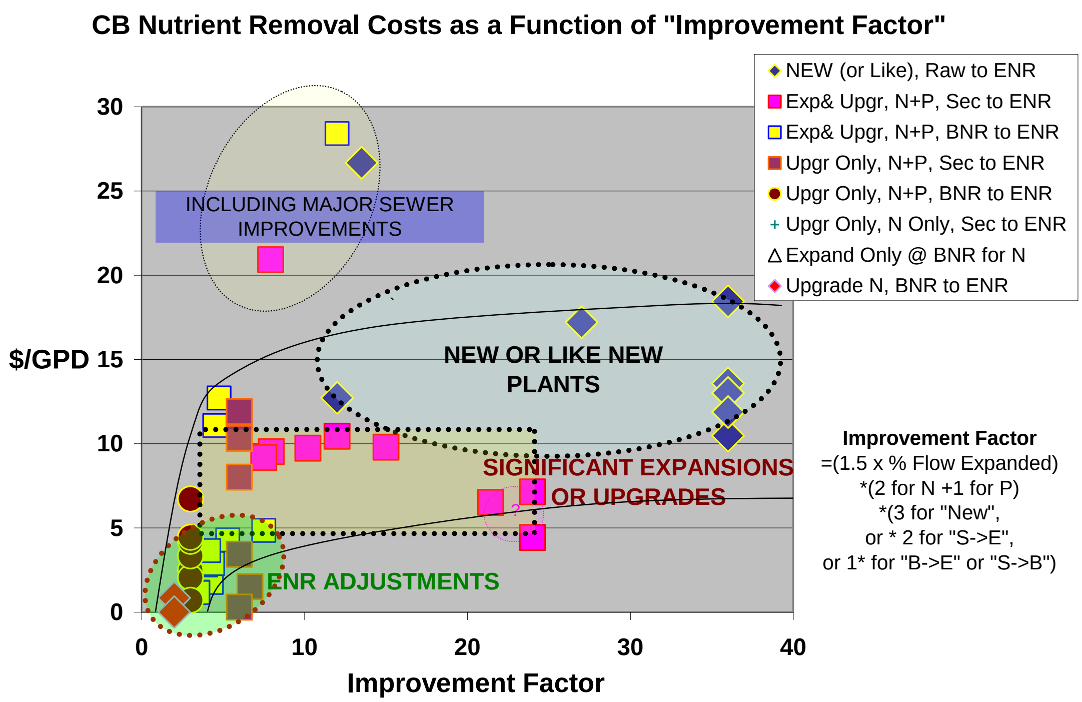
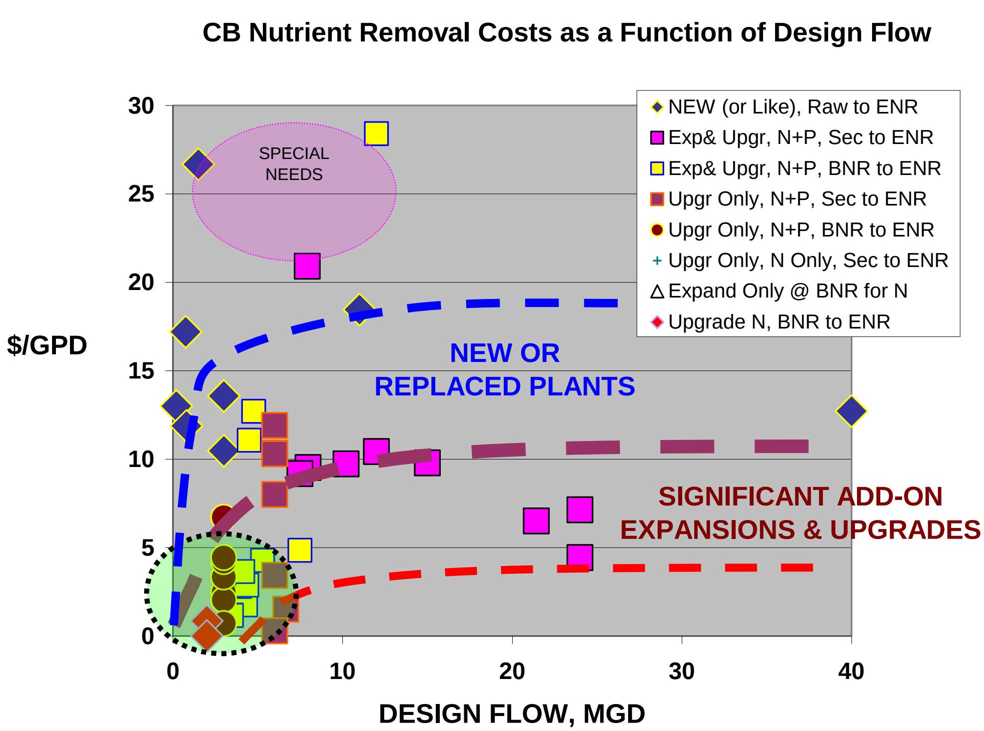


Figure 5.

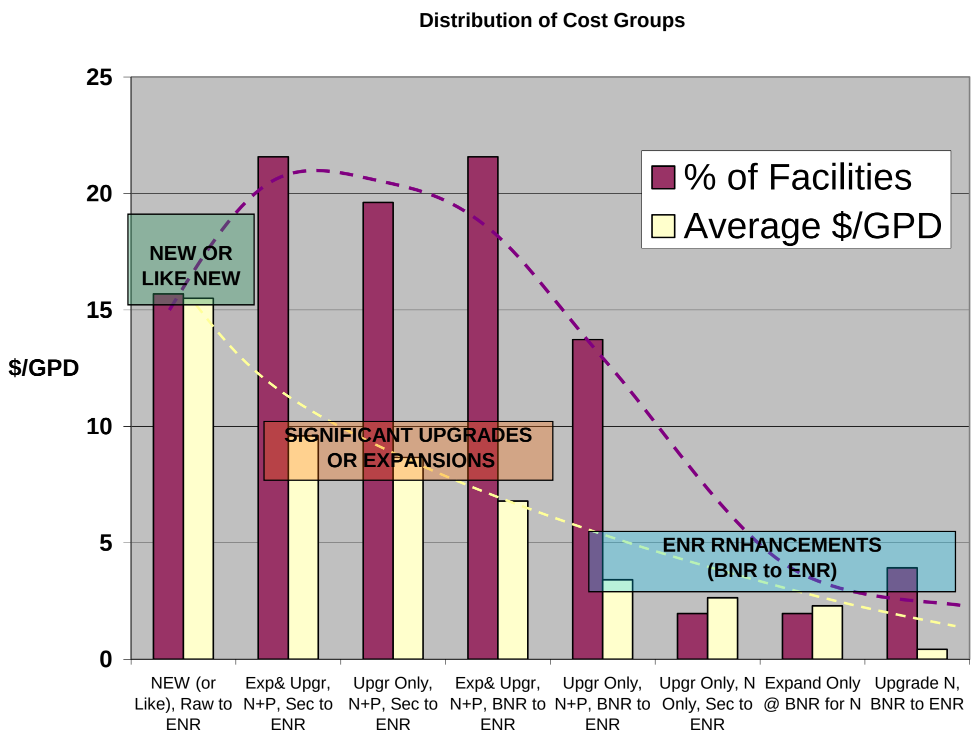


For the purposes of generalized analyses, such as comparing watersheds, States, or regions with many POTWS, the same information can be represented in average terms, such as illustrated in Figures 6 and 7. Figure 6 contains an indication of per-gallon costs at a variety of service levels. For the CB, the percentage of projects that were of each category is represented together with the average cost in each category.

Figure 7 contains an even more generalized summary of three groups of costs data from Figure 6, and an overall average for all project in the CB. The error bars show one standard deviation. Given the level of detailed knowledge regarding how the CB and MARB compare, the averages in Figure 7 are sufficiently applicable (in our opinion) for transferring results from the Chesapeake to the MARB.

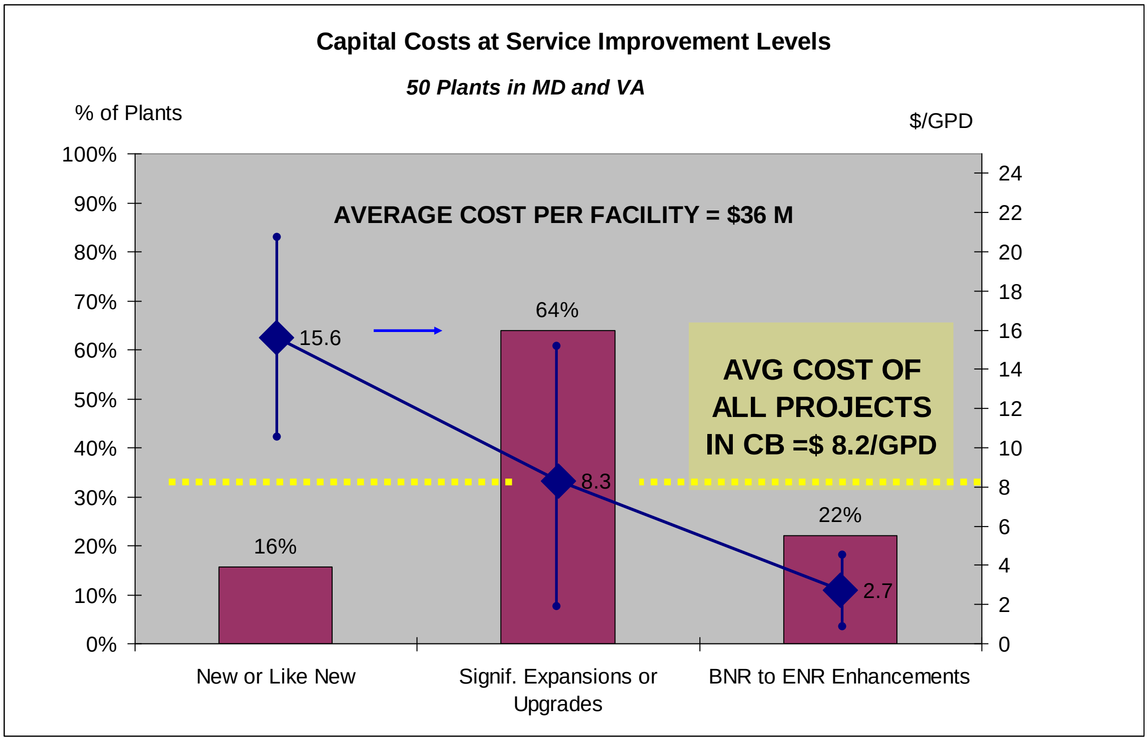
For example, the average influent (or pre-upgrade) TN level in the MARB was 9.6 mg/L[11] TN, as deduced from information in the Draft (Page 195, lines 18-34). This is somewhat lower than the average pre-upgrade TN level of 12.1 mg/L listed for the CB Plants in Table 1.

Figure 6. Barchart Showing Average per-Gallon Costs of Nutrient Removal Projects



[11] Based on an effluent load of 60M kgY @ 3 mg/L the total flow was back computed to be 14.45 BGD, and for this computed flow, an STP PS load of 192 M KgY yielded a Pre-upgrade TN concentration of 9.6 mg/L/
For TP, 8 MKgY @0.3 mg/L yielded 19.27 BGD and a corresponding Pre Upgrade TP of 1.5 mg/L (vs 2.1 mg/L in our CB data set).

Figure 7. General Averages of Cost Data for Major Classes of Upgrades



Discussion of CB to MARB Projections

Projecting the present cost analysis from the CB to the MARB can be accomplished on a volume basis, a per-plant basis, or a population basis.

Flow Basis:

- Several sources of information within the Draft, and our own estimates, point to 14 Billion gallons per day (BGD) as a reasonable total POTW flowrate for the MARB in 2010. As shown above, the generalized average construction cost, on a total project basis, from a variety of nutrient removal plants in the Chesapeake Bay was $8.2/GPD. If this CB average is applied to MARB flows, a total capital cost of 14 BGD x $8.2/GPD = $115 Billion (BN) is suggested as needed to implement nutrient removals at POTWs as recommended in the Draft.

- In addition, if industries in the MARB remove nutrients by 45% from present loads, it may be expected that $15 BN more in expenses may occur, bringing the total capital cost of the point-source program to $130 BN.

Per Plant Basis:

In the CB, The average per-plant cost has been $36 M per POTW. “Significant” facilities included in State programs were at first limited to 0.4 to 0.5 or 0.5 MGD but West Virginia has indicated inclusion of plants down to 0.05 MGD.

In the MARB, the number of POTWs roughly exceeding these “significant” cutoff flows is as follows. In the rightmost column, the total number of POTWs multiplied by the average CB per-plant costs projects that the cost of ENR development in the MARB will likely approach or exceed $90 BN.

Facilities > Than, MGD	# of Facilities	Total Cost @ $36M per POTW
0.0	9,502	
0.05	7,597	?
0.4	2,634	$92 BN
0.5	2,270	$82 BN

Table 1 – Chesapeake Bay Construction Cost Database

POTW	Project Total Cost ($ M)	Future Flow, MGD	Cost per GPD	TN- Pre & Post Project Conc.		TP- Pre & Post Project Conc.	
Aberdeen	7	4	1.8	8	3	0.65	0.3
Bowie	8.2	3.3	2.5	8	3	2	0.3
Brunswick	14.6	1.4	10.4	18	3	3	0.3
Celanese	15.8	1.66	9.5	18	3	3	0.3
Chesterton	9.3	0.9	10.3	18	3	3	0.3
Crisfield	10.3	1	10.3	18	3	3	0.3
Cumberland	30.6	15	2.0	8	3	2	0.3
Damascus WSSC	1.05	1.5	0.7	8	3	2	0.3
Easton	38.9	4	9.7	18	4	1.6	0.3
Elkton	40.7	3	13.6	18	3.8	2	0.3
Federalsburg	5.03	0.75	6.7	8	3	2	0.3
Frederick City	29.3	10.5	2.8	8	3	2	0.3
Georges Creek	7.1	0.6	11.9	18	3	2	0.3
Havre de Grace	38.1	3	12.7	8	3	2	0.3
Hurlock	7.3	1.65	4.4	18	3	2	0.3
Indian Head	14.2	0.5	28.4	8	3	2	0.3
Kent Is	33.2	3	11.1				
Kent/Stevens/Gasonville	31.4	3	10.5	18	3	4	0.3
Leonardtown	5.1	1.2	4.3	8	3	2	0.3
Mt. Airy	4	1.2	3.3	8	3	2	0.3
Patapsco	122	81	1.5	18	3	2	0.3
Perryville	13.2	1.65	8.0	18	3	2	0.3
Salisbury	78	8.5	9.2	18	3	1.6	0.3
St Michaels Talbot Co	13.8	0.66	20.9	18	3	3	0.3
Alexandria S.A. WWTP	45.6	54.00	0.8	8.0	3.0		
Arlington Co. WPCF	508.5	40.00	12.7	8.0	3.0		
City of Staunton and ACSA-Middle River	18.5	5.40	3.4	8.0	4.0	1.5	0.3
Colonial Beach STP	8.4	2.00	4.2	8.0	3.0	2.4	0.3
Culpeper WWTP	24.2	5.00	4.8	10.0	3.0	1.3	0.3
Dahlgren S.D. WWTP	6.5	1.00	6.5	13.0	4.0	0.7	0.3
Dale Serv. Corp #1	5.4	4.60	1.2	8.0	3.0	0.18	0.18
Dale Serv. Corp #8	5.3	4.60	1.2	8.0	3.0	0.18	0.18
Fairview Beach	2.6	0.20	13.0	16.0	6.5	3.7	1.0

Table 1, cont.

POTW	Proj	Future	Cost	TN- Pre &	TP- Pre &

	ect Total Cost ($ M)	Flow, MGD	per GPD	Post Project Conc.		Post Project Conc	
Farmville WWTP	0.7	2.40	0.3	16.0	5.0	2.8	0.5
FWSA-Opequon	35.0	12.20	2.9	8.0	3.0	1.5	0.3
Harrisonburg Rockingham RSA-North River	80.0	22.00	3.6	8.0	4.0	1.5	0.3
LCSA - Broad Run	203.0	11.00	18.5	-	4.0	-	0.1
MSA-Lexington	13.3	3.00	4.4	8.0	6.0	3.1	0.3
Mt. Jackson STP	9.5	0.80	11.9	14.0	4.0	1.8	0.3
Onancock WWTP	12.9	0.75	17.2	9.0	4.0	2.1	0.3
Orange STP	21.4	3.00	7.1	15.0	4.0	1.7	0.3
Parkins Mill FSWA	48.9	5.00	9.8	31.0	4.0	7.2	0.3
Petersburrg, SCWA	57	23	2.5	10	5	2	0.5
Purcellville-Basham Simms	40.0	1.50	26.7	8.0	4.0	1.0	0.3
RWSA-Moores Creek	33.5	15.00	2.2	22.0	5.0	3.8	0.3
Spotsylvania, FMC	44	5.4	8.1	6	3	2	0.3
Stafford Aquia Phase I	14.9	6.50	2.3	8.0	8.0		
Tappahannock WWTP	6.2	0.80	7.8	16.0	4.0	1.0	0.3
Warrenton STP	6.6	2.50	2.6	19.0	4.0		
Warsaw	10.2	0.33	30.9	19.0	3.0	5.4	0.3
Waynesboro STP	32.6	6.00	5.4	13.0	3.0	2.8	0.3
Woodstock STP	25.0	2.00	12.5	14.0	4.0	2.3	0.3