Supplemental Documentation Volume 3

Basis of Cost Opinions

Updated: September 1, 2009

Combined Sewer Overflow Control Alternatives Costing Tool Reference Manual

September, 2009

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1.0 INTRODUCTION AND OVERVIEW

The Philadelphia Water Department (PWD) has developed an alternatives cost estimation calculation tool (ACT) for use in planning level screening and comparison of CSO control technologies. The ACT provides planning-level cost estimates to facilitate the evaluation and comparison of preliminary alternatives for Philadelphia's Long Term CSO Control Plan Update.

The cost opinions created using the ACT are to be considered Level 4 cost estimates, as designated by The Association for the Advancement of Cost Engineering Recommended Practice No. 18R-97 (AACE, 2005), and actual costs are expected to fall within a range of 30% less to 50% more than the cost opinions given in this section. This estimate class and accuracy is appropriate for long term planning level use.

This user reference manual presents an overview of the contents, working and internal logic of the ACT.

1.1 Alternatives Costing Tool Scope

The ACT is an EXCEL workbook-based program which provides capital and operation and maintenance (O&M) costs of wet-weather conveyance, storage and treatment facilities based on costing algorithms developed from evolving and expanding national data sets, from PWD, and other regional capital and O&M cost data. Key outputs include:

- Current year (anticipated 2009) capital cost
- Current year O&M costs
- Present worth based on capital costs and projected O&M costs
- Future years' O&M costs based on assumed inflation
- Annual debt service costs
  Total capital costs

The user is to develop control alternatives which include conceptual level determinations of facility size, type and configuration. This information is entered into the costing tool through standardized templates. The ACT is configured to allow the user to rapidly evaluate sizing and configuration alternatives. Assumptions and calculations are displayed in a step-wise manner in the ACT, while providing the user the ability to reference the source data.

1.2 Control Technologies

Figure 1.2-1 displays the control technologies which are included in the ACT. The costing methodologies, inputs (conceptual design values) to be provided by the user, and conceptual design approach assumptions to be incorporated into the ACT are detailed in Section 2.0.

Table 1.2-1 ACT Technology Summary

Source Controls: Land-Based Stormwater Management (Green Stormwater Infrastructure) Private I/I Reduction Municipal I/I Reduction
Storage: Conventional Tunnel Tank Storage
Conveyance: Open Cut Pipe Pump Station Short-Bore Tunnel (Trenchless) Sewer Separation
Treatment: Retention Treatment Basin Vortex Separation High-Rate Clarification Screening Disinfection
Miscellaneous

1.3 Terminology

For purposes of this documentation the following definitions will apply. The specific meanings of some terms may vary depending on the context.

Control Element

"Control Element" means a facility serving as one component of a control alternative. A high-rate treatment (HRT) facility or a relief interceptor would be examples of control elements. Source reduction through municipal collection system rehabilitation or through green stormwater infrastructure would also be examples of control elements. The ACT will output estimated capital costs for control elements (e.g., the capital cost of a 30 million gallon per day (mgd) HRT based on the design and other parameters set by the user and the system-wide design assumptions discussed below in Section 2).

Control Alternative

"Control alternative" means an array of one or more control elements providing watershed-level overflow control at some specified level of performance. A relief interceptor sewer discharging to a HRT facility that was sized for eight overflows per typical year would be an example of a watershed-control alternative. The capital cost of a control alternative is the sum of the control element capital costs.

Construction Costs

"Construction costs" means the raw costs of building new control facilities, upgrading or expanding existing facilities or rehabilitating existing sewerage (i.e., the contractors' bid costs). Construction costs include: general conditions, overhead and profit, mobilization, demobilization, contractor's bonds and insurance, and sub-contractor markups.

Non-Construction Costs

Non-construction costs include all costs related to a control alternative other than building costs. Design and construction engineering costs are examples. Estimated non-construction costs, except for land acquisition, are based on a percentage of construction costs.

Capital Costs

Capital costs will be the sum of the estimated construction costs and the estimated non-construction costs.

Planning Period

For purposes of control alternatives evaluation, the planning period will be set at a default of 40 years. The planning period is relevant to calculating the present worth of various control elements.

Useful Life

The useful life of a control element is the period during which the control element will operate without requiring replacement or substantial reconstruction to maintain design performance. Preventive and corrective maintenance are assumed when establishing the useful lives of the control element components.

1.4 Economic Parameters

The following parameters have been incorporated into the ACT as standard values.

1.4.1 Useful Life

Useful life is relevant to alternatives evaluation because of the extended planning period. Present worth calculations need to include structural replacement or rehabilitation and equipment replacement costs that would occur during the planning period (e.g., a storage tank with effluent pumps coming on line in 2029 would likely require pump replacement or major overhaul before 2048). Because of the intermittent operation of wet-weather facilities, traditional estimates of equipment useful life may be inappropriate.

1.4.2 Discount Rate

The discount rate utilized by the ACT to calculate the present worth of control elements is an input variable. The default discount rate is 4.875%, and is based on the Department of Interior Federal water resources planning discount rate for fiscal year 2008.

1.4.3 Construction Cost Base Date

The base date, likely to be the current year, is a user input, and represents the date that the opinion of cost is in terms of. The default base date in the ACT is January 2009 as the base date for estimated construction costs.

1.4.4 Cost Inflation

Future Capital Costs

The ACT estimates future capital costs both in current year dollars and in future dollars. The default inflation value in the ACT is 4.0%.

Operations and Maintenance Cost Inflation

Base date (January 2009) O&M costs are inflated to the first year of operation as input into the model and for subsequent years throughout the planning period. The initiation of operation will be assumed to occur on January 1 of the year following construction completion. The default O&M cost inflation in the ACT is 4.0%.

1.4.5 Cost Indexes

Because the cost estimating sources were based on different dates and geographic locations, the cost estimates for the base year and base location were adjusted through cost indexes. Specifically, the Engineering News Record Construction Cost Index (ENRCCI) was used to adjust for the year of the cost estimate, and the 2008 RSMeans Location Factor (RSMeans) was used to adjust for the geographic location of the cost estimates. Table 1.4.5-1 shows the cost indexes for the cost estimating sources. The default base ENRCCI in the ACT is 8549, and the default RSMeans in the ACT is 115.2.

Table 1.4.5-1 Summary of Base Index Values for ACT Technologies Cost Data

<table>
<tr><th rowspan="2">Technology</th><th colspan="4">Cost Equation Data Base Index Values</th></tr>
<tr><th>ENRCCI Construction</th><th>RS Means Construction</th><th>ENRCCI O&M</th><th>RS Means O&M</th></tr>
<tr><td>Default ACT Project Analysis</td><td>8551</td><td>100.0</td><td>8551</td><td>100.0</td></tr>
<tr><td>Land-Based Stormwater Management</td><td>7966</td><td>115.2</td><td>8141</td><td>115.2</td></tr>
<tr><td>Private I/I Removal</td><td>8551</td><td>100.0</td><td>8551</td><td>100.0</td></tr>
<tr><td>Municipal I/I Removal</td><td>8551</td><td>100.0</td><td>8551</td><td>100.0</td></tr>
<tr><td>Conventional Tunnel</td><td>8551</td><td>100.0</td><td>8551</td><td>100.0</td></tr>
<tr><td>Tank Storage</td><td>8551</td><td>100.0</td><td>8551</td><td>100.0</td></tr>
<tr><td>Open Cut Pipe</td><td>7312</td><td>92.9</td><td>6771 (Detroit)</td><td>103.9 (Detroit)</td></tr>
<tr><td rowspan="2">Pump Station</td><td rowspan="2">8551</td><td rowspan="2">100.0</td><td>7939 (PWD)</td><td>115.2 (PWD)</td></tr>
<tr><td>7966 (EPA)</td><td>100.0 (EPA)</td></tr>
<tr><td>Trenchless Technologies</td><td>8578</td><td>113.2</td><td>6771 (Detroit)</td><td>103.9 (Detroit)</td></tr>
<tr><td>Sewer Separation</td><td>8551</td><td>100.0</td><td>8551</td><td>100.0</td></tr>
<tr><td>Retention Treatment Basins</td><td>8551</td><td>100.0</td><td>8551</td><td>100.0</td></tr>
<tr><td>Vortex Separation</td><td>8551</td><td>100.0</td><td>8551</td><td>100.0</td></tr>
<tr><td>High-Rate Clarification</td><td>8551</td><td>100.0</td><td>8551</td><td>100.0</td></tr>
<tr><td>Screening</td><td>8551</td><td>100.0</td><td>8551</td><td>100.0</td></tr>
<tr><td>Disinfection</td><td>8551</td><td>100.0</td><td>8551</td><td>100.0</td></tr>
</table>

Note: The unit cost values in the subsequent appendices reflect unadjusted costs. The index values are used for adjustment of cost to the project analysis ENRCCI and RSMeans values input by the user.

2.0 COST ESTIMATING APPROACH

This section outlines the wet-weather controls that are included in the ACT and the methodologies to be used in the ACT to scale estimated capital costs to the sizes and complexities identified by the user.

2.1 Non-Construction Costs

The ACT includes non-construction costs and economic parameters that impact the estimated total capital cost of a given control alternative.

The ACT automatically assigns non-construction costs to the construction costs calculated for a control element. With the exception of land acquisition and easement costs which are determined by the user, each non-construction cost is calculated as a percent of the estimated construction cost either before or after other multipliers are applied.

2.1.1 Construction Contingency

Construction contingencies are added to take into account how far advanced a design has proceeded. This contingency takes into account any design development concerns based on the status and phase of the project. For the initial planning work that is being done, a 25 percent contingency is added to the construction cost, which already includes (implicitly), the contractor's overhead and mark-up. The construction cost with this contingency included will be referred to as the opinion of probable construction cost.

2.1.2 Project Contingency

The ACT adds a project contingency to the opinion of probable construction cost. This contingency typically ranges from 5 to 30% depending upon such things as the level of difficulty of the project, the volatility of the bidding climate for the project type, the level of complexity of the site conditions, and the type and stage of funding being required. The default project contingency in the ACT is 20%.

2.1.3 Capitalized Interest

Capitalized interest, or interest during construction, reflects interest payments on the amount borrowed (through bonds), payment of which is deferred during construction. The ACT calculates the cost of capitalizing interest during construction based on the anticipated duration(s) of construction input by the user. For planning purposes, the annual draws on construction funding will be assumed to be straight line.

2.1.4 Land Acquisition and Easements/Rights-of-Way

Because of the specificity of local conditions, the ACT will not include a standard multiplier for land acquisition, easements and Rights-of-Way (ROW). Upon identifying preliminary routing (for relief or consolidation interceptors) or sites for control facilities, the user should overlay the potential routes and sites with existing easements and ROW to identify the need for new easements, ROW or parcels. The user will enter the total estimated costs for land acquisition, easements and ROW into the ACT.

2.1.5 Engineering and Implementation

Engineering and implementation costs are added as a percentage to the total of all costs described above. The ACT has a default setting of 20%, and is intended to address the following typical project costs:

- Permitting
- Engineering design
- Construction oversight /resident engineering
- Administration and program management
- Finance bonding costs
- Legal
- Geotechnical
- Survey
- Public participation.

2.1.6 Contractor's Overhead and Profit and Indirect Costs

Cost estimate sources presented in the ACT are in two different levels of cost. Most cost sources are in terms of construction costs as defined above: contractor's bid cost including overhead and profit and indirect costs. However, a few cost sources assembled directly from materials, labor, and equipment estimates are in terms of direct construction costs, excluding contractor's overhead and profit and indirect costs. Table 2.1.6 shows the breakdown between construction and direct construction in the ACT.

Overhead and profit and indirect costs are applied to the cost sources based on direct construction costs. The default value for contractor's overhead and profit in the ACT is 20%. The default value for contractor's indirect costs in the ACT is 4%.

Table 2.1.6 ACT Technology Cost Source Level of Cost

Technology Cost Curve/Cost Module	Direct Construction Cost (i.e. materials, labor, equipment)	Construction Cost Including Contractor's Overhead, Profit and Indirect Costs
Land Based Stormwater Management	X	
Trenchless Technologies	X	
Open Cut Pipe	X	
All Other Technologies		X

2.2 Construction Cost Approach

2.2.1 Cost Scaling

The ACT scales construction costs based on a series of cost per facility size equations developed for each of the structural control alternatives outlined in Section 2.3. Otherwise, it assembles construction and O&M costs from smaller components (e.g. material cost of a particular type and size of pipe, energy cost for pumping at a specific total dynamic head, flow rate, duration and electrical rate, etc).

2.2.2 Cost Data Sources

A variety of construction cost estimate data sources were used in development of the ACT. National wet-weather control facility costs of facilities in operation, as well as unit cost breakouts for such facilities (as they are available) were used extensively. These costs were updated for time and location.

The ACT also relied on cost curve data sets that have been developed for other wet weather programs nationally, such as: Perth Amboy, New Jersey; Indianapolis, Indiana; Cincinnati; Allegheny County, PA; Detroit, Michigan and Omaha, Nebraska. Data was also provided from the Philadelphia Water Department (PWD), and the Detroit Water and Sewer Department (DWSD). These cost curves were used for comparison purposes to verify the feasibility of the selected cost curve for a given technology. This combined knowledge base allowed for comparison of different cost estimation methodologies for each technology within the ACT.

The United States Environmental Protection Agency (U.S. EPA) publications containing control facilities cost data and cost curves will be used as a secondary source of guidance. These cost estimating curves were compared to installed project data, and adjusted chronologically using ENRCCI Index values.

2.3 Cost Estimation Methodology

The following subsection outlines inputs, default assumptions and methodologies used in the ACT to estimate construction costs of various control technologies that were identified in Section 1.2.

2.3.1 Land-Based Stormwater Management (Green Stormwater Infrastructure)

Land Based Stormwater Management (LBSM) costs are estimated using unit-area estimates. Underlying those unit-area estimates are more precise engineering cost opinions based on real site plans representing a variety of technologies, land use types, sizes, and land ownership.

A range of stormwater management plans using different LID techniques was selected. Five of these represented plans submitted by private developers and approved as complying with Philadelphia's stormwater ordinance and regulations. Ten plans were considered public funded projects, including two PWD demonstration projects. Engineering cost estimates were developed based on materials, labor, overhead, and profit using unit costs from RSMeans CostWorks (see example in Table 2.3.1-1). Costs were adjusted to represent construction taking place within Philadelphia with union labor rates in 2008 dollars and are considered construction costs with overhead, profit and without indirect costs.

Direct construction costs were estimated using materials and labor quantities for the following two cases:

- The marginal construction cost (beyond the cost of traditional measures) to implement each LBSM approach assuming that redevelopment is already taking place.
- The full construction cost required to implement each LBSM approach by retrofitting traditional development on an existing site.

Table 2.3.1-1 Example of Project Cost Estimate based on Quantities and Unit Costs

Category	Material	Units	Quantity	Unit Cost	Total Cost	Source*
Trees	Deciduous Tree	total	6	$385.00	$2,310.00	Means 32 93 4320 1600
	Bark Mulch	sq. yd	10.66	$6.15	$65.56	Means 32 91 1316 0100
	Geotextile Separation Fabric	sq. yd	10.67	$1.95	$20.80	Means 02620-300-0110
	Planting Backfill Mixture	cu. Yd	9.48	$29.50	$279.70	Means 31 05 1310 0700
	Hauling Backfill Mixture to Site	cu. Yd	9.48	$30.55	$289.66	Calculation
	Excavation	cu. Yd	10.67	$2.75	$29.31	Calculation
Porous Pavement	Pervious Asphalt	sq. yd	652.36	$20.90	$13,634.32	2X cost of traditional pavement
	AASHTO No. 57 Choker	cu. yd	18.12	$37.69	$682.94	Means 31 05 1610 0300
	AASHTO No. 2 Coarse Aggregate	sq. yd	652.36	$9.55	$6,230.04	Means 32 11 2323 0302
	Non-Woven Geotextile	sq. yd	784.36	$1.95	$1,529.50	Means 02620-300-0110
	Excavation	cu. Yd	217.88	$2.75	$598.84	Calculation
	Hauling Asphalt Materials to Site	cu. yd	163.20	$30.55	$4,985.76	Calculation
	Hauling for excavated soil	cu. Yd	217.88	$30.55	$6,656.17	Calculation
Pipe Trench Under Porous Pavement	24" Perf. Pipes	ft	774.00	$62.00	$47,988.00	Means 3311 1325 3070
	24" LF HDPE Header	ft	22.00	$62.00	$1,364.00	Means 3311 1325 3070
	Gravel	sq. yd	95.30	$15.40	$1,467.56	Means 32 11 2323 0300
	AASHTO No. 2 Coarse Aggregate	sq yd	91.21	$9.55	$871.06	Means 32 11 2323 0302
	Hauling Aggregate to Site	cu yd	91.21	$30.55	$2,786.47	Calculation
Inlet Structure	Reinforced Concrete Inlet Box	total	1	$4,800.00	$4,800.00	Means 334913-10-1000
	Excavation volume	cu. Yd	4.74	$2.75	$13.03	Calculation
	Hauling for excavated soil	cu. yd	4.74	$30.55	$144.83	Calculation
	Footing	each	1	$27.78	$27.78	Anecdotal
	Reinforced Concrete Top Unit	total	1	$440.00	$440.00	Means 33-49-1310-1300
	Heavy Duty Inlet Frame	total	1	$1,125.00	$1,125.00	Means 02630-110-1582
	AASHTO Coarse Aggregate Size No. 57	cu yd	0.67	$37.69	$25.13	Means 31 05 1610 0300
	Hauling Aggregate to Site	cu yd	0.67	$30.55	$20.37	Calculation
Outlet Structure	Cast Iron Manhole Frame and Cover	total	1	$505.00	$505.00	Means 33-44-1313-2100
	Precast Manhole Slab	total	1	$650.00	$650.00	Means 33-49-1310-1400
	Precast Reinforced Concrete Inlet Box	total	1	$4,800.00	$4,800.00	Means 334913-10-1000
	Cast Iron Trap	total	1	$550.00	$550.00	Means 22-13-1660-1160
	AASHTO Coarse Aggregate Size No. 57	cu yd	0.89	$37.69	$33.50	Means 31 05 1610 0300
	Hauling Aggregate to Site	cu yd	0.89	$30.55	$27.15	Calculation
Cleanout (Storm water piping)	Cast Iron Cleanout Housing	total	1	$880.00	$880.00	Means 22-05-7620-0280
	8" Dia. PVC Cleanout with Screw Plug	ft	0.75	$14.30	$10.73	Means 33-31-1325-2080
	8" Dia. PVC Spool Piece	ft	0.33	$14.30	$4.77	Means 33-31-1325-2080
Piping	12" Dia. PVC Pipe	ft	80.00	$23.50	$1,880.00	Means 33-31-1325-2160
	Redevelopment Cost				**$107,727**	

* Most unit costs are taken from R.S. Means Costworks Version 11.0, Building Construction Cost Data 2008. Some are based on local bid data or best engineering judgment. Some are calculations based on combinations of individual items and are too complex to describe in this table. Detailed calculations are available on request.

LBSM Input Variables

To calculate the construction cost of a LBSM technology, the following variables must be input into the ACT by the user:

Impervious Area - For calculating the LBSM construction cost, the user must first input the calculated impervious area (in acres) proposed for the LBSM technology alternative. This value will be determined by the user based on the alternative design.

Control Type - Next, the type of control is to be selected out of the five LBSM technologies: Bioretention, Green Roof, Porous Pavement, Street Trees, and Subsurface Infiltration.

Control Level - The third input variable is the control level, either retrofit or redevelopment.

Based on the user input values, the ACT will calculate direct construction costs as well as operation and maintenance (O&M) costs. These values were developed from unit costs per acre for each scenario provided in the ACT. A summary of the LBSM unit costs is provided in Table 2.3.1-6. A summary of LBSM O&M costs is provided in Table 2.3.1-14.

Summary of Results

The results from the takeoffs of LID stormwater management plans are summarized in the following sections. Descriptions of the projects that are selected for the analysis are listed in Table 2.3.1-2. A list of the cost estimates that were calculated for direct construction costs are shown in Table 2.3.1-3. The estimates were summarized into five categories: bioretention, subsurface infiltration, green roof, porous pavement and street trees in Table 2.3.1-4. Each category was further broken down into a redevelopment and retrofit cost. Due to the small sample size costs for bioretention, subsurface infiltration and porous pavement do not appear to be significantly different. For the purpose of the study the pooled value for all controls was assigned to these three types.

Table 2.3.1-2 Project Descriptions and Characteristics

Project Name	BMP Type	Land Use	Lot Size (sq ft)	Pre Construction Impervious Cover (sq ft)	Post Construction Impervious Cover (sq ft)
Private (1)	Subsurface Infiltration	High Density Residential	23760	21701	23760
47th and Grays Ferry Traffic Triangle	Bioretention	Street	6835	19318	19318
Private (2)	Green Roof	High Density Mixed Use	30593	0	23012
Public (2)	Pervious Pavement and Detention	School	52254	43655	52254
Private (3)	Subsurface Infiltration	School and Parking	371239	107530	121384
Mill Creek Tree Trench	Subsurface Infiltration	Street	1131	17346	17346
Private (4)	Green Roof and Pervious Pavement	High Density Residential	64600	25874	52230
Private (5)	Subsurface Infiltration	Commercial	122839	0	105415
Public (4)	Bioretention	Parking	551470	12235	424870
Public (5)	Subsurface Infiltration	School	95738	81218	29053
Curb Extension	Bioretention	Street	190	3508	3358
Swale without Parking	Bioretention	Street	192	2716	2550
Swale with Parking	Bioretention	Street	192	2429	2263
Planter with parking	Bioretention	Street	175	922	862
Planter without parking	Bioretention	Street	99	1147	1067
Street Trees	street trees	Street	43560	43560	43000*

* - 30.2 trees per acre placed in 16 sq. ft. tree boxes.

Table 2.3.1-3 Direct Construction Cost Estimates in 2008 Dollars

Project Name	BMP Type	Cost Estimates ($/impervious acre)		Actual Project Cost (PWD projects)
		Redevelopment	Retrofit	($/acre)
Private (1)	Subsurface Infiltration	$150,000	$230,000	
47th and Grays Ferry Traffic Triangle	Bioretention	$72,000	$80,000	$150,000
Private (2)	Green Roof	$290,000	$570,000	
Public (2)	Pervious Pavement and Detention	$85,000	$128,000	
Private (3)	Subsurface Infiltration	$44,000	$79,000	
Mill Creek Tree Trench	Subsurface Infiltration	$100,000	$120,000	$170,000
Private (4a)	Green Roof	$200,000	$430,000	
Private (4b)	Pervious Pavement	$190,000	$410,000	
Private (5)	Subsurface Infiltration	$120,000	$170,000	
Public (4)	Bioretention	$150,000	$200,000	
Public (5)	Subsurface Infiltration	$200,000	$350,000	
Curb Extension	Bioretention	$50,000	$65,100	
Swale without Parking	Bioretention	$70,000	$90,000	
Swale with Parking	Bioretention	$80,000	$100,000	
Planter with parking	Bioretention	$130,000	$160,000	
Planter without parking	Bioretention	$80,000	$100,000	
Street Trees	street trees	$15,000	$18,000	

Table 2.3.1-4 Summary of Direct Construction Cost Estimates [ENRCCI 7966; RSMEAN 115.2]

Control	**Type**	**Minimum Cost ($ / impervious acre)**	**Median Cost ($ / impervious acre)**	**Mean Cost ($ / impervious acre)**	**Max Cost ($ / impervious acre)**
Bioretention	Retrofit	$65,000	$120,000	$160,000	$410,000
	Redevelopment	$44,000	$90,000	$110,000	$200,000
Subsurface Infiltration	Retrofit	$65,000	$120,000	$160,000	$410,000
	Redevelopment	$44,000	$90,000	$110,000	$200,000
Green Roof	Retrofit	$430,000	$500,000*	$500,000	$570,000
	Redevelopment	$200,000	$250,000*	$250,000	$290,000
Porous Pavement	Retrofit	$65,000	$120,000	$160,000	$410,000
	Redevelopment	$44,000	$90,000	$110,000	$200,000
Street Trees	Retrofit	$18,000	$18,000	$18,000	$18,000
	Redevelopment	$15,000	$15,000	$15,000	$15,000

* Other cities have been experiencing costs in the range of $7-16 per square foot ($305,000 - $700,000 per impervious acre), with a typical range of $10-14 per square foot ($435,000 - $610,000 per impervious acre). A

recent green roof at Temple-Ambler campus was approximately $11 per square foot ($480,000 per impervious acre). The least expensive green roofs in Chicago, which has the largest-scale program in the U.S., are on the order of $6-7 per square foot ($285,000 per impervious acre), and this may be a reasonable estimate of what can be achieved in the future with a large-scale program in Philadelphia.

Learning Curve Assumptions

Over the long term, the cost of low impact development techniques is expected to decline for a number of reasons. A list of estimated long-term reduced construction costs in shown in Table 2.3.1-5 and summary statistics are shown in Table 2.3.1-6. The reductions shown in this table are credited to improvements in site layouts, a reduction in the cost for materials, reduction in design costs, and reductions in perceived risk as low impact development becomes the standard way of doing business.

Better Site Design: Site designers are required to comply with Philadelphia's stormwater regulations today. However, design features needed to comply are often added as an afterthought, after the site layout has been determined. Designs are very dense and do not leave open space for stormwater management (or resident enjoyment). This forces stormwater management features into underground, infrastructure-intensive facilities. Over time, local engineers will adopt better site design techniques. In the estimates in Table 2.3.1-5, it is assumed that impervious area on each site is reduced by 20% compared to the actual designs submitted in recent years. A 20% reduction is reasonable; the Philadelphia stormwater regulations provide an incentive for a 20% reduction, and there is a precedent for this level of reduction in surrounding states.

Reductions in Material Cost: As low impact development techniques such as porous pavement and green roofs become the standard way of doing business, materials needed to build them will no longer be considered specialty materials. For example, the estimates in Table 2.3.1-5 assume that in the future porous pavement have the same unit cost as traditional pavement today.

Reductions in Design Cost: Because low impact development techniques are unfamiliar to many local engineers, design costs are currently high relative to total construction cost. In the Alternative Costing Tool, future design costs are assumed to be no more than a project of "typical complexity" on the ASCE engineering fee cost curve (discussed in more detail in ACT cost curve). This assumption does not affect the direct construction costs shown in Table 2.3.1-5.

Reductions in Perceived Risk: In the ACT, a relatively low contingency will be used for low impact development, assuming that contractors will perceive less risk over time as these techniques become the standard way of doing business. This assumption does not affect the direct construction costs shown in Table 2.3.1-5.

Table 2.3.1-5 Summary of Direct Construction Cost Estimates with Improved Development Practices and Economies of Scale in 2008 Dollars

Project Name	BMP Type	Cost Estimates ($/impervious acre)		Percent Reduction	
		Redevelopment	Retrofit	Redevelopment	Retrofit
Private (1)	Subsurface Infiltration	$110,000	$180,000	27%	24%
47th and Grays Ferry Traffic Triangle	Bioretention	$57,000	$64,000	20%	20%
Private (2)	Green Roof	$230,000	$460,000	20%	20%
Public (2)	Pervious Pavement	$66,000	$100,000	22%	22%
Private (3)	Subsurface Infiltration	$35,000	$63,000	20%	20%
Mill Creek Tree Trench	Subsurface Infiltration	$80,000	$100,000	19%	19%
Private (4a)	Green Roof	$160,000	$340,000	20%	20%
Private (4b)	Pervious Pavement	$120,000	$290,000	36%	27%
Private (5)	Subsurface Infiltration	$90,000	$130,000	20%	20%
Public (4)	Bioretention	$120,000	$160,000	20%	20%
Public (5)	Subsurface Infiltration	$160,000	$280,000	20%	20%
Curb Extension	Bioretention	$43,000	$52,000	20%	20%
Swale without Parking	Bioretention	$58,000	$74,000	20%	20%
Swale with Parking	Bioretention	$70,000	$80,000	20%	20%
Planter with parking	Bioretention	$100,000	$130,000	20%	20%
Planter without parking	Bioretention	$60,000	$79,000	20%	20%
Street Trees	street trees	$12,000	$15,000	20%	20%

The green roof cost estimate for improved development practices is based on the direct construction cost estimate with no improved practices/economies of scale.

Table 2.3.1-6 Summary Statistics of Direct Construction Cost Estimates with Improved Development Practices and Economies of Scale in 2008 Dollars

Control	Type	Minimum Cost ($ / impervious acre)	Median Cost ($ / impervious acre)	Mean Cost ($ / impervious acre)	Max Cost ($ / impervious acre)
Bioretention	Retrofit	$52,000	$100,000	$130,000	$290,000
	Redevelopment	$35,000	$80,000	$80,000	$160,000
Subsurface Infiltration	Retrofit	$52,000	$100,000	$130,000	$290,000
	Redevelopment	$35,000	$80,000	$80,000	$160,000
Green Roof	Retrofit	$340,000	$400,000	$400,000	$460,000
	Redevelopment	$160,000	$200,000	$200,000	$230,000
Porous Pavement	Retrofit	$52,000	$100,000	$130,000	$290,000
	Redevelopment	$35,000	$80,000	$80,000	$160,000
Street Trees	Retrofit	$15,000	$15,000	$15,000	$15,000
	Redevelopment	$12,000	$12,000	$12,000	$12,000

* Based on anecdotal information, resulting costs of approximately $6-9 per square foot ($260,000 - $395,000 per impervious acre) are in line with the experience of the large-scale program in Chicago.

Public-Sector Cost Sharing Assumptions

For some land use types, it is assumed that entities other than PWD assume a portion of the stormwater retrofit capital and O&M costs as follows:

- Schools (50% PWD, 50% other public entities)
- Park and recreation facilities (50% PWD, 50% other public entities)
- Other public lands - libraries, police, fire, health, etc. (50% PWD, 50% other public entities)
- Street trees - not part of green streets; this refers to street trees in the absence of other controls (50% PWD, 50% other public entities)
- Sidewalk replacement grant programs (50% PWD, 50% other public entities)
- Waterfront sewer separation (0% PWD, 100% other entities)
- Retrofit of vacant and abandoned lands (0% PWD, 100% other entities)
- Private lands affected by the stormwater ordinance and regulations (0% PWD, 100% other entities)

Operations & Maintenance Cost Analyses

Operations and maintenance (O&M) costs were summarized into five categories, Porous Pavement, Subsurface Vault, Green Roofs, Bioretention, and Street Trees, for the selected LID stormwater management plans. For each category O&M costs were broken down into required operations and maintenance activities as described in the Philadelphia Stormwater Management Guidance Manual. Operations and maintenance activities, length and frequency were also estimated. The operations and maintenance labor costs associated with each LID design were determined from union contract agreements with the city of Philadelphia. The operations and maintenance costs were marked up to cover the costs associated with overhead & profit, estimated at 25%. The labor rates that were used in the analysis are shown in Table

2.3.1-7. The equipment costs utilized in the analysis are presented in Table 2.3.1-8. All equipment costs are from RS Means Costworks 2008. Materials costs were assumed to be the 10% of the median marginal redevelopment cost (see Table 2.3.1-6) distributed over 25 years.

Table 2.3.1-7 Labor Rates

General Description	Class	Basic Hourly Rate	Fringe Benefits
Truck Driver	Journeyman Class II	$22.60	$11.37
Truck Driver	Journeyman Class III	$22.85	$11.37
Landscape Laborer	Class I	$17.13	$16.87
Landscape Laborer	Class II	$17.88	$16.87

Table 2.3.1-8 Equipment Costs

General Description	Units	Unit Cost
Rent Vacuum Truck, hazardous materials, 5000 gallons	per day	$335.00
Rented sewer/catch basin vacuum, 14 cy, 1500 gallon	per day	$485.00
Truck, pickup, 3/4 ton, 2 wheel drive	per day	$80.50

The O&M activity and schedule associated with porous pavement are included in Table 2.3.1-9.

Table 2.3.1-9 Porous Pavement O&M Activities

Activity	Schedule	Visits Per Year Per Impervious Acre	Hours Per Visit Per Impervious Acre	Total Hours Per Year per Impervious Acre
Vacuum porous asphalt or concrete surface with commercial cleaning unit (Pavement washing systems and compressed air units are not recommended)	Twice per Year	2	4	8
Clean out inlet structures within or draining to the subsurface bedding beneath porous surface	Twice per Year	2	4	8
Maintain records of all Inspections and maintenance activity	Ongoing	1	1	1

The O&M activity and schedule associated with subsurface infiltration are included in Table 2.3.1-10.

Table 2.3.1-10 Subsurface Infiltration O&M Activities

Activity	Schedule	Visits Per Year Per Impervious Acre	Hours Per Visit Per Impervious Acre	Total Hours Per Year per Impervious Acre
Regularly clean out gutters and catch basins to reduce sediment load to infiltration system. Clean intermediate sump boxes, replace filters, and otherwise clean pretreatment areas in directly connected systems	As needed	3	5	15
Inspect and clean as needed all components of and connections to subsurface infiltration systems	Twice per Year	2	3	6
Evaluate the drain-down town of the subsurface infiltration system to ensure the drain-down time of 24-72 hours	Twice per Year	2	1	2
Maintain records of all inspections and maintenance	Ongoing	1	1	1

The O&M activity and schedule associated with green roofs are included in Table 2.3.1-11.

Table 2.3.1-11 Green Roof O&M Activities

Activity	Schedule	Visits Per Year Per Impervious Acre	Hours Per Visit Per Impervious Acre	Total Hours Per Year per Impervious Acre
Roof drains should be cleared when soil substrate, vegetation, debris or other materials clog the drain inlet. Sources of sediment and debris may be identified and corrected	As needed	2	3	6
Plant material should be maintained to provide 90% plant cover. Weeding should be manual with no herbicides or pesticides used. Weeds should be removed regularly	As needed	2	8	16
Irrigation can be accomplished either through hand watering or automatic sprinkler system if necessary during the establishment period.	As needed	5	1	5
Growing medium should be inspected for evidence of erosion from wind or water. If erosion channels are evident, they can be stabilized with additional growth medium similar to the original material.	Quarterly	4	3	12
Inspect drain inlet pipe and containment system	Annually	1	4	4
Test growing medium for soluble nitrogen content. Fertilize as needed	Annually	1	1	1

Activity	Schedule	Visits Per Year Per Impervious Acre	Hours Per Visit Per Impervious Acre	Total Hours Per Year per Impervious Acre
Maintain a record of all inspections and maintenance activity	Ongoing	1	1	1

The O&M activity and schedule associated with bioretention are included in Table 2.3.1-12.

Table 2.3.1-12 Bioretention O&M Activities

Activity	Schedule	Visits Per Year Per Impervious Acre	Hours Per Visit Per Impervious Acre	Total Hours Per Year per Impervious Acre
Remulch void areas	As needed	1	0.5	0.5
Treat diseased trees and shrubs	As needed	1	0.5	0.5
Keep overflow free and clear of leaves	As needed	3	0.5	1.5
Inspect soil and repair eroded areas	Monthly	12	0.5	6
Remove litter and debris	Monthly	12	0.5	6
Clear leaves and debris from overflow	Monthly	12	0.5	6
Inspect trees and shrubs to evaluate health, replace if necessary	Twice per Year	2	1	2
Inspect underdrain cleanout	Twice per Year	2	2	4
Verify drained out time of system	Twice per Year	2	1	2
Add additional mulch	Annually	1	1	1
Inspect for sediment buildup, erosion, vegetative conditions, etc.	Annually	1	1	1
Maintain records of all inspections and maintenance activity	Ongoing	1	1	1

The O&M activity and schedule associated with street trees are included in Table 2.3.1-13.

Table 2.3.1-13 Street Trees O&M Activities

Activity	Schedule	Visits Per Year Per Impervious Acre	Hours Per Visit Per Impervious Acre	Total Hours Per Year per Impervious Acre
Treat diseased trees and shrubs	As needed	3	3	9
Remove litter and debris	Monthly	12	1	12
Inspect trees and shrubs to evaluate health	Twice per Year	2	3	6

A summary of annual operation and maintenance costs are listed in Table 2.3.1-14.

Table 2.3.1-14 Annual Operation & Maintenance Costs [ENRCCI 8141; RSMEAN 115.2]

Control	Annual O&M Costs ($/imp. Acre/yr)
Porous Pavement	$2,400
Subsurface Infiltration	$2,900
Green Roof	$4,000
Bioretention	$3,100
Street Tree	$1,800

Personnel Estimates for Green Streets

Based on the assumptions presented in the operations and maintenance descriptions, each acre of impervious drainage area requires approximately 24 hours of labor per year. Street lengths and widths vary widely, but on average the street and two sidewalks on one block make up approximately 0.5 acres of impervious surfaces. Assuming each employee averages 1600 hours of task work per year (excluding vacation, training), the following estimates are reached:

- 12 hours of labor are required per block of green streets per year.
- A 2-person crew can visit 266 blocks once per year, 133 blocks twice per year, or 66 blocks four times per year. In all cases, the crew would visit approximately 1 block per day.
- Streets and sidewalks make up 10,774 acres in the City-wide combined areas. A program to mitigate a portion of these through green infrastructure would result in the following estimated personnel requirements:
  - 10% (1,077 ac): 17 employees
  - 25% (2,693 ac): 41 employees
  - 50% (5,387 ac): 81 employees
  - 75% (8,080 ac): 122 employees
  - 100% (10,774 ac): 162 employees

Life Cycle Assumptions

During the analysis a literature study was conducted on lifespan assumptions for each of the five categories of LID stormwater management designs and results can be found in Table 2.3.1-15.

Table 2.3.1-15 Life Cycle Assumptions

Control	Lifespan
Bioretention	25[1]
Green Roofs	25-30[1,2]
Subsurface Infiltration	25[1]
Porous Pavement	25[1]
Street Trees	25-40[1,2]

[1]- EconNorthwest, 2007

[2]- internal communications

Based on these results, green infrastructure is typically overhauled or replaced every 25-40 years. Based on this and assuming a comprehensive O&M program, it appears reasonable to assume that an overhaul will not be performed until the end of the LTCPU planning horizon of 40 years. However, replacement costs are discussed in the following section in case they are needed.

Replacement Costs

Replacement cost is determined by assuming that most traditional stormwater infrastructure components do not need replacing based on PWDs existing infrastructure life cycle. Traditional components include inlets, manholes, diversion structures, and pipes and related materials (i.e. gravel and fill). Most green infrastructure components have a shorter lifecycle and may need to be replaced more often. These costs are weighted with a percentage to determine the extent of the components cost to the replacement for a given LID technique. Trees and plants have definite lifecycles and are assumed to be replaced completely if used in a given technique. Components such as gravel and soil are assumed to be replaced to a lesser extent, because their functionality is longer lasting. Other specific components, such as porous pavement and green roof components are assumed to be replaced completely. Table 2.3.1-16 is an example of how replacement costs are determined

Table 2.3.1-16 Example Specific Material Replacement Costs

Material	Units	Quantity	Unit Cost	Total Cost	Replacement Cost % Of Original	Replacement Cost
Deciduous Tree	total	6	$385.00	$2,310.00	100%	$2,310
Bark Mulch	sq. yd	10.7	$6.15	$65.56	100%	$66
Geotextile Separation Fabric	sq. yd	10.7	$1.95	$20.80	100%	$21
Planting Backfill Mixture	cu. Yd	9.5	$29.50	$279.70	100%	$280
Hauling Backfill Mixture to Site	cu. Yd	9.5	$30.55	$289.66	100%	$290
Excavation	cu. Yd	10.7	$2.75	$29.31	100%	$29
Porous Pavement						
Pervious Asphalt	sq. yd	652	$10.45	$6,817.16	100%	$6,817
AASHTO No. 57 Choker	cu. yd	18	$37.69	$682.94	50%	$341
AASHTO No. 2 Coarse Aggregate	sq. yd	652	$9.55	$6,230.04	50%	$3,115
Non-Woven Geotextile	sq. yd	784	$1.95	$1,529.50	50%	$765
Excavation	cu. Yd	218	$2.75	$598.84	50%	$299
Hauling Asphalt Materials to Site	cu. yd	163	$30.55	$4,985.76	100%	$4,986
Hauling for excavated soil	cu. Yd	218	$30.55	$6,656.17	50%	$3,328
Pipe Trench Under Porous Pavement						
24" Perf. Pipes	ft	774	$62.00	$47,988.00	0%	$0
24" LF HDPE Header	ft	22	$62.00	$1,364.00	0%	$0
Gravel	sq. yd	95	$15.40	$1,467.56	0%	$0
AASHTO No. 2 Coarse Aggregate	sq yd	91.2	$9.55	$871.06	0%	$0
Hauling Aggregate to Site	cu yd	91.2	$30.55	$2,786.47	0%	$0
Inlet Structure						
Reinforced Concrete Inlet Box	total	1	$4,800.00	$4,800.00	0%	$0

Material	Units	Quantity	Unit Cost	Total Cost	Replacement Cost % Of Original	Replacement Cost
Excavation volume	cu. Yd	4.7	$2.75	$13.03	0%	$0
Hauling for excavated soil	cu. yd	4.7	$30.55	$144.83	0%	$0
Footing	each	1	$27.78	$27.78	0%	$0
Reinforced Concrete Top Unit	total	1	$440.00	$440.00	0%	$0
Heavy Duty Inlet Frame	total	1	$1,125.00	$1,125.00	0%	$0
Coarse Aggregate Size No. 57	cu yd	0.67	$37.69	$25.13	0%	$0
Hauling Aggregate to Site	cu yd	0.67	$30.55	$20.37	0%	$0

The summary of estimated replacement costs for specific control techniques is summarized in Table 2.3.1-17.

Table 2.3.1-17 Replacement costs

Control	Median Cost ($ / Impervious Acre)
Bioretention	$35,000
Subsurface Infiltration	$35,000
Green Roof	$220,000
Porous Pavement	$35,000
Street Trees	$12,000

Literature Review

A literature review of documents referencing stormwater management construction cost information utilizing low impact development was performed. The estimates were then updated to account for changes in cost due to inflation and location. Cost estimates were adjusted for inflation using the ENR cost index and adjusted for location using RS Means location factors. Stormwater management practices are listed in Table 2.3.1-18. This table lists the redevelopment construction cost ranges from CWP, 2007. The retrofit construction cost ranges are listed within Table 2.3.1-19. The construction cost range for retrofits are broken down into three stormwater management practices pond retrofit, new storage retrofit, and urban on-site retrofit. Urban on-site retrofit is the most similar to the type of development we expect in Philadelphia.

Table 2.3.1-18 Construction Cost Ranges by Category for New Development

Stormwater Practice	Min ($/impervious acre)	Median ($/impervious acre)	Max ($/impervious acre)
Constructed Wetlands	$2,100.00	$3,000.00	$10,000.00
Extended Detention	$2,300.00	$4,000.00	$7,800.00
Wet Ponds	$3,200.00	$8,700.00	$30,000.00
Water Quality Swales	$11,000.00	$19,000.00	$38,000.00
Bioretention	$21,000.00	$27,000.00	$44,000.00
Infiltration	$21,000.00	$27,000.00	$44,000.00
Residential Green Rooftop	$11,000.00	$28,000.00	$51,000.00
Filtering Practices	$19,000.00	$60,000.00	$83,000.00
Non-Residential Green Roof	$23,000.00	$95,000.00	$1,100,000.00

Table 2.3.1-19 Construction Cost Range by Category for Retrofit

Stormwater Practice	Min ($/impervious acre)	Median ($/impervious acre)	Max ($/impervious acre)
Pond Retrofit	$3,800	$12,000	$39,000
New Storage Retrofit	$9,400	$20,000	$34,000
Urban On-site Retrofit	$61,000	$92,000	$160,000

Additional & Validation Cost Estimates

The continued implementation of additional green infrastructure and LID stormwater features in Philadelphia has allowed for the addition of more projects and plans, which can be used to validate the original cost estimates created in the beginning of this memo. Additional estimates include an on street retrofit and a compilation of the draft PWD standard details for stormwater management.

An example project is a street level tree planter and subsurface infiltration system. The construction cost estimate for the project was determined to be $250,000 per impervious acre. The construction cost estimate for the project is within the maximum range of the retrofit cost estimates in Table 2.3.1-4.

PWD has drafted several standard details for street retrofits of green infrastructure. These include on street planters, porous pavement and other types of street retrofits to manage stormwater. Table 2.3.1-20 is a summary of the construction cost estimates for the standard detail plans with a summary of the average and median of these estimates.

Table 2.3.1-20: Construction Cost Estimates of Draft PWD Standard Details

Standard Detail Description	Retrofit Cost ($ / Impervious Acre)
Curb Extention - Apex Inlet	$162,000
Curb Extention - End Inlet	$168,000
Mid-Block Curb Extention	$116,000
Infiltration Planter	$138,000
Porous Pavement	$151,000
Tree Planter	$79,000
Tree Planter - No Tree Grate	$38,000
Tree Planter Direct Opening	$158,000
Tree Planter Direct Opening - No Tree Grate	$116,000
Tree Planter w/additional storage	$128,000
Tree Planter w/additional storage - No Tree Grate	$86,000
Tree Trench	$108,000
Tree Trench - No Tree Grates	$82,000
Average	$118,000
Median	$116,000

2.3.2 Municipal Inflow and Infiltration Reduction

The ACT allows for planning level estimation of rehabilitation costs of municipal sewer infrastructure in an effort to reduce inflow and infiltration (I/I). Calculations for estimating cost of these rehabilitation alternatives are structured into the ACT with the user providing any additional costs for O&M of a given alternative. The ACT includes rehabilitation costs for the following municipal I/I reduction measures. Tables 2.3.2-1 and 2.3.2-2 summarize the Municipal I/I unit costs within the ACT.

Pipe Lining

The ACT determines pipe lining costs based on the following user inputs:

- Type of lining (cured-in-place or user defined)
- Pipe diameter (8-inch through 48-inch; see Table 2.3.2-1 for unit costs)
- Pipe length (in linear feet)

The ACT calculates the cost of pipe lining per linear foot of pipe installed. A default unit cost per linear foot, varying by pipe diameter, is provided in the ACT. The user has the ability to change this unit cost, but must provide acceptable documentation of the basis of cost.

Manhole Rehabilitation

The ACT assumes that manhole rehabilitation includes sealing manholes and installing water tight frames and covers. The user inputs the number of manholes to be rehabbed, which are multiplied by a default unit cost value ($2500 per manhole) to determine the total manhole rehabilitation cost. The user has the ability to change this unit cost, but must provide documentation of the basis of cost.

Catch Basin Rehabilitation

Catch basin rehabilitation includes sealing-off the connection from a catch basin to a sanitary or combined sewer. Construction cost estimates are based upon the input of number of catch basins or storm inlets to be removed, with a default unit cost per rehabilitation to be applied ($600 per catch basin). This unit cost does not include the new pipe and surface restoration required to reroute the catch basin. These items can be calculated separately in the open cut pipe section of the ACT. The ACT unit cost is configured for this default type of catch basin rehabilitation; the user has the ability to change this unit cost, but must provide documentation of the basis of cost.

Service Lateral Spot Repair

The ACT estimates the cost spot repair cost of municipal service laterals. Existing laterals would be reconnected with street wyes replaced. Construction cost estimates are based upon the input of linear feet of laterals to be repaired, with a default unit cost to be applied ($350 per LF repaired). The unit cost value in the ACT is configured for this default type of service lateral repair. The user has the ability to change this unit cost, but must provide acceptable documentation of the basis of cost.

Table 2.3.2-1 Municipal Pipe Lining Unit Costs in ACT [ENRCCI 8551; RSMEAN 100]

Diameter (in)	CIPP Pipe Lining Unit Cost ($/LF)
8	$137
10	$159
12	$199
15	$258
18	$280
21	$318
24	$395
27	$476
30	$572
36	$706
42	$846
48	$985

Table 2.3.2-2 Municipal Pipe Lining Unit Costs in ACT [ENRCCI 8551; RSMEAN 100]

Technology	Default Unit Cost	Units	User Defined Unit Cost Option?	O&M Cost Estimate
Manhole Rehabilitation	$2500	Per manhole	Yes	User to input a lump sum value for all Municipal I/I reduction alternatives where applicable.
Catch Basin Rehabilitation	$600	Per catch basin	Yes	
Service Lateral Pipe Repair	$350	Per LF of lateral repair	Yes	

2.3.3 Private Inflow and Infiltration Removal

As for municipal collection sewer rehabilitation, the user may choose to evaluate the cost-effectiveness of wet-weather flow reduction by reducing I/I from private sources. Calculations for estimating cost of these removal alternatives are structured into the ACT with the user providing any additional costs for O&M of a given alternative. The ACT includes rehabilitation costs for the following private I/I reduction measures. Table 2.3.3-1 summarizes the Private I/I unit costs within the ACT.

Service Lateral Lining

This work includes spot repairs to the service lateral from a house or other building to the sewer pipe. Construction cost estimates are based upon the input of the combined length (in LF) of service laterals which require lining, with a default unit cost per LF to be applied ($120 per LF). The unit cost value in the ACT is configured for this default type of service lateral repair. The user has the ability to change this unit cost, but must provide acceptable documentation of the basis of cost.

Sump Pump Discharge Rerouting

For existing homes or other establishments with a sump pump that discharges flow from footing drains (and possibly roof leaders) into the sanitary system, this work includes constructing a hard pipe from the sump pump through the basement wall to an adequate discharge location (work will conform to applicable plumbing codes and other municipal regulations). The user will input the number of homes or other establishments for which this work will be performed, with a default unit cost per home to route sump pump discharge below grade to storm system ($4,700 per rerouting). The user has the ability to change this unit cost, but must provide acceptable documentation of the basis of cost.

Footing Drain Disconnection

For existing homes or other establishments where footing drains (and possibly roof leaders) are tied into the interior sanitary plumbing, this work includes removing and replacing portions of the basement floor as needed to separate the interior plumbing so that footing drains are routed to new sump. This work also includes constructing a hard pipe form the sump pump through the basement wall to a curb drain system, or existing catch basin. The unit cost includes the homeowner’s share of the curb drain system cost. The user will input the number of homes or other establishments for which this work will be performed, with a default unit cost applied ($8,000 per disconnection). The user has the ability to change this unit cost, but must provide acceptable documentation of the basis of cost.

Exterior Roof Leader Disconnect

For buildings where roof leaders are tied into the footing drains and make their way to the sanitary lateral, this work includes disconnecting (cutting) the down pipe and providing a discharge to the ground for homes or other establishments with an adequate discharge location and where local codes permit. The user will need to specify the estimated number of roof leaders to be disconnected, as well as distinguish the type of roof leader disconnection. The user also needs to specify whether will be performed by the homeowner or municipality. The user has the ability to change this unit cost, but must provide acceptable documentation of the basis of cost.

Private Drain Disconnection

This work includes sealing the connection from a driveway drain or other private storm drain to a sanitary sewer. It also includes re-routing the drain line to an existing storm outlet or constructing a new drain outlet. The user will need to specify the estimated number of drains to remove and the total length of new storm sewer required. Based on these assumptions, a default unit cost is applied ($600 per disconnection). The user has the ability to change this unit cost, but must provide acceptable documentation of the basis of cost.

Table 2.3.3-1 Private I/I Removal Unit Costs [ENRCCI 8551; RSMEAN 100]

<table>
<tr><th>Technology</th><th>Default Unit Cost</th><th>Units</th><th>User Defined Unit Cost Option?</th><th>O&M Cost Estimate</th></tr>
<tr><td>Service Lateral Lining</td><td>$120</td><td>Per LF of lateral lining</td><td>Yes</td><td rowspan="6">User to input a lump sum value for all Private I/I reduction alternatives where applicable.</td></tr>
<tr><td>Sump Pump Discharge Rerouting</td><td>$4700</td><td>Per sump pump rerouting</td><td>Yes</td></tr>
<tr><td>Footing Drain Disconnection</td><td>$8000</td><td>Per disconnection</td><td>Yes</td></tr>
<tr><td rowspan="2">Exterior Roof Leader Disconnection</td><td>$20</td><td>Per homeowner disconnection</td><td rowspan="2">Yes</td></tr>
<tr><td>$70</td><td>Per municipality disconnection</td></tr>
<tr><td>Private Drain Disconnection</td><td>$600</td><td>Per drain disconnection</td><td>Yes</td></tr>
</table>

2.3.4 Sewer Separation

Sewer separation construction costs were based on three components: new sanitary sewer construction costs, sewer lateral construction costs, and streetscape reconstruction cost. Unit cost data is based on recent construction bids received by PWD and are considered construction costs with overhead, profit and indirect costs included. Data is summarized in Table 2.3.4.1.

Table 2.3.4.1 Sewer Separation Component Costs [ENRCCI: 8551; RSMeans: 115.2]

Component	Unit Cost	Units
New Sanitary Sewers	$1,700,000	$/mile
Lateral from new sewer to property	$6,000	$/lateral
Interior plumbing modifications - Residential	$6,000	$/lateral
Interior plumbing modifications - Non-Residential	$20,000	$/lateral
Concrete Street Base	$6	$/square foot
Asphalt Paving	$3	$/square foot
Concrete Sidewalk	$7	$/square foot
Concrete Curb	$26	$/foot

2.3.5 Open Cut Pipe

The ACT performs cost estimation for new conveyance. Open cut installation of gravity sewer pipe is included as a technology alternative in the ACT. Construction cost estimates for open cut pipe in the ACT require the following user input values:

- Pipe cross-section, either circular or a box section;
- The nominal size of the cross-section in terms of diameter for circular pipe or a specified box size
  - Circular pipe nominal diameters range between six and 108 inches. In addition to the nominal diameter, the pipe material must be chosen by the user from a menu list (PVC, Class II, III, IV, and V concrete pipe, or ductile iron).
  - Box culverts range in size between four foot by eight foot and 12 foot by 12 foot. The orientation of the box is also an input value, either wide or tall dependant on the orientation of the longer side of the box. A "wide" box would have a longer horizontal orientation, while a "tall" box would have a longer vertical orientation. The orientation designation of a square box will have no effect on unit cost.
- The proposed length of the pipe in the street as well as the length of the pipe out of the street, both in linear feet.
- The average depth to the pipe invert in vertical feet. The maximum depth to invert is 24 vertical feet.
- The volume percentage of rock excavation to total excavation.
- The pavement type. The tool has default values for eight inch bituminous pavement or 11.5 inch pavement. There is also an option of a user-defined pavement type in which the user must input the pavement thickness and the street restoration unit cost in dollars per square yard.
- The user must define the street restoration efforts, choosing between two configurations: a partial street opening which equals the trench width plus one foot on either side of the trench, or a complete restoration equal to the entire street width. The street width is a user input.
- The number of manholes and their typical diameter.
- The number of utility crossings encountered in the street.
- The number of service laterals to be installed or restored.
- Any sidewalk or curb restoration anticipated, and several user inputs for this type of restoration if it is needed.
- User defined costs including: railroad costs, stream crossing costs, additional force main costs, and miscellaneous.
- Finally, several open pipe construction conditions are estimated as a percentage of total construction cost. These conditions include dewatering requirements, flow maintenance requirements, and traffic maintenance requirements.

The total cost estimate for open cut is determined by summing numerous direct unit construction costs (e.g. pipe material costs, equipment and labor costs for soil excavation).

Open Cut cost data is considered to be direct construction costs excluding overhead and profit, and indirect costs, and are summarized in Tables 2.3.5-1 through 2.3.5-14. The base index values for all open cut pipe cost data is ENRCCI 7312 and RS Means 92.9.

Figure 2.3.5-1 displays the open cut pipe cost estimating schematic which outlines the methodology followed in the ACT.

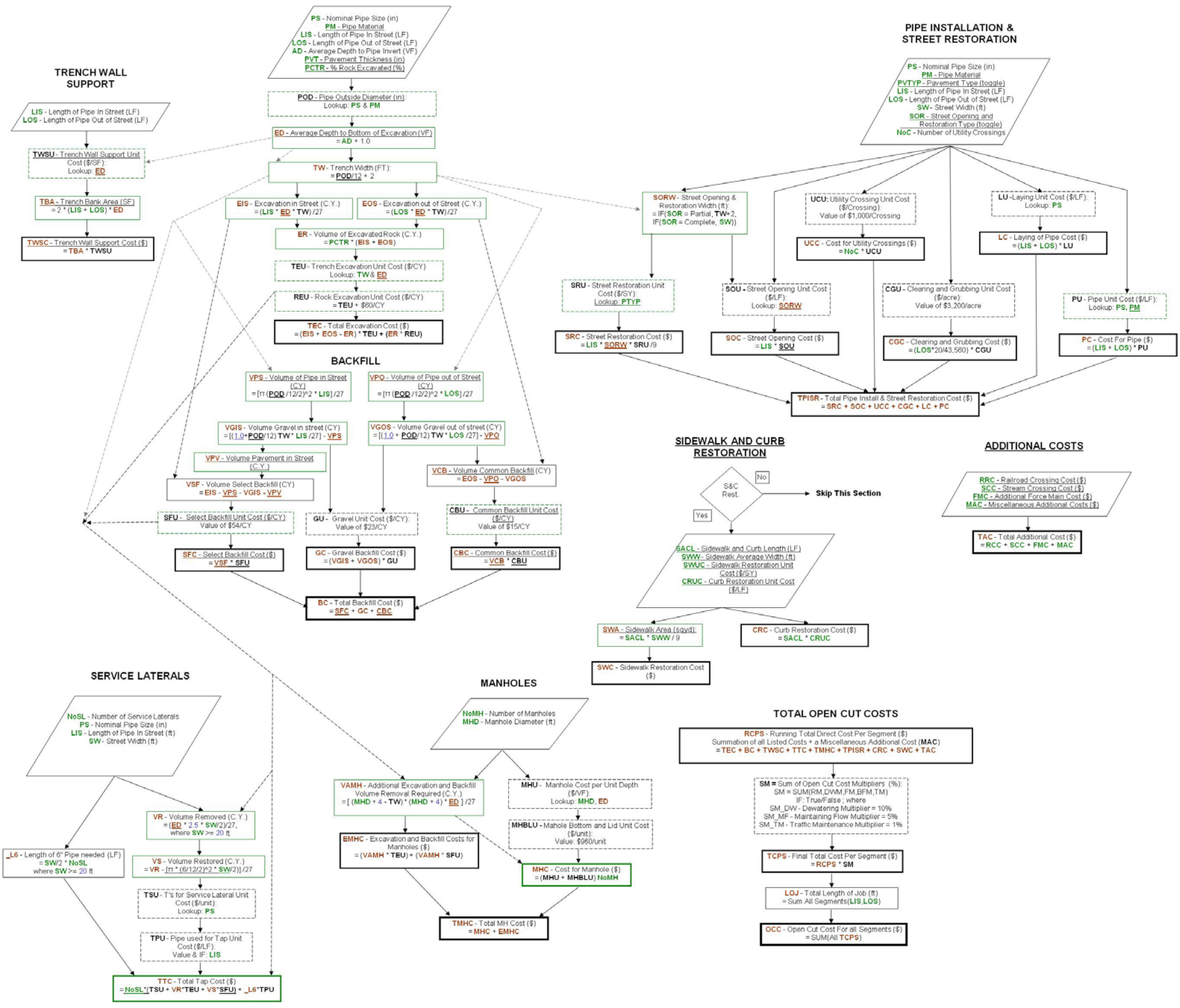


Figure 2.3.5-1 Open Cut Pipe Logic and Flow Diagram

Table 2.3.5-1 Pipe Material Unit Cost Values used in the ACT ($/LF) [ENRCCI 7312; RS MEANS 92.9]

Pipe Diameter (in)	Pipe Classification					
	CL II	CL III	CL IV	CL V	PVC	Ductile Iron
6	-	-	-	-	-	14.6
8	-	-	-	3.3	3.3	16.15
10	-	-	-	5.6	5.6	22
12	-	-	13	14	7.7	26.5
14	-	-	-	-	-	34.5
15	-	-	15	16	10.9	-
16	-	-	-	-	-	37.5
18	-	17	18	20	13.3	47
20	-	-	-	-	-	55
21	-	21	23	28	17.5	-
24	-	27	29	33	23.9	70.5
27	30	31	34	44	24.5	-
30	37	37	41	51	41.4	-
33	42	44	51	62	-	-
36	49	51	61	74	62.6	-
42	66	68	78	101	82.8	-
48	80	85	100	126	109.3	-
54	97	101	123	166	118.9	-
60	123	132	156	184	-	-
66	149	156	190	218	-	-
72	176	175	226	252	-	-
78	209	224	269	306	-	-
84	258	276	330	369	-	-
90	289	308	365	404	-	-
96	320	337	400	442	-	-
102	351	372	444	482	-	-
108	359	409	491	526	-	-

Table 2.3.5-2 Pipe Laying Unit Cost used in ACT [ENRCCI 7312; RS MEANS 92.9]

Pipe Diameter (in)	Cost ($/LF)
0	0.00
6	6.70
8	6.70
10	6.70
12	7.70
15	8.80
18	9.90
21	12.30
24	13.30
27	15.40
30	17.60
33	19.70
36	20.70
42	25.50
48	27.60
54	28.70
60	32.90
66	35.10
72	37.20
78	40.00
84	42.00
90	45.00
96	47.00
102	49.00
108	52.00

Table 2.3.5-3 Box Culvert Unit Costs [ENRCCI 7312; RS MEANS 92.9]

Box Culvert Size	Material Cost ($/LF)	Laying Cost ($/LF)
8'x4'	$395	$23.00
8'x6'	$435	$27.00
8'x8'	$474	$31.00
10'x6'	$553	$30.00
10'x8'	$632	$35.00
10'x10'	$711	$42.00
12'x4'	$632	$27.00
12'x6'	$751	$33.00
12'x8'	$830	$40.00
12'x10'	$909	$49.00
12'x12'	$988	$60.00

Note: Reinforced Concrete Box Sewer per ASTM C 1433

Table 2.3.5-4 Trench Width Values used in ACT [ENRCCI 7312; RS MEANS 92.9]

Pipe Diameter (in)	Range of Trench Depth		
	0' to 10'	11' to 16'	17' to 25'
6	2.5	2.5	2.5
8	2.5	2.5	3
10	2.5	2.5	3
12	2.5	2.5	3
15	3	3.5	3.5
18	3.5	4	4
21	4	4.5	4.5
24	4	4.5	4.5
27	4.5	5	5
30	4.5	5	5
33	5	5.5	5.5
36	5.5	6	6
42	6.5	6.5	6.5
48	7	7	7
54	7.5	7.5	7.5
60	8.5	8.5	8.5
66	9	9	9
72	9.5	9.5	9.5
78	10	10	10
84	10.5	10.5	10.5
90	11	11	11
96	12	12	12
102	12.5	12.5	12.5
108	13	13	13

Table 2.3.5-5 Trench Wall Support Unit Cost Used in ACT [ENRCCI 7312; RS MEANS 92.9]

Excavation Depth (ft)	Unit Cost ($/Bank SF)
5	0.06
6	0.06
7	0.06
8	0.06
9	0.06
10	0.06
11	0.06
12	0.06
13	0.06
14	0.06
15	0.06
16	33
17	33
18	33
19	33
20	33
21	33
22	33
23	33
24	33
25	33

Table 2.3.5-6 Trench Excavation Unit Costs used in the ACT ($/CY) [ENRCCI 7312; RS MEANS 92.9]

Depth (ft)	Trench Width (ft)																
	0	2.5	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
5	0	9	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	0	12	10	9	9	8	-	-	-	-	-	-	-	-	-	-	-
7	0	14	13	12	10	10	9	9	8	8	8	7	7	7	7	6	6
8	0	16	15	13	12	12	10	10	10	9	9	9	8	8	8	8	8
9	0	18	16	14	13	13	12	12	12	11	11	10	10	10	10	10	9
10	0	20	18	16	14	14	13	13	12	11	11	11	10	10	10	10	9
11	0	23	20	17	16	15	14	13	13	12	11	11	11	10	10	10	9
12	0	25	23	19	17	16	15	14	14	13	12	12	11	11	10	10	10
13	0	27	25	21	19	17	16	15	14	13	13	12	12	11	11	10	10
14	0	29	27	24	20	18	17	16	15	14	13	13	12	12	11	11	11
15	0	30	29	25	23	20	18	17	16	15	15	14	13	13	12	12	12
16	0	33	30	27	24	21	20	18	17	16	16	15	14	14	13	13	12
17	0	36	32	28	26	24	21	20	18	18	17	16	15	15	14	14	13
18	0	38	34	29	27	25	23	21	19	19	18	17	16	16	15	15	14
19	0	40	37	30	28	26	24	23	21	20	19	18	18	17	17	16	16
20	0	42	38	33	30	27	26	24	23	22	21	20	19	19	18	17	17
21	0	44	39	36	31	29	27	25	24	23	22	21	20	19	19	18	18
22	0	45	42	37	33	30	28	26	25	24	23	22	21	20	20	19	18
23	0	47	44	39	34	31	29	27	26	24	23	22	22	21	20	20	19
24	0	50	45	40	37	33	30	29	27	26	25	24	23	22	21	21	20
25	0	52	47	42	38	34	32	30	28	27	26	25	24	23	22	22	21

Table 2.3.5-7 Street Opening Unit Costs used in the ACT [ENRCCI 7312; RS MEANS 92.9]

Opening Width (ft)	Cost ($/LF)
2	0
4.5	3.3
5	4.4
5.5	4.4
6	5.6
6.5	6.7
7	6.7
7.5	7.7
8	8.8
8.5	8.8
9	9.9
10	11.0
11	12.1
12	13.2
13	14.3
14	15.4
15	16.5
16	17.6

Table 2.3.5-8 Pipe Tap Unit Cost used in the ACT [ENRCCI 7312; RS MEANS 92.9]

Pipe Diameter (in.)	Cost ($/unit)
8	160
10	165
12	170
15	186
18	191
21	202
24	213
27	234
30	245
33	266
36	292
42	340
48	388

Table 2.3.5-9 Additional Pipe Tap Costs ($/LF) [ENRCCI 7312; RS MEANS 92.9]

In Street?	Cost ($/LF)	Comment
No	38	Under Grass
Yes	65	Under Pavement -granular backfill. For CDF use pipe sheet.

Table 2.3.5-10 Manhole Unit Costs used in ACT [ENRCCI 7312; RS MEANS 92.9]

Manhole Depth (ft.)	MH Diameter (ft.)									
	0	4*	5	6	7	8	9	10	11	12
5	0	$800	$1,500	-	-	-	-	-	-	-
10	0	$1,100	$2,100	$3,300	$3,700	$5,900	$6,500	$6,700	$9,800	$12,000
15	0	$1,500	$2,600	$4,300	$4,900	$7,500	$8,300	$8,500	$12,500	$15,400
20	0	$1,800	$3,100	$5,300	$6,000	$9,000	$10,100	$10,200	$15,100	$18,700
25	0	$2,100	$3,700	$6,200	$7,100	$10,600	$11,900	$11,900	$17,800	$22,100

* Note: The ACT has a four foot diameter manhole as the default manhole diameter suggestion

Table 2.3.5-11 Street Restoration Unit Cost used in ACT [ENRCCI 7312; RS MEANS 92.9]

Name	Total Thickness (in)	Cost ($/SY)	Description
8" Bit.	14	33	6" Stone, 6" Bit. Base, 2" Bit Surface
11.5" Phila. Spec.	17.5	43	Standard Philadelphia Street Section: 6" Stone, 8" Cement Base, 2" Bit. Base, 1.5" Bit Surface

Table 2.3.5-12 Curb and Sidewalk Restoration Unit Costs used in ACT [ENRCCI 7312; RS MEANS 92.9]

Restoration Type	Unit Cost	Description
Curb Restoration ($/LF)	$17	Typical 4” Concrete with 4” of Stone
Sidewalk Restoration ($/SY)	$30	

Table 2.3.5-13 Miscellaneous Installation and Restoration Costs Associated with Open Cut Pipe [ENRCCI 7312; RS MEANS 92.9]

Description	Units	Unit Cost
Select backfill unit cost	$/CY	54
Gravel Unit Cost	$/CY	23
Common Backfill Unit Cost	$/CY	15
Manhole Bottom and Lid Unit Cost	$/unit	960
Utility Crossing/Relocation Unit Cost	$/unit	1000
Clearing and Grubbing Unit Cost	$/acre	3200
Rock Excavation Unit Cost - in add to TEU	$/CY	60

Table 2.3.5-14 Miscellaneous Construction Cost Multipliers used in the ACT [ENRCCI 7312; RS MEANS 92.9]

Category	Added Cost
In Rock (Y/N)?	50.00%
Dewatering Required (Y/N)?	10.00%
Flow Maintenance Required (Y/N)?	5.00%
In Brownfields (Y/N)?	5.00%
Traffic Maintenance Required (Y/N)?	1.00%

Conveyance Pipe O&M Costs

Maintenance of open-cut and trenchless pipes are based upon the same data set, and the costs to maintain both conveyance means can be estimated in a similar manner. The reference for O&M of both is a 2003 Detroit Water and Sewer Department (DWSD) report titled *Wastewater Master Plan Volume 4: Capital Improvements Program*. This report analyzed operation and maintenance of the conveyance pipe in the DWSD system between 1992 and 1996, and developed target maintenance frequency equations for three most important maintenance issues: pipe cleaning, root intrusion removal, and TV inspections. The report also provided an audit of O&M costs and assigned a maintenance unit cost in dollars per linear foot of pipe for each of the three maintenance issues. These values were updated for time and location within the ACT using ENR CCI and RS Means index values respectively.

Similar to the pipe maintenance analysis, an additional analysis of O&M costs related to manhole cleaning was determined in the DWSD report. This value is reported in dollars per manhole per year.

An additional option for calculating O&M costs for conveyance pipe in the ACT is for the user to input their own unit costs. The default configuration is based on the same units used in the DWSD report. Table 2.3.5-15 contains open cut pipe O&M costs.

Table 2.3.5-15 Open Cut Pipe O&M Cost Data [ENRCCI 7312; RS MEANS 92.9]

Detroit Conduit O&M	$/LF-yr	4.00
Detroit Manhole O&M	$/MH-yr	2.60
Detroit O&M ENRCCI		6771.00
Detroit O&M Means		103.90

2.3.6 Pump Stations

For purposes of the ACT, all pump stations were assumed to be constructed as stand-alone structures − not part of a larger treatment or storage facility.

Construction cost estimates including overhead and profit, and indirect costs for three different pump station types were developed: custom built wet-well/dry well, submersible, and deep tunnel dewatering. Deep tunnel dewatering pump stations can be significantly deeper than typical pump stations and will be used to dewater CSO storage tunnels. Custom built wet-well/dry-well and submersible pump stations are typical wet weather pump types, and will be used for collection and interceptor transmission, pumping into and dewatering satellite treatment facilities, and pumping into and through treatment plants. Low, intermediate, and high cost curves were determined for custom built wet-well/dry well and submersible pump stations. The primary factor for selecting a cost curve range is total dynamic head (TDH). For the purposes of cost estimating in the ACT, high cost custom built wet-well/dry well pump stations generally have a TDH greater than 70 feet, whereas high cost submersible pump stations generally have a TDH greater than 50 feet. A secondary factor for selecting a cost curve range is standby power. For the purposes of cost estimating in the ACT, intermediate cost pump stations are generally shallower than high cost pump station and have standby power, whereas low cost pump stations are generally shallower and without standby power.

The ACT provides pump station cost estimates based on the following user inputs:

- Type of pump station including low, intermediate, and high cost range
- Required firm pumping capacity

In addition, the user has the option of adding user defined cost multipliers for pump station facility components which could add to typical pump station costs such as: bar screens, maintenance dewatering pumps, grit removal provisions, odor control, variable speed motors, and special building requirements for motors and electrical controls.

The custom built wet-well/dry-well and submersible pump station cost estimating curves were based on the 2006 text book reference *Pumping Station Design (Third Edition).* The deep tunnel dewatering pump station cost curve was based on a collection of costs for existing and proposed large capacity deep tunnel dewatering pump stations in the United Stated. These costs were in the form of bids and basis of design costs, and a power trendline was developed through the cost data points.

Pump station construction cost data is included in Figure 2.3.6-1.

The design curves for pump stations were developed from Jones et al. *Pumping Station Design (3rd Ed.)*. Cost estimation curves from this publication were developed from a range of pump station installations around the US, and classified as either a custom built wet-well/dry-well facilities (Figure 2.3.6-1) or submersible facilities (Figure 2.3.6-2).

From each of these classifications, a low, intermediate, and high cost curve was developed to encapsulate the range of costs which can be encountered in different pump station applications.

The selection of which curve to use is dependant primarily on depth and secondarily on whether standby power is needed at the station. Table 2.3.6-1 is a matrix for selecting low, intermediate or high cost curves. These curves represent construction costs including contractor's overhead and profit and indirect costs.

In addition, a cost estimation curve was provided for deep tunnel dewatering pump stations (Figure 2.3.6-3). This curve was developed from project cost data of installed dewatering pump stations. (Note: Figure 2.3.6-3 also displays two curves along with equations, developed via the *Pumping Station Design (3rd Ed.)* method. These curves are used for comparison; the ACT only contains one cost estimation curve for deep tunnel dewatering).

Table 2.3.6-1 Cost Curve Selection Matrix for Pump Stations [ENRCCI 8551; RS MEANS 100]

Cost Curve	Depth[1]	Standby Power[2]
High	Deep	Yes or No
Intermediate	Shallow	Yes
Low	Shallow	No

[1]Deep Depths: Submersible (>50' TDH)
Custom-Built Wet Well-Dry Well (>70' TDH)
[2]Standby Power: Back-up generators or dual electrical supply

For custom-built wet well/dry well pumping stations, the selected curves are as follows:

High Cost Curve: $y = 803{,}151x^{0.9002}$
Intermediate Cost Curve: $y = 385{,}002x^{0.8941}$
Low Cost Curve: $y = 182{,}255x^{0.8914}$

For submersible pumping stations, the selected curves are as follows:

High Cost Curve: $y = 1{,}077{,}394x^{0.6158}$
Intermediate Cost Curve: $y = 473{,}381x^{0.6910}$
Low Cost Curve: $y = 207{,}992x^{0.7662}$

For deep tunnel dewatering pumping stations, the equation for the selected curve was:

$$y = 1{,}077{,}394x^{0.6158}$$

For all pump station cost estimate equations, y equals construction cost in dollars, and x equals pump station capacity in MGD.

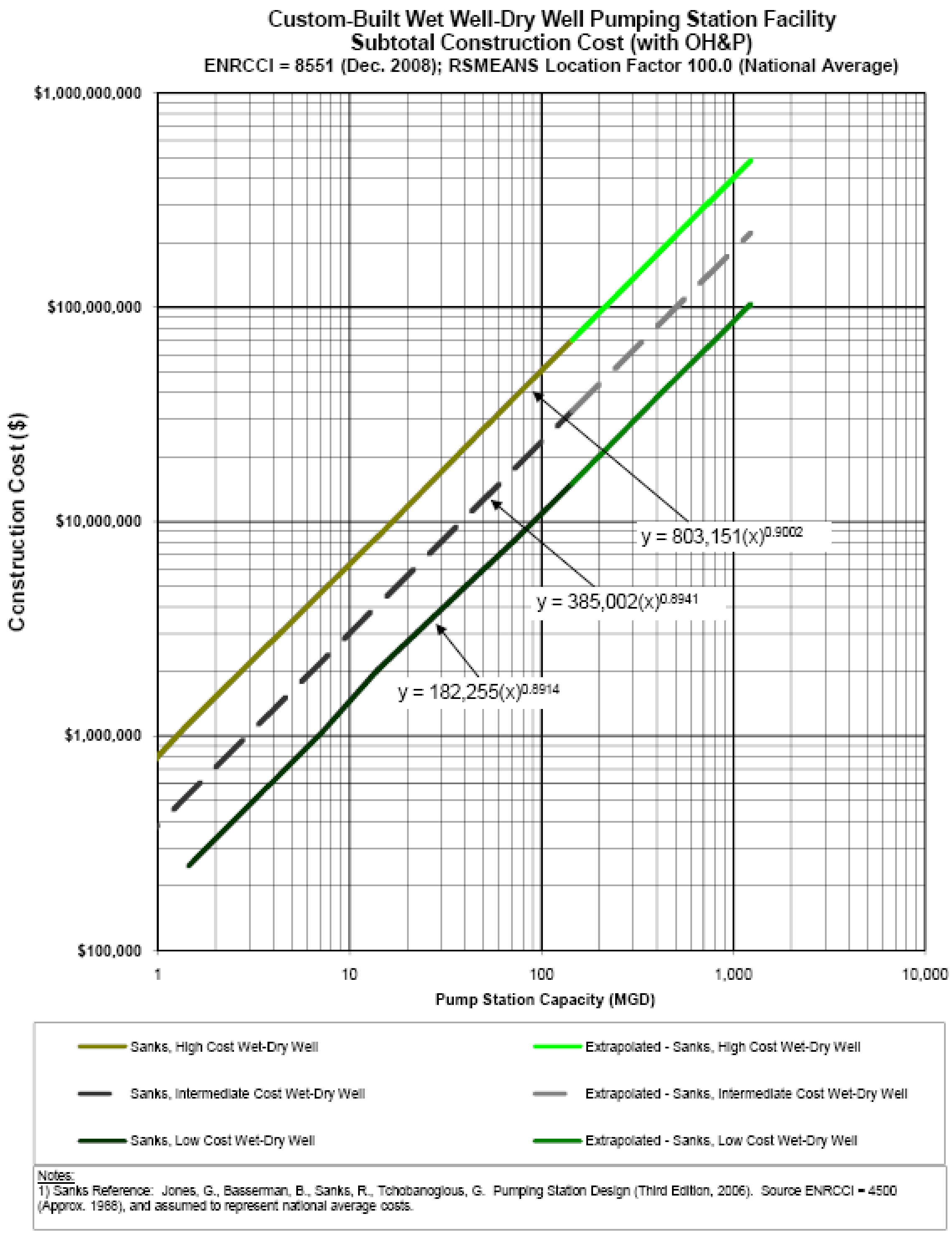


Figure 2.3.6-1 Custom-Built Wet-Well / Dry-Well Pump Station Curves [ENRCCI 8551; RS MEANS 100]

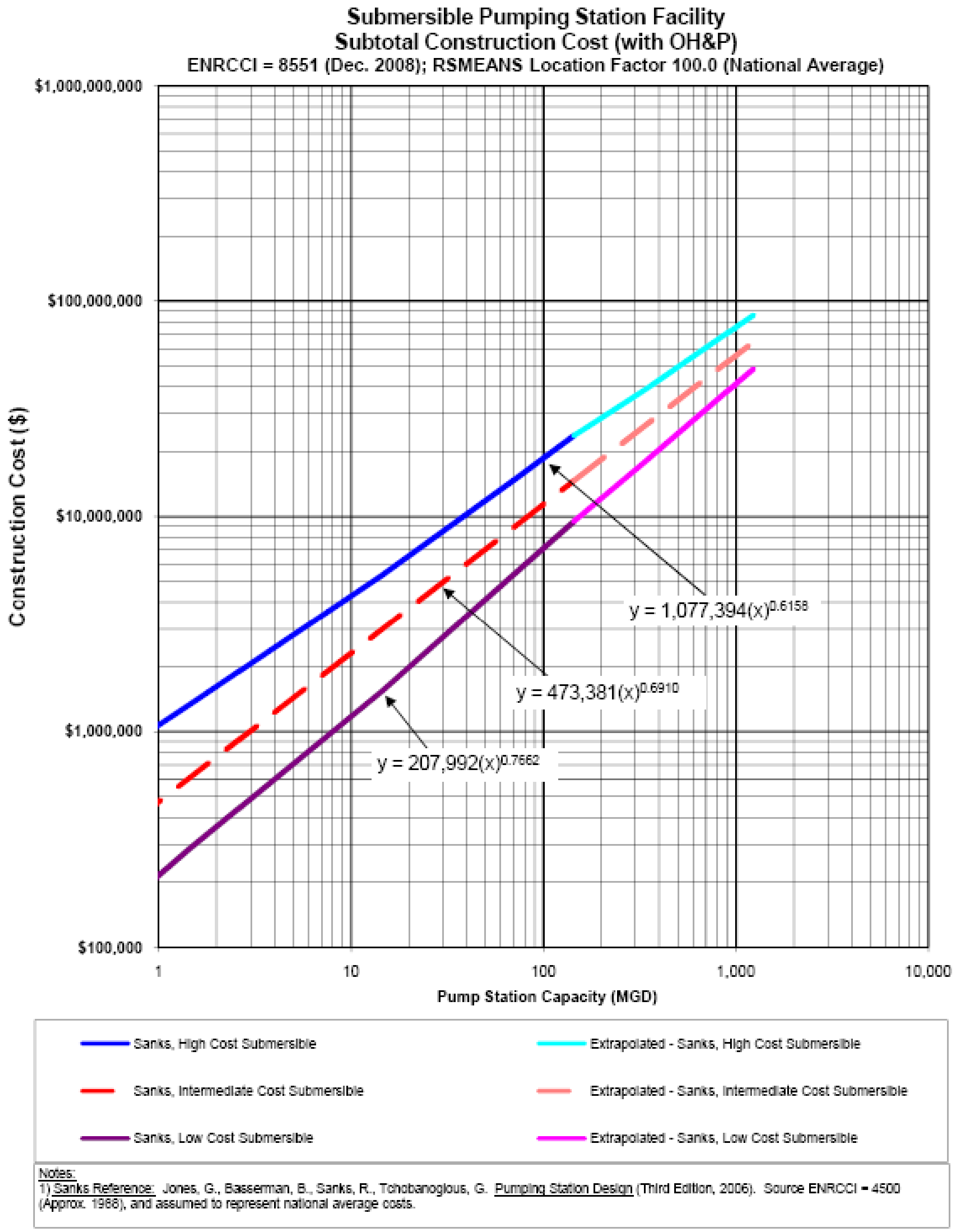
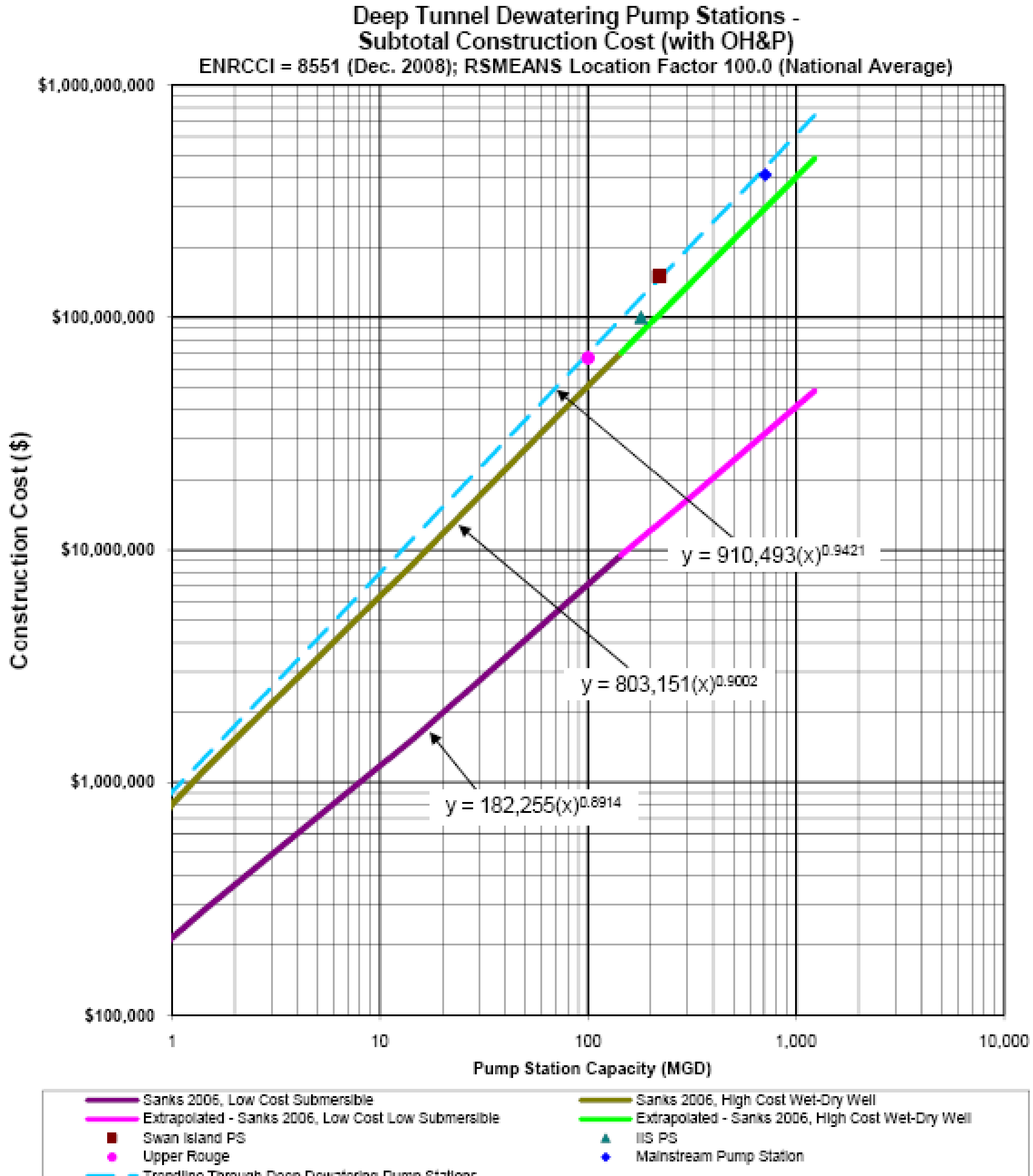


Figure 2.3.6-2 Submersible Pump Station Curves [ENRCCI 8551; RS MEANS 100]



Notes:
1) Sanks Reference: Jones, G., Basserman, B., Sanks, R., Tchobanoglous, G. Pumping Station Design (Third Edition, 2006). Source ENRCCI = 4500 (Approx. 1988), and assumed to represent national average costs.
2) Swan Island Dewatering Pump Station: City of Portland (220 mgd capacity, 150 ft deep); based on correspondence with Corollow Engineers. *Limitations: unknown cost type (bid, bod, etc), unknown year of cost (construction started 2002, ended 2006) assumed 2001.*
3) IIS Pump Dewatering Pump Station: Milwaukee (180 mgd capacity, approx. 300 ft deep); based on Dec. 14, 2007 Black and Veatch Report titled: IIS Pump Station Upgrade Conceptual Design Report Contract NO. J01009E01. *Limitation: basis of design cost.*
4) Upper Rogue Dewatering Pump Station: Detroit (100 mgd capacity, 185 ft deep); based on conceptual design costs determined by CDM in 2005. *Limitation: basis of design cost.*
5) Mainstream Pump Station: Chicago TARP (2 levels of pumps: 710 MGD High TDH, 320 MGD Low TDH; used 710 MGD as the representative capacity); cost estimated from highest of the three lowest bid prices (dated 1979) provided by Chief Engineer at MWRDGC. *Limitations: unknown if costs include excavation and other geotech. unknown which bid won the job.*

Figure 2.3.6-3 Deep Tunnel Dewatering Pump Station Curves [ENRCCI 8551; RS MEANS 100]

Pump Station O&M Costs

Pump station O&M costs are calculated based on three cost components: energy costs, material costs and labor costs. Energy costs are calculated based upon user input values for the annual volume pumped (in mgd), the dynamic head (in feet), the "wire to water" efficiency, and electrical rate (in dollars per kilowatt-hour). The "wire to water" efficiency is the overall efficiency of the pump, motor and variable speed drive. This efficiency is the product of the efficiency percentages of these three components and is a percentage represented as a decimal value.

Three different options can be applied to calculate both material and labor costs for pump stations in the ACT. The first method is derived from USEPA document 430/9-78-009, *Innovative and Alternative Technology Assessment Manual* dated February 1980. This document includes cost curves for both materials and labor annual cost as a function of wastewater flow (in mgd).

The second option for determining costs of pump station material and labor in the ACT was derived from cost data provided by PWD. Labor and material costs were calculated for each of 13 pumping stations based on materials purchased, annual maintenance man hours (including overtime hours) and an average hourly labor rate including fringe benefits applied from actual laborer salary data for calendar year 2007. Also applied to the labor costs is a site specific work overhead percentage. The total annual labor and material costs were plotted individually against the rated pump station capacity (in mgd), and a linear line of best fit of these points determined the labor and materials cost equations.

The final option for calculating O&M costs for pumping stations in the ACT is for the user to input their own cost equation. The default configuration is for a linear cost equation with rated capacity (in mgd) as the independent variable. Figure 2.6.3-4 summarizes the pump station O&M cost curves based on pump station capacity and compares the PWD costs to EPA O&M cost data.

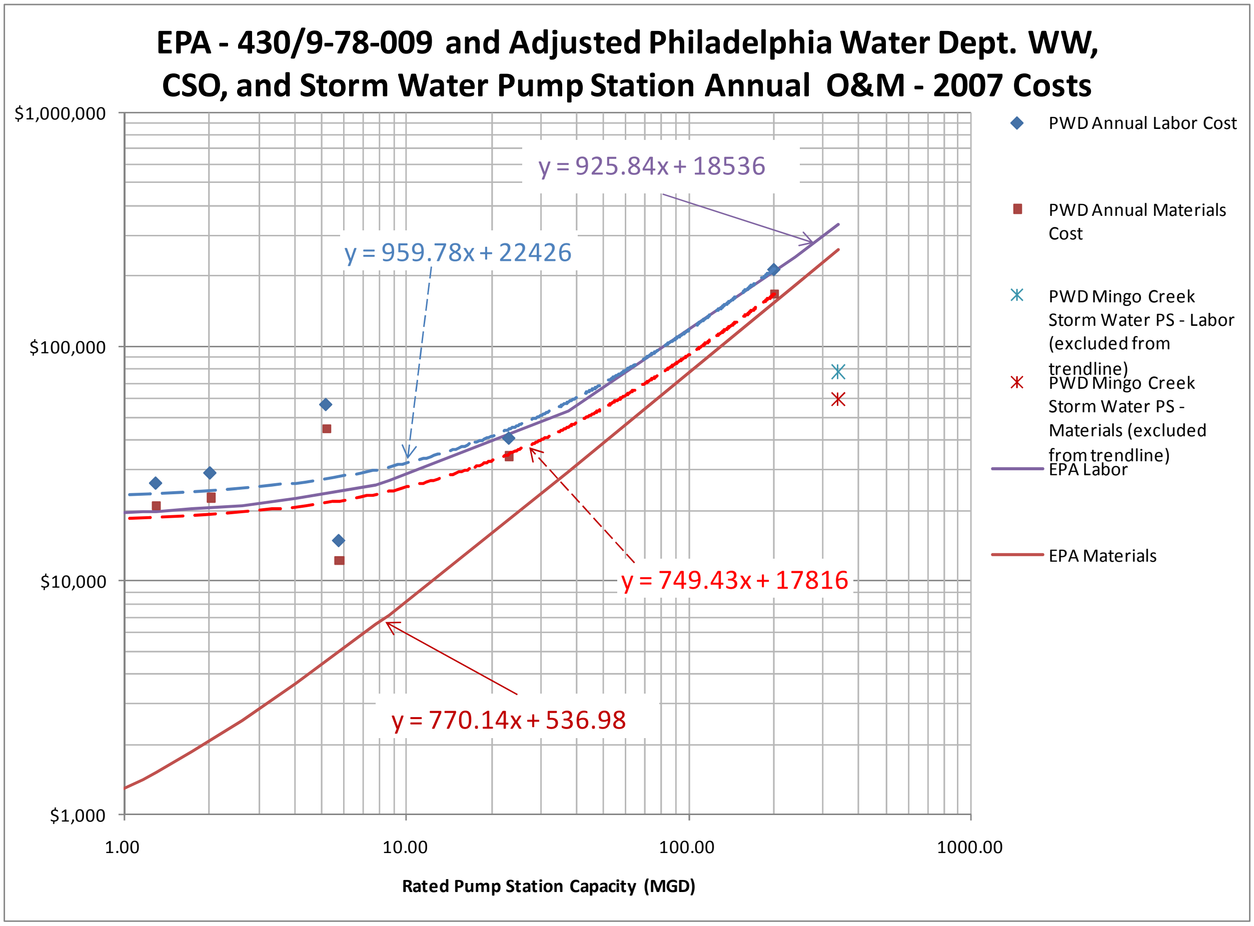


Figure 2.6.3-4 Pump Station Operations and Maintenance Costs [ENRCCI: 7939(PWD), 7966(EPA); RSMeans: 115.2 (PWD), 100.0 (EPA)]

2.3.7 Force Mains

There is not a separate control category for force mains in the ACT. Construction costs for force mains are to be calculated in the same manner as open-cut pipe, with the exception that the construction cost will assume installation of ductile iron pipe. Air release valves can be added as additional costs in the open-cut pipe cost estimate worksheet in the ACT.

2.3.8 Short-Bore Tunnel (Trenchless)

Trenchless methods of pipeline construction can be superior to open cut methods, or the only option for special applications. Trenchless methods result in less surface disturbance, minimize pavement damage, and reduce utility conflicts, which is important when working in urban areas. Trenchless methods should be used when crossing highways, railroads, and other obstacles that are poorly suited for open cut methods. Trenchless methods might be less expensive than open cut methods depending on various factors including pipe depth, pipe diameter, distance between pits, geology, the bidding environment, etc. Trenchless methods can be used for pipe depths deeper than what is feasible for open cut methods.

Many trenchless methods exist; however, the two most applicable methods were included in the ACT for cost estimating purposes: Microtunneling, and Pipe Jacking. These two methods work by pushing segments of pipe through the ground from a Jacking Pit. Microtunneling utilizes a micro-tunnel boring machine (MTBM) for advancement at the front of the pipe segments, whereas Pipe Jacking utilizes an open face. Pipe Jacking is typically a little less expensive, but because it utilizes an open face it should not be used below the groundwater table. Pipe Jacking is less favored than Microtunneling for diameters less than 48 inches and greater than 72 inches. For cost estimating purposes it is reasonable to not consider Pipe Jacking, and assume that Microtunneling will be used on all trenchless jobs. Both techniques require a Receiving Pit for retrieving equipment at the end of a pipe run. Significant cost savings can occur when two or more pipe runs share the same receiving or jacking pit.

Trenchless costs are sensitive to the geology at the pit locations and along the pipe run. For planning level cost estimation, basic geological conditions can be identified along the pipe run (e.g. soil, rock, and mixed), and in the pits (soil, rock). Mixed face conditions occur when both rock and soil conditions are experienced along the pipe run. Mixed face conditions should be avoided when possible, and will increase the uncertainty of the cost estimate. Steel pipe is recommended in mixed face conditions.

The ACT provides construction cost estimates for pipelines constructed by trenchless methods based on the following user inputs:

- Pipeline
    - Method (Microtunneling or Pipe Jacking)
    - Nominal Pipe Size (ranging between 24 to 144 inches, but extreme minimum and maximum sizes are not feasible for all applications)
    - Pipe Material (RCP, HOBAS, Composite FRP, Steel)
    - Pipe Length (distance between pits)
    - Ground Type (Soil, Rock, Mixed)
- Jacking and Receiving Pits

- Depth of Soil (i.e. depth from the ground surface to the bottom of excavation in soil)
- Depth of Rock (i.e. depth from the bottom of excavation in soil to the bottom of excavation in rock)
- Manhole at Pit (yes, or no)

Planning level trenchless unit costs are presented in Tables 2.3.8-1 through 2.3.8-10 and are in terms of direct construction costs (i.e. materials, labor, and equipment), and do not include contractor's overhead and profit and indirect costs.

The total direct construction cost estimate for a trenchless pipeline is determined by the summation of the following cost groups: piping, pits, and manholes or just backfill. The piping costs listed by the soil group are complete and include the pipe material costs. Pit costs are determined by summing the Set Floor, Thrust Wall & Jacking Frames cost, cost per vertical foot in soil, and additional cost per vertical foot in rock. More specifically, costs per vertical foot are calculated separately for each depth group. When in rock, the cost per vertical foot in soil and additional cost in rock is summed together. The manhole costs per vertical foot are complete. If a manhole is not built the backfill cost per vertical foot should be used.

Trenchless tunneling costs ultimately depend on site specific and local geotechnical conditions, and other factors; the planning level unit costs presented in Tables 2.3.8-1 through 2.3.8-10 represent optimum conditions and other assumptions:

- Planning level classifications of geotechnical soil conditions were used: soil, rock, mixed face.
- Ground improvement costs were not included.
- Production rates reflect work in urban streets with timely delivery of materials.
- Jacking and receiving pits were estimated using soldier piles and lagging for earth support.
- Rock was assumed to be below 15,000 psi compressive strength.
- Risk of boulders and manmade obstructions were not considered.
- Dewatering costs were excluded.

The planning level unit costs presented in Tables 2.3.8-1 through 2.3.8-10 were developed by summing numerous direct unit construction costs (e.g. pipe material costs, equipment and labor costs for soil excavation). The logic for assembling the costs was based on engineering judgment and current industry practices. Unit cost sources and methods include:

- Labor Costs
    - Labor rates for Philadelphia.
    - Workman's compensation, liability insurance, and taxes were included in the labor rates.
    - Provisions for some overtime were included.
    - The following were excluded: stewards, surveyors, costs for off-shift, 10 hour shifts, and weekend work.
    - Crew size based on assumed collective bargaining coverage for this type of work.

- Equipment and operating costs represent compiled "owned" equipment rates for the Northeast area of the country.
- Material quotations were solicited from various vendors and represent budget estimates.

General guidelines for using the trenchless unit costs include the following:

- Mixed face areas should be avoided if possible; tunneling at a deeper depth in rock is preferred.
- Tunneling in "mixed face" conditions if necessary, should be limited to steel pipe as the machine tends to deflect in the interface areas, thus stressing the joints on concrete or Hobas type pipes.
- Pipe runs with diameters less than 36 inches should be limited in length to less than 500 feet, due to the inability to remove intermediate jacking stations.
- Small diameter concrete or clay pipes should be limited to 400 feet.
- Hobas discourages pipes larger than 84 inches from being used for direct microtuneling or jacking as the bell / gasket bank will deform on the larger sizes.
- Diameters greater than 108 inches should not be "jacked" using open face machines, TBM's should be employed and segments should be considered.
- Shafts deeper than 30 feet to 50 feet should be constructed using circular caissons, which can ultimately be used as the permanent access.
- Tunneling in rock should be limited to machines 60 inches and above in diameter, this is due to face access for cutter head replacement and the limited power of the smaller machines.

Table 2.3.8-1 Microtunneling: Reinforced Concrete Non-Pressure Pipe Unit Costs used in the ACT [ENRCCI 8578; RS MEANS 113.2]

Lining system: R. Concrete Non-Pressure Pipe

Pipe Internal Diameter	Pipe Material Unit Cost	Soil				Rock				Mixed Ground			
		Short Range 150-300’	Medium Range 300-600’	Long Range 600-1000’	Extra Long Range >1000’	Short Range 150-300’	Medium Range 300-600’	Long Range 600-1000’	Extra Long Range >1000’	Short Range 150-300’	Med Range 300-600’	Long Range 600-1000’	Extra Long Range >1000’
(Inches)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)
24	160	558	448	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
30	140	581	472	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
36	180	611	501	N/R	N/R	688	578	N/R	N/R	650	540	N/R	N/R
42	200	715	580	553	511	772	637	610	568	744	609	582	540
48	230	788	652	629	586	868	733	709	666	828	693	669	626
54	270	971	792	752	699	1,095	917	877	824	1,033	855	815	762
60	310	1,035	857	824	768	1,171	992	960	904	1,103	925	892	836
66	360	1,159	956	919	855	1,305	1,103	1,066	1,002	1,232	1,030	993	929
72	410	1,322	1,119	1,085	1,020	1,602	1,399	1,365	1,300	1,462	1,259	1,225	1,160
78	480	1,451	1,242	1,211	1,142	1,754	1,536	1,504	1,436	1,603	1,389	1,358	1,289
84	570	1,644	1,434	1,410	1,339	2,105	1,895	1,871	1,800	1,875	1,665	1,641	1,570
90	630	1,962	1,712	1,682	1,597	2,333	2,083	2,053	1,969	2,148	1,898	1,868	1,783
96	690	2,091	1,842	1,812	1,727	3,167	2,917	2,888	2,803	2,629	2,380	2,350	2,265
108	950	2,711	2,619	2,416	2,380	3,638	3,545	3,342	3,306	3,175	3,082	2,879	2,843
120	1,300	3,310	3,216	2,973	2,933	4,395	4,301	4,058	4,018	3,853	3,759	3,516	3,476
144	2,060	4,344	4,294	4,032	3,998	5,680	5,630	5,367	5,333	5,012	4,962	4,700	4,666

Note: “N/R” indicates configurations which are not recommended for alternatives.

Table 2.3.8-2 Microtunneling: HOBAS GRP Pipe Unit Costs used in the ACT [ENRCCI 8578; RS MEANS 113.2]

Lining system: HOBAS GRP Pipe	Pipe Internal Diameter	Pipe Material Unit Cost	Soil				Rock				Mixed			
			Short Range 150-300’	Medium Range 300-600’	Long Range 600-1000’	Extra Long Range >1000’	Short Range 150-300’	Medium Range 300-600’	Long Range 600-1000’	Extra Long Range >1000’	Short Range 150-300’	Medium Range 300-600’	Long Range 600-1000’	Extra Long Range >1000 ft
	(Inches)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)
	24	198	618	508	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
	30	264	686	577	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
	36	345	771	661	N/R	N/R	847	738	N/R	N/R	809	700	N/R	N/R
	42	420	928	793	766	724	986	850	823	781	957	822	795	753
	48	476	1025	890	887	823	1106	971	947	904	1066	931	917	864
	54	571	1261	1083	1044	990	1387	1208	1168	1115	1324	1146	1106	1053
	60	635	1348	1170	1137	1081	1484	1305	1273	1217	1416	1238	1205	1149
	66	745	1530	1327	1290	1226	1676	1473	1437	1373	1603	1400	1364	1300
	72	810	1706	1502	1468	1403	1985	1782	1748	1683	1846	1642	1608	1543
	78	900	1852	1642	1612	1543	2146	1937	1906	1837	1999	1790	1759	1690
	84	1000	2051	1841	1817	1746	2512	2302	2278	2207	2282	2072	2048	1977

Note: “N/R” indicates configurations which are not recommended for alternatives.

Table 2.3.8-3 Microtunneling: Composite FRP Pipe Unit Costs used in the ACT [ENRCCI 8578; RS MEANS 113.2]

Lining System: Composite FRP Pipe

Pipe Internal Diameter	Pipe Material Unit Cost	Soil				Rock				Mixed			
		Short Range 150-300’	Medium Range 300-600’	Long Range 600-1000’	Extra Long Range >1000’	Short Range 150-300’	Medium Range 300-600’	Long Range 600-1000’	Extra Long Range >1000’	Short Range 150-300’	Medium Range 300-600’	Long Range 600-1000’	Extra Long Range >1000’
(Inches)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)
24	116	514	404	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
30	152	593	484	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
36	182	613	503	N/R	N/R	690	580	N/R	N/R	651	541	N/R	N/R
42	223	738	603	576	534	795	660	633	591	766	631	604	562
48	254	812	676	653	610	892	757	733	690	852	717	693	650
54	314	1015	836	796	743	1139	961	921	868	1077	899	859	806
60	346	1071	893	860	804	1207	1028	996	940	1139	960	928	872
66	398	1197	994	957	893	1343	1141	1104	1040	1270	1067	1030	966
72	434	1346	1143	1109	1044	1626	1423	1389	1324	1486	1283	1249	1184
78	490	1461	1252	1221	1152	1764	1546	1514	1446	1612	1399	1367	1299
84	522	1596	1386	1362	1291	2057	1847	1823	1752	1827	1617	1593	1522
90	613	1945	1695	1665	1580	2316	2066	2036	1952	2130	1880	1850	1766
96	672	2073	1824	1794	1709	3149	2899	2870	2785	2611	2362	2332	2247
110	770	2531	2439	2236	2200	3458	3365	3162	3126	2994	2902	2699	2663

Note: “N/R” indicates configurations which are not recommended for alternatives.

Table 2.3.8-4 Microtunneling: Steel Pipe Unit Costs used in the ACT [ENRCCI 8578; RS MEANS 113.2]

Lining system: Steel Pipe	Pipe Internal Diameter	Pipe Material Unit Cost	Soil				Rock				Mixed			
			Short Range 150-300’	Medium Range 300-600’	Long Range 600-1000’	Extra Long Range >1000’	Short Range 150-300’	Medium Range 300-600’	Long Range 600-1000’	Extra Long Range >1000’	Short Range 150-300’	Medium Range 300-600’	Long Range 600-1000’	Extra Long Range >1000’
	(Inches)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)
	24	124	544	434	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
	30	136	559	449	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
	36	148	575	465	N/R	N/R	651	541	N/R	N/R	613	503	N/R	N/R
	42	172	681	546	518	477	738	603	576	534	710	575	547	506
	48	198	748	612	589	546	828	693	670	627	788	653	630	587
	54	248	939	761	721	668	1064	886	846	793	1002	824	784	731
	60	299	1012	834	802	746	1148	970	938	881	1080	902	870	814
	66	353	1138	935	898	834	1285	1082	1045	981	1212	1009	972	908
	72	409	1304	1102	1068	1003	1585	1382	1348	1283	1445	1242	1208	1143
	78	472	1424	1215	1184	1115	1718	1509	1478	1409	1571	1362	1331	1262
	84	536	1587	1378	1353	1282	2048	1839	1814	1743	1818	1609	1584	1513
	90	571	1877	1627	1597	1513	2248	1998	1969	1884	2063	1813	1783	1699
	96	599	1971	1721	1692	1607	3047	2797	2767	2683	2509	2259	2230	2145
	108	772	2447	2355	2152	2116	3374	3281	3079	3043	2911	2818	2616	2580
	120	1033	3004	2910	2667	2627	4090	3996	3753	3713	3547	3453	3210	3170
	144	1199	3430	3381	3118	3084	4766	4716	4474	4419	4098	4049	3796	3752

Note: “N/R” indicates configurations which are not recommended for alternatives.

Table 2.3.8-5 Pipe Jacking: Reinforced Concrete Non-Pressure Pipe Unit Costs used in the ACT [ENRCCI 8578; RS MEANS 113.2]

Lining system: Reinforced Concrete Non-Pressure Pipe

Pipe Internal Diameter	Pipe Material Unit Cost	Soil				Rock				Mixed			
		Short Range 150-300'	Medium Range 300-600'	Long Range 600-1000'	Extra Long Range >1000'	Short Range 150-300'	Medium Range 300-600'	Long Range 600-1000'	Extra Long Range >1000'	Short Range 150-300'	Medium Range 300-600'	Long Range 600-1000'	Extra Long Range >1000'
(Inches)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)
24	160	530	420	N/R	N/R	663	525	N/R	N/R	N/R	N/R	N/R	N/R
30	140	554	444	N/R	N/R	693	555	N/R	N/R	N/R	N/R	N/R	N/R
36	180	583	473	N/R	N/R	729	591	N/R	N/R	N/R	N/R	N/R	N/R
42	200	682	546	519	477	853	683	649	596	767	614	584	537
48	230	747	611	588	544	934	764	735	680	840	687	662	612
54	270	919	740	700	647	1149	925	875	809	1034	833	788	728
60	310	979	800	768	711	1224	1000	960	889	1101	900	864	800
66	360	1099	896	859	795	1374	1120	1074	994	1236	1008	966	894
72	410	1123	1033	999	934	1404	1291	1249	1168	1263	1162	1124	1051
78	480	1362	1151	1120	1051	1703	1439	1400	1314	1532	1295	1260	1182
84	570	1531	1321	1296	1225	1914	1651	1620	1531	1722	1486	1458	1378
90	630	1812	1562	1532	1447	2265	1953	1915	1809	2039	1757	1724	1628
96	690	1926	1675	1645	1560	2408	2094	2056	1950	2167	1884	1851	1755
108	950	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
120	1300	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
144	2060	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R

Note: “N/R” indicates configurations which are not recommended for alternatives.

Table 2.3.8-6 Pipe Jacking: Reinforced Concrete Non-Pressure Pipe Unit Costs used in the ACT [ENRCCI 8578; RS MEANS 113.2]

Lining system: HOBAS GRP Pipe

Pipe Internal Diameter	Pipe Material Unit Cost	Soil				Rock				Mixed			
		Short Range 150-300'	Medium Range 300-600'	Long Range 600-1000'	Extra Long Range >1000'	Short Range 150-300'	Medium Range 300-600'	Long Range 600-1000'	Extra Long Range >1000'	Short Range 150-300'	Medium Range 300-600'	Long Range 600-1000'	Extra Long Range >1000'
(Inches)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)
24	198	590	480	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
30	264	659	549	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
36	345	743	633	N/R	N/R	929	791	N/R	N/R	836	712	N/R	N/R
42	420	895	759	732	690	1119	949	915	863	1007	854	824	776
48	476	984	849	825	782	1230	1061	1031	978	1107	955	928	880
54	571	1210	1031	991	938	1513	1289	1239	1173	1361	1160	1115	1055
60	635	1292	1113	1081	1024	1615	1391	1351	1280	1454	1252	1216	1152
66	745	1470	1266	1229	1165	1838	1583	1536	1456	1654	1424	1383	1311
72	810	1620	1416	1382	1317	2025	1770	1728	1646	1823	1593	1555	1482
78	900	1762	1552	1521	1452	2203	1940	1901	1815	1982	1746	1711	1634
84	1000	1938	1728	1703	1632	2423	2160	2129	2040	2180	1944	1916	1836

Note: “N/R” indicates configurations which are not recommended for alternatives.

Table 2.3.8-7 Pipe Jacking: Composite FRP Pipe Unit Costs used in the ACT [ENRCCI 8578; RS MEANS 113.2]

Lining System: Composite FRP Pipe	Pipe Internal Diameter	Pipe Material Unit Cost	Soil				Rock				Mixed			
			Short Range 150-300'	Medium Range 300-600'	Long Range 600-1000'	Extra Long Range >1000'	Short Range 150-300'	Medium Range 300-600'	Long Range 600-1000'	Extra Long Range >1000'	Short Range 150-300'	Medium Range 300-600'	Long Range 600-1000'	Extra Long Range >1000'
	(Inches)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)
	24	116	486	376	N/R	N/R	619	481	N/R	N/R	N/R	N/R	N/R	N/R
	30	152	566	456	N/R	N/R	705	567	N/R	N/R	N/R	N/R	N/R	N/R
	36	182	585	475	N/R	N/R	731	593	N/R	N/R	N/R	N/R	N/R	N/R
	42	223	705	569	542	500	875	705	671	619	790	637	606	559
	48	254	771	635	612	568	958	788	759	704	864	711	686	636
	54	314	963	784	744	691	1193	969	919	853	1078	877	832	772
	60	346	1015	836	804	747	1260	1036	996	925	1137	936	900	836
	66	398	1137	934	897	833	1412	1158	1112	1032	1274	1046	1004	932
	72	434	1147	1057	1023	958	1427	1315	1272	1191	1287	1186	1147	1074
	78	490	1372	1161	1130	1061	1712	1448	1410	1323	1542	1304	1270	1192
	84	522	1483	1273	1248	1177	1866	1603	1572	1483	1674	1438	1410	1330
	90	613	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
	96	672	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
	110	770	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R

Note: “N/R” indicates configurations which are not recommended for alternatives.

Table 2.3.8-8 Pipe Jacking: Steel Pipe Unit Costs used in the ACT [ENRCCI 8578; RS MEANS 113.2]

Lining system: Steel Pipe	Pipe Internal Diameter	Pipe Material Unit Cost	Soil				Rock				Mixed			
			Short Range 150-300'	Medium Range 300-600'	Long Range 600-1000'	Extra Long Range >1000'	Short Range 150-300'	Medium Range 300-600'	Long Range 600-1000'	Extra Long Range >1000'	Short Range 150-300'	Medium Range 300-600'	Long Range 600-1000'	Extra Long Range >1000'
	(Inches)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)	($/LF)
	24	124	532	422	N/R	N/R	665	528	N/R	N/R	599	475	N/R	N/R
	30	136	547	437	N/R	N/R	684	546	N/R	N/R	615	492	N/R	N/R
	36	148	562	452	N/R	N/R	703	565	N/R	N/R	632	509	N/R	N/R
	42	172	669	534	507	465	836	668	634	581	753	601	570	523
	48	198	707	571	548	505	884	714	685	631	795	642	617	568
	54	248	887	708	669	615	1109	885	836	769	998	797	753	692
	60	299	957	778	745	689	1196	973	931	861	1077	875	838	775
	66	353	1078	875	838	774	1348	1094	1048	968	1213	984	943	871
	72	409	1219	1015	981	916	1524	1269	1226	1145	1371	1142	1104	1031
	78	472	1334	1124	1093	1024	1668	1405	1366	1280	1501	1265	1230	1152
	84	536	1475	1265	1240	1168	1844	1581	1550	1460	1659	1423	1395	1314
	90	571	1727	1477	1447	1362	2159	1846	1809	1703	1943	1662	1628	1532
	96	599	1805	1555	1525	1440	2256	1944	1906	1800	2031	1749	1716	1620
	108	772	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
	120	1033	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
	144	1199	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R

Notes: “N/R” indicates configurations which are not recommended for alternatives.

Table 2.3.8-9 Jacking Pit Unit Cost Values used in the ACT [ENRCCI 8578; RS MEANS 113.2]

Pipe Diameter Range (inch)	Jacking Pit Footprint - Length x Width (ft x ft)	Receiving Pit Footprint - Length x Width (ft x ft)	Set Floor, Thrust Wall & Jacking Frames (Receiving Pit Cost is 75% of Jacking Pit Cost)	Jacking Pit in Soil (Receiving Pit Cost is 75% of Jacking Pit Cost)					Additional Cost if Pit in Rock (Receiving Pit Cost is 75% of Jacking Pit Cost)				
				0-30' Deep ($/VF)	31-60' Deep ($/VF)	61-90' Deep ($/VF)	91-120' Deep ($/VF)	121-150' Deep ($/VF)	0-30' Deep ($/VF)	31-60' Deep ($/VF)	61-90' Deep ($/VF)	91-120' Deep ($/VF)	121-150' Deep ($/VF)
24 - 36	16 x 10	12 x 10	24,000	3,330	3,700	4,070	4,810	5,920	720	800	880	960	1,040
42 - 54	18 x 12	12 x 12	32,000	4,050	4,500	4,950	5,850	7,200	1,080	1,200	1,320	1,440	1,560
60 - 72	20 x 14	14 x 14	39,000	4,860	5,400	5,940	7,020	8,640	1,440	1,600	1,760	1,920	2,080
78 - 84	24 x 14	14 x 14	45,000	5,670	6,300	6,930	8,190	10,080	1,800	2,000	2,200	2,400	2,600
90 - 108	26 x 16	16 x 16	74,000	7,020	7,800	8,580	10,140	12,480	2,790	3,100	3,410	3,720	4,030
120 - 144	28 x 20	20 x 20	96,000	8,370	9,300	10,230	12,090	14,880	3,780	4,200	4,620	5,040	5,460

Table 2.3.8-10 Jacking Pit Manhole, Backfill & Bracing Removal Unit Cost Values used in the ACT [ENRCCI 8578; RS MEANS 113.2]

Pipe Diameter Range (inch)	Manhole, Backfill & Bracing Removal						Just Backfill				
	Manhole Diameter (ft)	0-30' Deep ($/VF)	31-60' Deep ($/VF)	61-90' Deep ($/VF)	91-120' Deep ($/VF)	121-150' Deep ($/VF)	0-30' Deep ($/VF)	31-60' Deep ($/VF)	61-90' Deep ($/VF)	91-120' Deep ($/VF)	121-150' Deep ($/VF)
24 - 36	6	1,627	1,350	1,485	1,755	2,025	675	750	825	975	1,125
42 - 54	8	2,350	1,800	1,980	2,340	2,700	900	1,000	1,100	1,300	1,500
60 - 72	10	3,517	2,450	2,695	3,185	3,675	1,125	1,250	1,375	1,625	1,875
78 - 84	12	4,633	3,300	3,630	4,290	4,950	1,350	1,500	1,650	1,950	2,250
90 - 108	16	6,608	4,675	5,143	6,078	7,013	1,688	1,875	2,063	2,438	2,813
120 - 144	20	8,833	6,000	6,600	7,800	9,000	2,250	2,500	2,750	3,250	3,750

2.3.9 Conventional Tunnel - Storage/Conveyance

The term Conventional Tunnel refers to large diameter tunnels created by tunnel boring machines (TBM) that are advanced from the TBM location, unlike Short-Bore Tunnels (Trenchless) that are advanced from the pit location.

Supplemental materials outside of the ACT were used to determine key components of a complete CSO storage tunnel alternative cost, including cost estimates for Conventional Tunnels in Rock and Primary Tunnel components, and some Secondary Tunnel Alternative components. The following sections document the supplemental materials and ACT modules used to determine a complete CSO storage tunnel alternative cost.

The Primary Tunnel components include the following:

- Shafts
  - Work
  - Maintenance
  - Vent
  - Access
- CSO Tunnel Components
  - CSO vortex near surface structure
  - CSO drop shaft structure
  - Adits (tunnel connecting CSO drop shafts to the storage tunnel)

The Secondary Tunnel Alternative components include the following:

- New or modified CSO regulating structures
- Consolidation piping – near surface piping that directs flow from the CSO regulators to the CSO vortexing/drop structures
- Tunnel dewatering pump station

Supplemental Materials - Conventional Tunnel in Rock and Primary Tunnel Components

A tunnel costing spreadsheet was developed to estimate the cost of conventional rock tunnels and primary tunnel components. The key user inputs used for determining a tunnel cost estimate include:

- Tunnel
  - Tunnel Inside Diameter
  - Tunnel Length
  - Lining Type (Cast in place, or Segmental)
  - Corrosion Protection Liner (Yes, or No)
- Shafts (numerous types)
  - Number of shafts
  - Shaft diameter
  - Depth in soil
  - Depth in rock

- CSO Tunnel Components
    - Design flowrate

It should be noted and emphasized that there is no industry standard cost estimating tool for rock tunnel construction available at this time (i.e. equivalent of RS Means®, Mining Cost Services® etc.). This is due to the highly sensitive nature of the cost of tunneling relative to geology, depth, groundwater issues, the end use and application of the structures, among many other labor, finance and risk allocation issues. The result is that there is no uniform way of evaluating the cost across the industry.

Therefore, the user of the spreadsheet should be extremely careful and cognizant of the implication of each factor on the tunneling method and related cost. As such, the program can render a reasonable planning level estimate of the potential tunnel cost if it is used within the ranges specified herein. For variations beyond these values, the formulas will need to be revised.

The estimated cost is based on the assumption of using a tunnel boring machine (TBM) (open or shielded) as the tunneling method. The TBM deep tunnel drilling will be assumed to be in full rock face, which offers two choices of ground support, including temporary support plus cast in place (CIP) as well as Concrete Segmental lining. Most of the tunnel cost elements were based on a conventional tunnel in New York, detailed cost estimate for a conventional tunnel in St. Louis, MO, and general rule of thumb values for tunnel construction.

The formulas used to adjust the estimated cost of tunnel are empirical and in general vary by using power functions. The adjustment for diameter is considered to be proportional with tunnel diameter or linear function (power of 1) with the ratio of tunnel diameters. The adjustment for tunnel length is done based on a power function to account for the spread of the fixed cost items over the longer tunnel, meaning a gradual decrease in estimated cost per foot as the tunnel gets longer. Although these powers are variable and can be changed, they have been set to 0.3-0.25 for excavation and final lining, respectively. The values used are based on personal judgment of the overall trend in the adjustment curve.

Costs associated with site Mobilization/Demobilization are estimated based on the tunnel diameter and length. The length of the tail or starter tunnel in rock can be selected as needed and again a rule of thumb for this level of planning is to use a minimum of 10 times the tunnel excavated diameter to allow for assembly of the machine and its back up system. Cost per unit for hand mining of the starter/tail tunnel is calculated by the spreadsheet and the length is deducted from the length of the bored tunnel.

A short list of assumption behinds the conventional tunnel cost estimate is listed as follows:

- Construction of main tunnel to be performed by TBMs.
- Tunnel cost varies proportional to tunnel diameter.
- Tunnel cost will decrease with tunnel length within a certain range. The rate of decrease is estimated by using a power function (power of 0.25-0.3).

- Tunnel is in uniform ground. Mixed face conditions are not accounted for and it is recommended to choose the vertical alignment to stay within rock.
- Variation of rock types is acceptable.
- Tunneling is done with a circular profile and by a tunnel boring machine.
- Open hard rock TBMs will be used for excavation of rock while installing temporary support, and followed by CIP concrete lining. Alternatively, one pass system can be used with double shield machine and concrete segmental lining. Additional cost of tunneling is reflected in the cost per foot of segments.
- Access to the tunnel is through the work shaft and not portals.
- No exceptional or extraordinary complications exist in the ground, normal variation of lithology and some structural features are included. Unusual conditions with high groundwater pressure, abnormal in situ stresses, extended area of fault zones, contaminated ground, encountering high volume of methane, etc. is not considered in the costs.
- Normal contracting practice with design-bid-build is assumed to be used for the project.
- Operations are based on 24 hour activities and full access to the site 7 days a week.
- Cost of tunneling comprises labor, equipment, and consumables, with 1/3 rule.
- Geographical impact is primarily in terms of labor cost, and can impact the 1/3 contribution of the labor.
- Shaft depths in the range of around 200 ft can be estimated based on unit price of excavation. Deeper shafts may require special provisions.
- Shaft diameters of 10-75 ft can be estimated based on unit prices, larger shafts may need special provisions.
- Excavation cost includes transportation of muck in the tunnel and off the site within reason. Additional cost of muck haulage to a long distance or special provisions of dump sites was not accounted for.

CSO vortex drop shaft costs were determined by using Sage Timberline software to estimate the cost of numerous structures, based on basis of design drawings, designed to handle specific flow rates.

ACT - Conventional Tunnel Module

The cost estimate from the supplemental materials can be input into the Conventional Tunnel module. The user input parameters are listed as follows:

- Length of Tunnel
- Inside Diameter of Tunnel
- Unit Cost of Tunnel ($/gal)

Supplemental Materials - Secondary Tunnel Alternative Components

Cost estimates for new or modified CSO regulator structures were determined by using Sage Timberline software to estimate the cost of numerous structures, based on basis of design drawings, designed to handle specific flow rates.

ACT - Secondary Tunnel Alternative Structures Components

Consolidation piping was costed with unit costs from the open cut pipe module of the ACT.

Deep CSO storage dewatering pump stations were costed with unit costs from the pump station module of the ACT. Specifically the deep tunnel dewatering pump station costing curve was used.

Supplemental Materials - CSO Storage Tunnel O&M Costs

Supplemental materials were used outside of the ACT to determine O&M costs for CSO storage tunnels. Conventional CSO storage tunnel O&M was largely based on two WEFTEC 2007 Session 8 references:

- Murphy, S. Operations and Maintenance Requirements for Storage Tunnels and In-System Storage Facilities
- Sherrill, J. Fujita, G. Budget Development for Operations/Maintenance Requirements For CSO/SSO Control Facilities

These references provided a general framework to perform O&M cost estimates. Tunnel storage O&M activities were broken into two groups: event (operations), and non-event (maintenance). Non-event activities are maintenance activities on the tunnel, dewatering pump station, and associated structures, that occur when the tunnel is not being operated. Event activities are operations activities that occur immediately before a CSO storage event, while the tunnel is filling, and while the tunnel is being dewatered and flushed. Guidelines for estimating event and non-event labor hours were provided, along with a breakout of labor hours per labor classification. Guidelines for marking up labor hours to include training, vacation, and other benefits were included. In addition, estimates for materials and electrical costs were provided.

Several modifications to the cost estimating approach were performed. The primary consumer of electricity was the dewatering pump station, and was calculated directly. Additional cost markups for tunnel length and dewatering pump station capacity was included in the estimate.

The following inputs were used to estimate an annual O&M cost:

- Estimates of annual event duration
- Labor rates for specific labor classifications
- Pump station electrical consumption
    - Annual Volume Pumped

    - Total Dynamic Head
    - Wire to Water Efficiency
    - Electrical Rate
- Tunnel Length
- Pump Station Capacity

ACT – Conventional Tunnel O&M

Upon completion of a CSO storage tunnel O&M cost estimate from the supplemental materials, the cost can be input to the Conventional Tunnel Module of the ACT in terms of dollars per gallon. From this value, the ACT will provide a present worth analysis of the conventional storage tunnel alternative for comparison with other planning alternatives.

2.3.10 Tank Storage

Off-line tank storage within the collection system can be used to reduce combined sewer overflows (CSOs) or sanitary sewer overflows (SSOs) by storing wet-weather flows. After an event, the stored combined sewage and flushed solids would be conveyed to the existing interceptor system (by gravity or pumping) for treatment at the treatment plant.

A costing curve for tank storage was developed for the ACT based on tank storage costing curves used for other CSO control programs around the nation, as well as cost data of completed storage tanks in varying CSO and SSO storage applications. The following items are included in the cost estimation equation for surface storage facilities:

- A below-grade, cast-in-place, covered storage tank between 0.1 and 30 MG of storage.
- Each tank includes an automated flushing system.
- Odor control is required.
- A control building is required.

If pumping into the surface storage facility is required or if it must be dewatered via pumping, the pump station is to be provided in a separate structure, and its costs are accounted for separately in the ACT. Dewatering pumping is required if gravity dewatering time exceeds 48 hours from the end of an event.

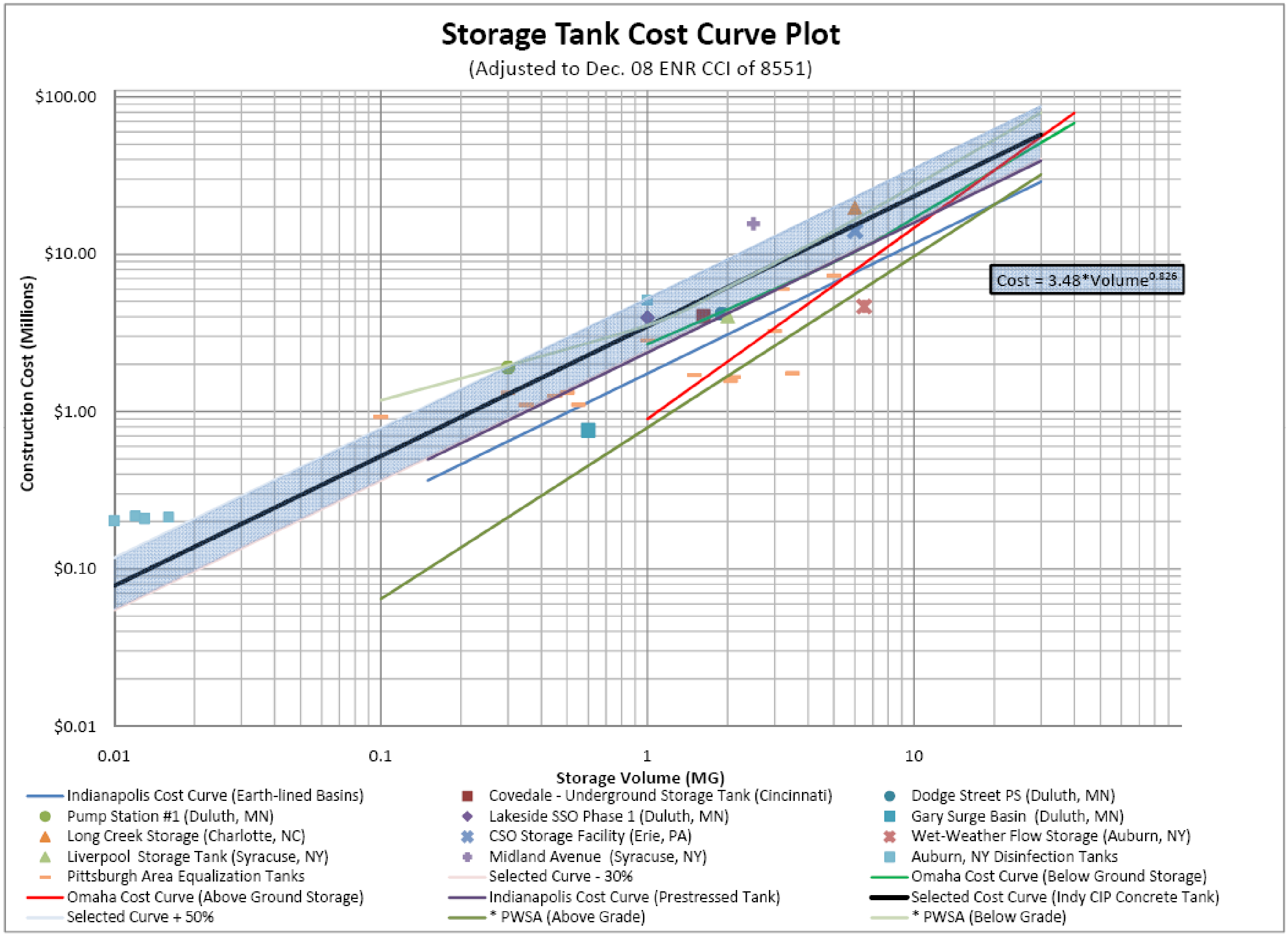
Conveyance from the existing collection system to the storage facility or from the facility to the interceptor will be accounted for separately in the ACT.

Figure 2.3.10-1 displays the plot of the data used for determining the storage tank cost curve for the ACT. The user must input the tank storage to calculate the initial facility cost. The equation for the storage tank costing curve is:

$$y = 3.48x^{0.826}$$

Where y equals cost in million dollars and x equals the storage volume in MG

O&M Costs for CSO storage tanks were estimated based on the WEFTEC07 approach for CSO/SSO facility O&M. This methodology is used for Retention Treatment Basins as well.



* Source: PWSA *Basis of Cost for CSO Control Technologies* , March 2007

Figure 2.3.10-1 Storage Tank Cost Curve [ENRCCI 8551; RS MEANS 100]

2.3.11 Screening

While screens serve as a pre-treatment device in several types of high rate treatment facilities, fine screens can also serve as a stand-alone CSO control measure with disinfection. With screen sizes ranging from 4 to 6 mm, these facilities can be very effective at removing floatables, including sanitary trash.

Screening facility costs are estimated as a standalone technology within the ACT. However, since screening facilities are not designed to remove fecal solids, disinfection generally must be achieved via chlorination and dechlorination. Chlorination/dechlorination facilities are included in the ACT as a separate control technology, and described further in Section 2.3.15 of this manual. For disinfection at screening facilities, the use of sodium hypochlorite for chlorination and sodium bisulfite for dechlorination will be the default assumptions. Any wastewater pumping required as part of the screening facility will be accounted for separately in the ACT; Section 2.3.6 details pump station cost estimation within the ACT.

The cost curve equation for screening was developed from construction cost data provided by the PM, BC, and BPs, as well as cost curves from other CSO control programs around the nation. The curve is displayed in Figure 2.311-1. The equation of the selected curve for screening is:

$$y = 0.0834x^{0.843}$$

Where y equals construction cost in million dollars, and x equals treatment capacity in MGD

From the equation of the selected curve, the user is to input the design flow rate in MGD.

O&M costs for screening facilities are estimated based on the WEFTEC07 approach for CSO/SSO facility O&M. An example O&M calculation for a screening facility is provided below.

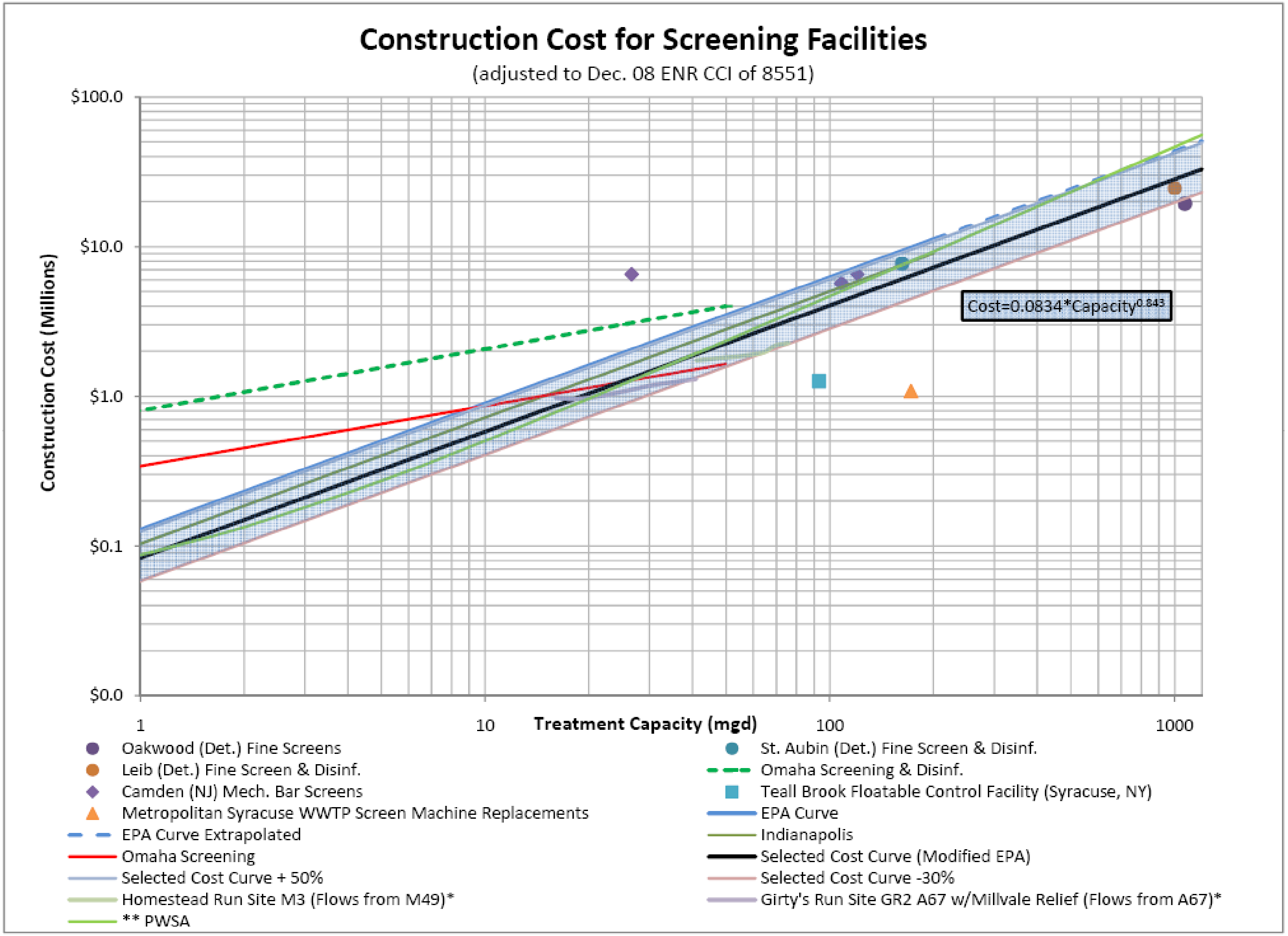
Example Calculation for Determination of O&M Costs for Screening Facilities

Notes:
1. *Input variables are highlighted in yellow.*
2. *O&M Costs for chlorine disinfection are included*

	Annual "Task" Hours	***Annual Staff Hours***	***Hourly Rate***	***Annual Costs***
Annual Number of Non-Task Hours per Full-Time Employee	480			
Maintenance				
Supervisory Maintenance	80	104	$150	$15,600
Non-Supervisory Maintenance	1570	2041	$100	$204,100
Total:	1650	2145		$219,700
Annual Event-Hrs*	800			
Operations				
Supervisory Operations (0.6 hours / event hour)	480	624	$150	$93,600
Non-Supervisory Operations (3.6 hours / event hour)	2880	3744	$100	$374,400
Total:	3360	4368		$468,000
Non-Staff Resources ($70,000 / year)				$70,000
	Total Annual O&M Costs			**$757,700**

Source: Budget Development for Operations/Maintenance Requirements for CSO/SSO Control Facilities, WEFTEC 2007.

* Annual event hours include pre-event, treatment and post-event periods as defined in the WEFTEC source paper.



* Source: *ALCOSAN Overflow Control Facilities Alternatives* , August 2008

** From PWSA *Basis of Costs for CSO Control Technologies* , March 2007

Figure 2.311-1 Screening Facility Construction Cost Curve [ENRCCI 8551; RS MEANS 100]

2.3.12 Vortex Separation

Vortex separator capital cost and operations and maintenance costs were assumed to be similar whether they are built at an existing water pollution control plant or at satellite locations. Planning-level estimates of their costs are described in Analysis of Wet Weather Alternatives for Southeast WPCP, Supplemental Documentation Volume 10.

2.3.13 Retention Treatment Basins

Retention treatment basins (RTBs) are satellite HRT facilities designed to provide screening, settling, skimming (with a fixed baffle) and disinfection of combined sewer flows before discharging to the receiving water. RTBs serve to capture combined sewage during small wet weather events and are gradually dewatered after the event for treatment at a wastewater treatment plant. In larger events, RTBs will begin to overflow and discharge treated effluent, but the captured volume left at the end of the event is also dewatered for treatment.

RTBs can be designed with a variety of screen types, disinfection methods and basin geometries. The surface loading rates can also vary but are typically higher than rates used for design of primary clarifiers. RTBs can be constructed above or below grade but typically require at least an above-grade process/control building. If pumping of the combined sewer flow is required, the pump station may be integral to the RTB facility or constructed as a separate structure.
For planning purposes, all RTBs will be assumed to be configured as described below. The RTB facilities are assumed to include:

- Coarse, mechanically cleaned bar screens at the headworks of the facility.
- Disinfection via chlorination using sodium hypochlorite with sodium bisulfite dechlorination. The basins are sized to achieve the design chlorine contact time at the design flow rate with no additional volume for pre-disinfection settling. The tool allows for an assumed design contact time of 10 to 30 minutes at design flow.
- A settling/contact basin with flushing provisions. Assumed rectangular basin configuration with side water depths to approximately 20 ft.
- Captured volume including solids are dewatered to the interceptor.
- A fixed baffle located just upstream of the effluent weir to provide skimming.
- Provisions to dewater the facility to the interceptor system, including pumping if required.
- An option for an above or below ground facility, which will be covered with odor control.
- A building for screenings removal, chemical storage, electrical and process control.
- A basin divided into two parallel compartments just below grade, with an effluent weir and geometry based on a design surface overflow rate of 6,000 gallons per day (gpd)/square foot (sf).
- If pumping is required, it will be provided in a separate structure. Its costs will be accounted for separately in the ACT.

Design factors to be input into the ACT by the user will include:

- Design flow rate

- Chlorine contact time

Figure 2.3.13-1 displays the selected retention treatment basin facility cost estimating curve and equation, and is considered a construction cost with overhead, profit and indirect costs included.

Given the unique nature of RTBs, actual facility construction costs from around the country are a good source for developing planning level costs. In the mid to late 1990's, a number of retention treatment basins were constructed in Michigan as part of the Rouge River National Wet Weather Demonstration Project. Due to the readily available actual construction cost data for each of these RTBs, nine were selected to serve as the basis for deriving planning level construction costs.

The verified data was plotted with facility volume as the dependant variable. As a test of fit, a USEPA cost curve[1] for tank storage capital costs was plotted to determine any fit with the RTB actual construction cost data. The EPA curve was used due to the similar structural configurations among tank storage and RTBs, and that this particular cost curve was based on a large, wide ranging data set. The curve was updated for time, and modified by a factor of 50% for a more complete fit with the verified data points. The resulting curve fit well enough to render it the selected curve for costing RTB capital costs. All verified points are displayed in Figure 2.3.13-1 along with the selected costing curve. The cost equation from the selected curve is:

$$y = 9.72x^{0.826}$$

Where y equals construction cost in million dollars, and x equals facility volume in MG

[1] *Combined Sewer Overflow Control*, United States Environmental Protection Agency, September 1993

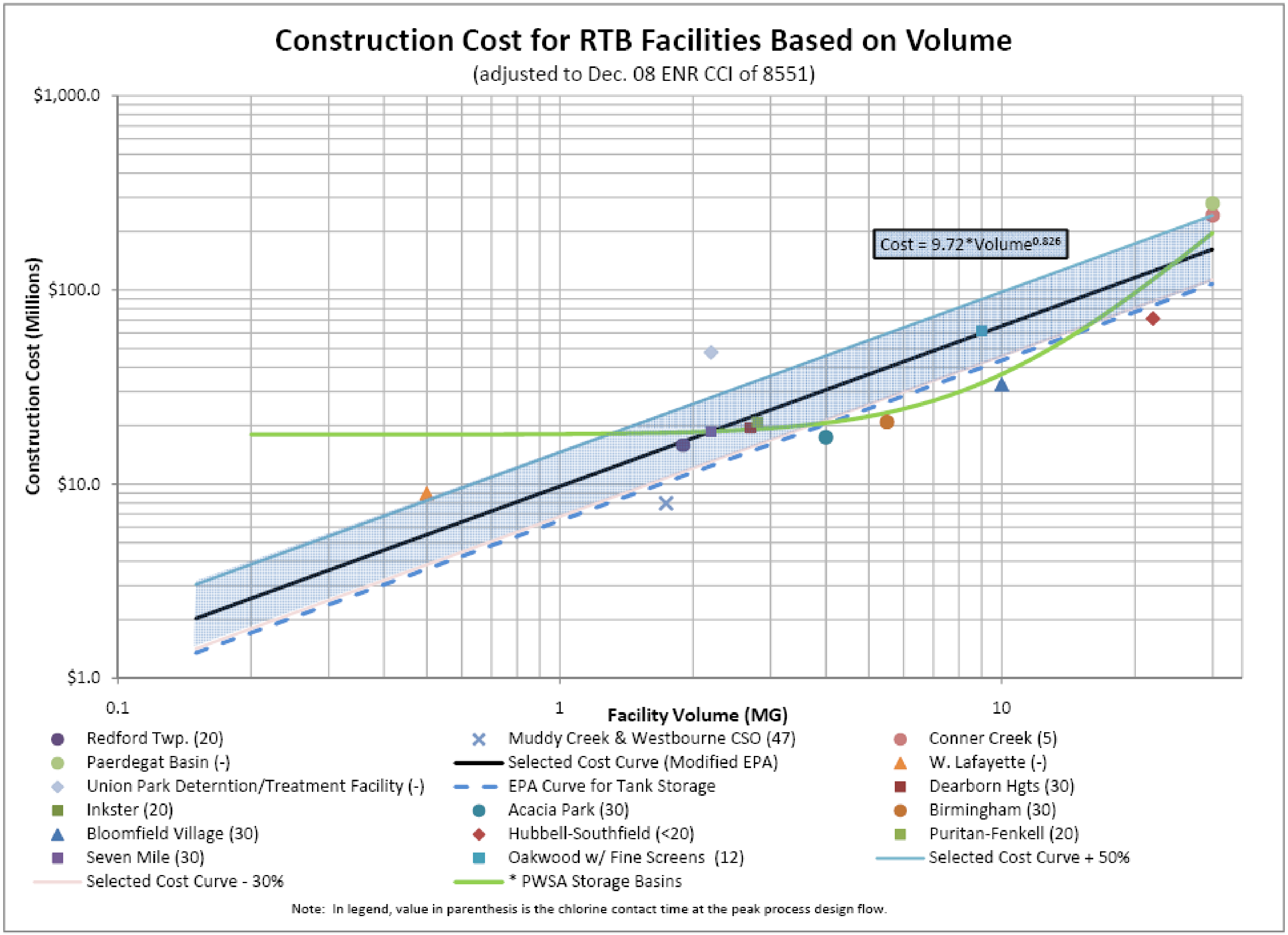


Figure 2.3.13-1 Retention Treatment Basin Cost Curve based on Facility Volume [ENRCCI 8551; RS MEANS 100]

RTB O&M Costs

O&M cost estimates for RTBs were developed based on the WEFTEC07 approach for CSO/SSO facility O&M. An example calculation is provided below, and Figures 2.3.13-2 through 2.3.13-4 display supplemental estimate curves based on the WEFTEC approach.

Example Calculation for Determination of O&M Costs for Retention Treatment Basins

Note: Input variables are highlighted in yellow.

	Annual "Task" Hours	Annual Staff Hours	Hourly Rate	Annual Costs	Notes
Peak Treatment Rate (MGD)	250				
Design Chlorine Contact Time (minutes)	20				
Basin Volume (MG)	3.47				
Annual Number of Non-Task Hours per Full-Time Employee	480				
Total Maintenance	2319				See Figure 2.3.13-2 for curve & equation**
Supervisory Maintenance (15% of total)	348	452	$89	$40,255	
Non-Supervisory Maintenance (85% of total)	1972	2563	$54	$138,403	
Annual Event-Hrs*	1400				
Total Operations	2955				See Figure 2.3.13-3 for curve & equation**
Supervisory Operations (11% of total)	325	423	$92	$38,881	
Non-Supervisory Operations (89% of total)	2630	3419	$63	$215,422	
Non-Staff Resources				$98,642	See Figure 2.3.13-4 for curve & equation**
		Total Annual O&M Costs		**$531,604**	

Source: Budget Development for Operations/Maintenance Requirements for CSO/SSO Control Facilities, WEFTEC 2007.

* Annual event hours include pre-event, treatment and post-event periods as defined in the WEFTEC source paper.

** Curves obtained from cited source.

Estimated Data Points from Reference

Basin Size (MG)	Annual Manhours
2.5	1400
3.75	2600
5	3300
7.5	4400
10	5300
12.5	5800
15	6400
20	7100
25	7800
30	8300
35	8700
40	9100

Assumed Straight-Line Extrapolation at Low End

Basin Size (MG)	Annual Manhours
0	500
2.5	1411

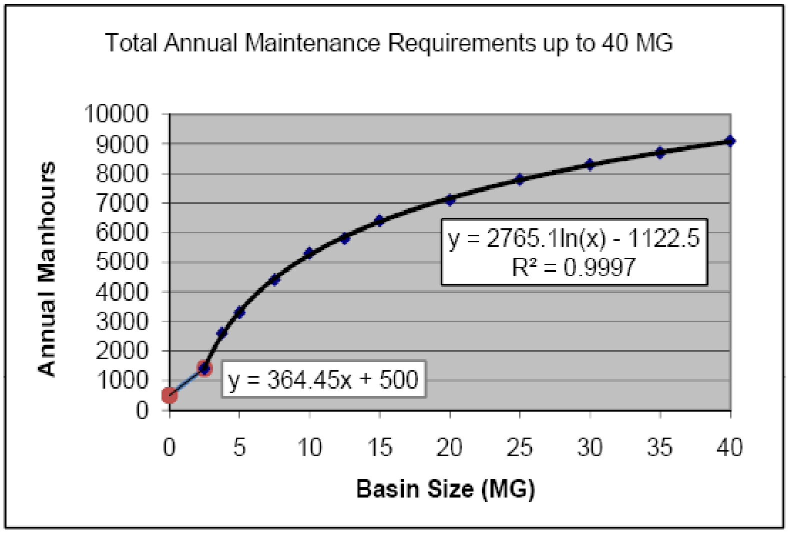


Figure 2.3.13-2 Typical Annual Maintenance Staff for RTBs [ENRCCI 8551; RS MEANS 100]

Estimated Data Points from Reference

Annual Event-Hrs	Annual Manhours
250	1000
500	1750
750	2250
1000	2550
1500	3050
2000	3300
2500	3700
3000	3800
3600	4050

Assumed Straight-Line Extrapolation at Low End

Annual Event-Hrs	Annual Manhours
0	0
250	979

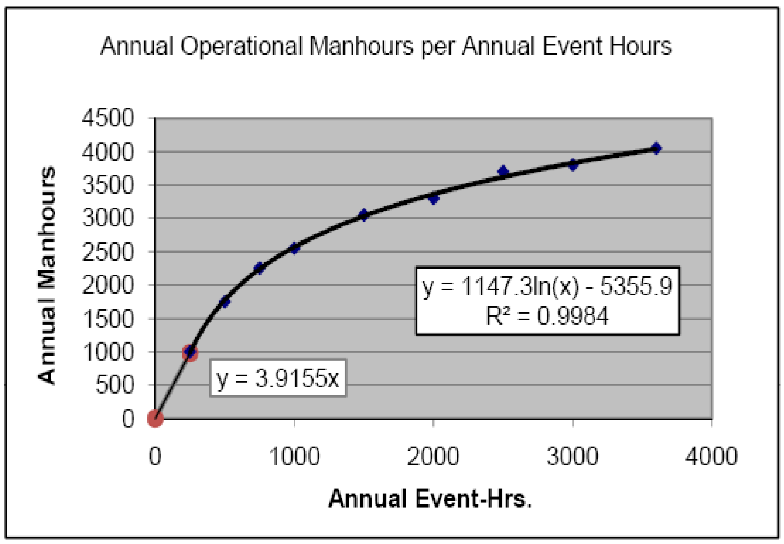


Figure 2.3.13-3 Typical Annual Staff Operation for RTBs [ENRCCI 8551; RS MEANS 100]

Estimated Data Points from Reference

Basin Size (MG)	Annual Non-Staff Resources ($)
2.5	$70,000
3.75	$110,000
5	$137,500
7.5	$175,000
10	$210,000
12.5	$235,000
15	$255,000
20	$290,000
25	$320,000
29	$340,000

Assumed Straight-Line Extrapolation at Low End

Basin Size (MG)	Annual Non-Staff Resources ($)
0	0
2.5	$62,585

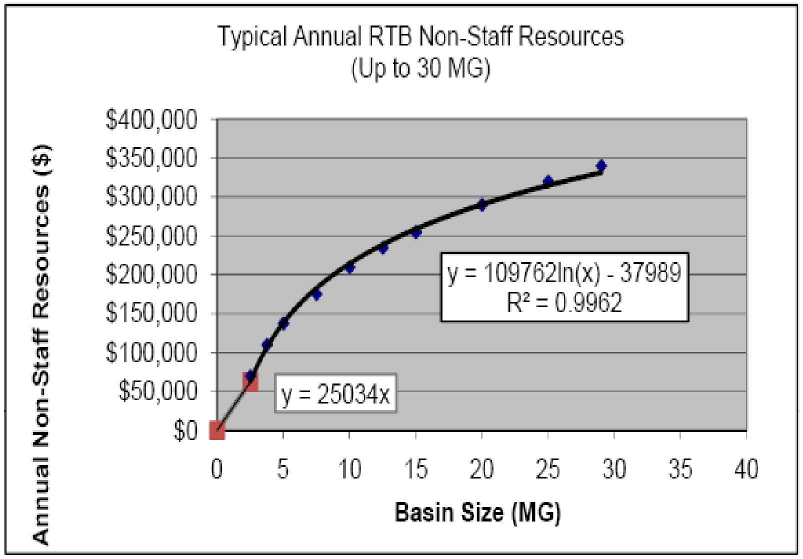


Figure 2.3.13-4 Typical Annual Non-Staff Resources for RTBs [ENRCCI 8551; RS MEANS 100]

Table 2.3.13-1 – Miscellaneous RTB Construction Cost Multipliers applied in ACT [ENRCCI 8551; RS MEANS 100]

Description	Units	Value
Foundation Cost Multiplier	%	15%
Sitework Cost Multiplier	%	6%
Dewatering Multiplier	%	2%
Dechlorination Multiplier	%	3%

Table 2.3.13-2 RTB Design Assumptions used in ACT [ENRCCI 8551; RS MEANS 100]

Description	Value
Overflow Rate	6000 gpd/sf
Footprint Area Multiplier	125%
Basin Freeboard	4 ft

2.3.14 High Rate Clarification

High rate clarification capital cost and operation and maintenance costs were assumed to be similar whether they are built at an existing water pollution control plant or at satellite locations. Planning-level estimates of their costs are described in Supplemental Documentation Volumes 9 through 11.

2.3.15 Disinfection

Disinfection is assumed to be a component of all high rate treatment (HRT) facilities. All costs for disinfection (including contact tanks or conduits) will be included in the cost estimates for applicable alternatives, with sizing scaled to appropriate design flows.

As a default assumption, the equipment and appurtenance costs for chlorination using sodium hypochlorite and dechlorination using sodium bisulfite. However, it is recognized that UV disinfection may be a viable alternative for HRC, and an option to select UV disinfection is included in the ACT.

The users are to select a disinfection type, and input the design flow rate for the disinfection alternative into the ACT.

Figure 2.3.15-1 displays the selected disinfection cost estimating curve and equation.

Chlorination/Dechlorination Construction Costs

The construction cost curve equation for chlorination / dechlorination facilities was developed from the 1993 USEPA report *Combined Sewer Overflow Control*. It was compared to construction cost data provided by other CSO control programs around the nation. The equation of the selected curve for chlorination / dechlorination facilities, displayed in Figure 2.3.15-1 is:

$$y = 0.223x^{0.464}$$

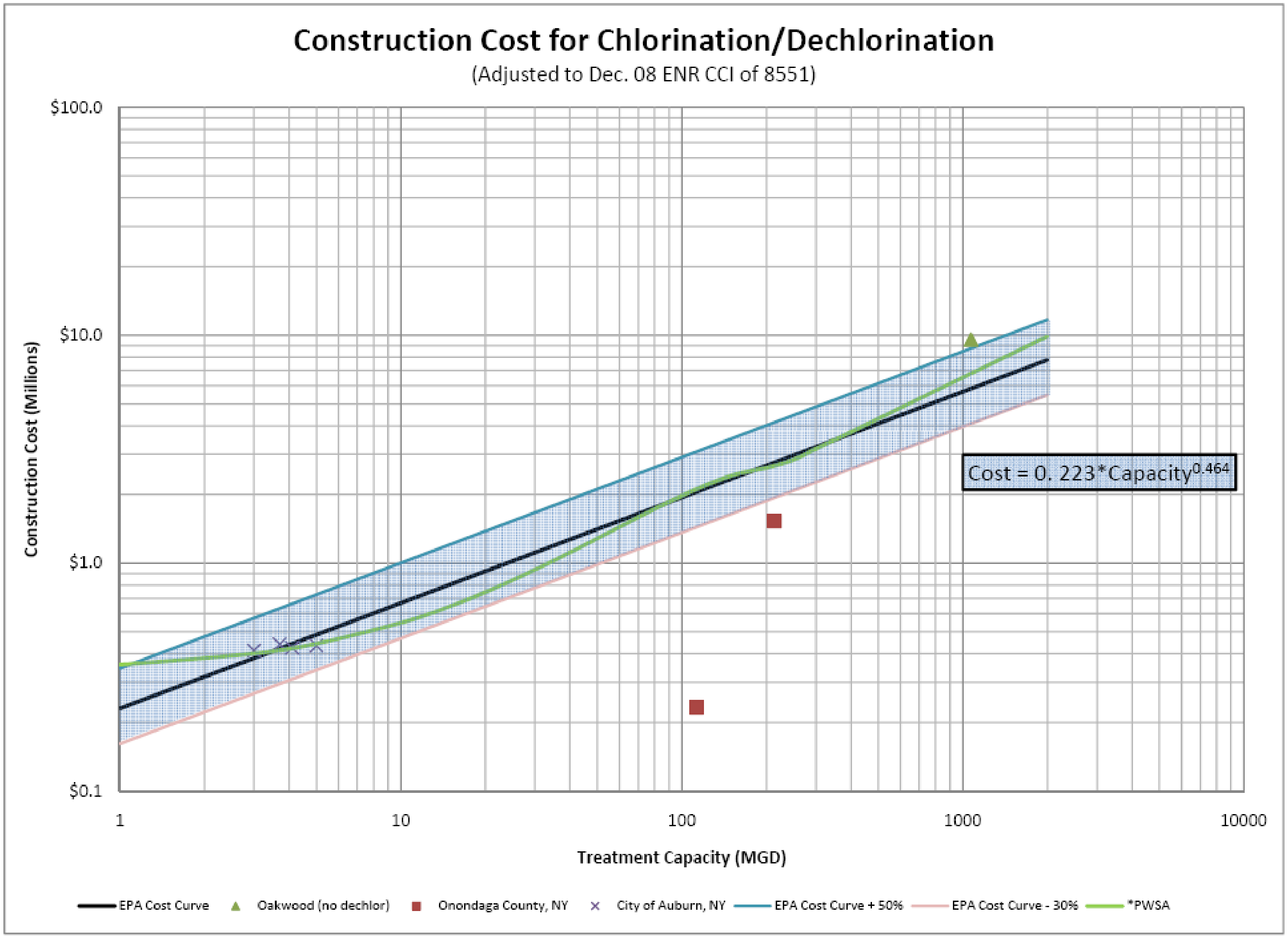
Where y equals construction cost in million dollars, and x equals treatment capacity in MGD.

Ultraviolet Disinfection Construction Costs

The cost curve equation for UV disinfection facilities was developed from the City of Indianapolis *CSO Control Cost Estimating Procedures Memo* which modified a chlorination cost curve found in the 1993 USEPA report *Combined Sewer Overflow Control*. It was compared to cost curves from other CSO control programs around the nation. The equation of the selected curve for ultraviolet disinfection, displayed in Figure 2.3.15-3 is:

$$y = 0.719x + 0.540$$

Where y equals construction cost in million dollars, and x equals treatment capacity in MGD



* Source: PWSA *Basis of Cost for CSO Control Technologies* , March 2007

Figure 2.3.15-1 Chlorination / Dechlorination Construction Cost Curve [ENRCCI 8551; RS MEANS 100]

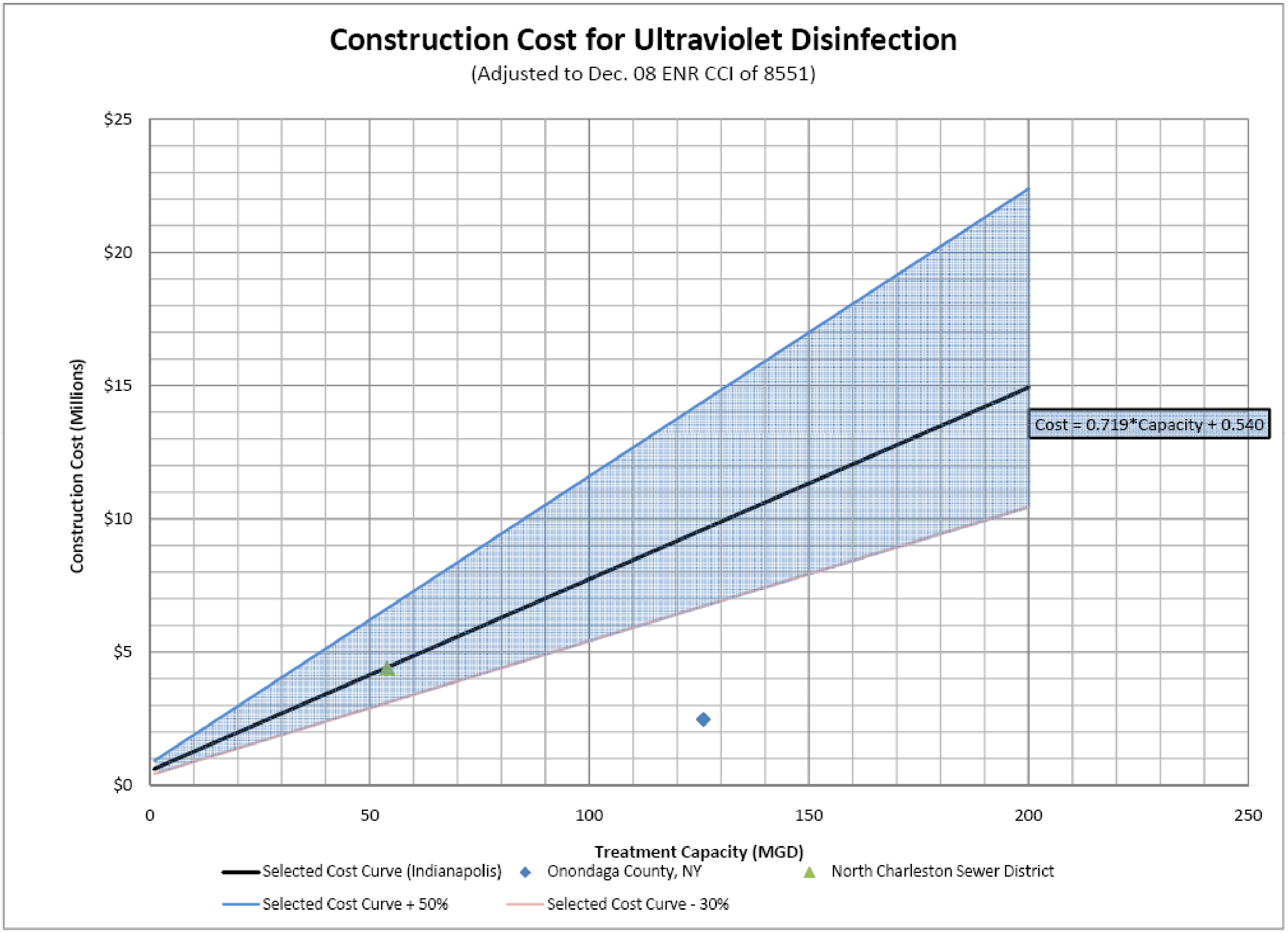


Figure 2.3.15-3 Construction Cost Curve for Ultraviolet (UV) Disinfection [ENRCCI 8551; RS MEANS 100]

Chlorination/Dechlorination & Ultraviolet Disinfection O&M Costs

Disinfection facility O&M cost equations are provided for both ultraviolet disinfection and chlorination/dechlorination facilities. These equations were developed from the City of Indianapolis CSO Program[2], and are based on USEPA curves adjusted to the proper ENRCCI value.

O&M costs for chlorination / dechlorination facilities were derived from the City of Indianapolis *CSO Control Cost Estimating Procedures Memo* which modified a chlorination cost curve found in the 1993 USEPA report *Combined Sewer Overflow Control*. For the ACT, the curve was updated to a base period of December 2008. The resulting cost curve, displayed in Figure 2.3.15-2, is:

$$y = (\text{Current ENRCCI}/6635) * 12.531 * x^{0.614}$$

Where y equals construction cost in $Thousands, and x equals facility capacity in MGD.

O&M costs for UV disinfection facilities were derived from the City of Indianapolis *CSO Control Cost Estimating Procedures Memo* which modified a chlorination cost curve found in the 1993 USEPA report *Combined Sewer Overflow Control*. For the ACT, the curve was updated to a base period of December 2008. The resulting cost curve, displayed in Figure 2.3.15-4, is:

$$y = (\text{Current ENRCCI}/6635) * 5475 * x$$

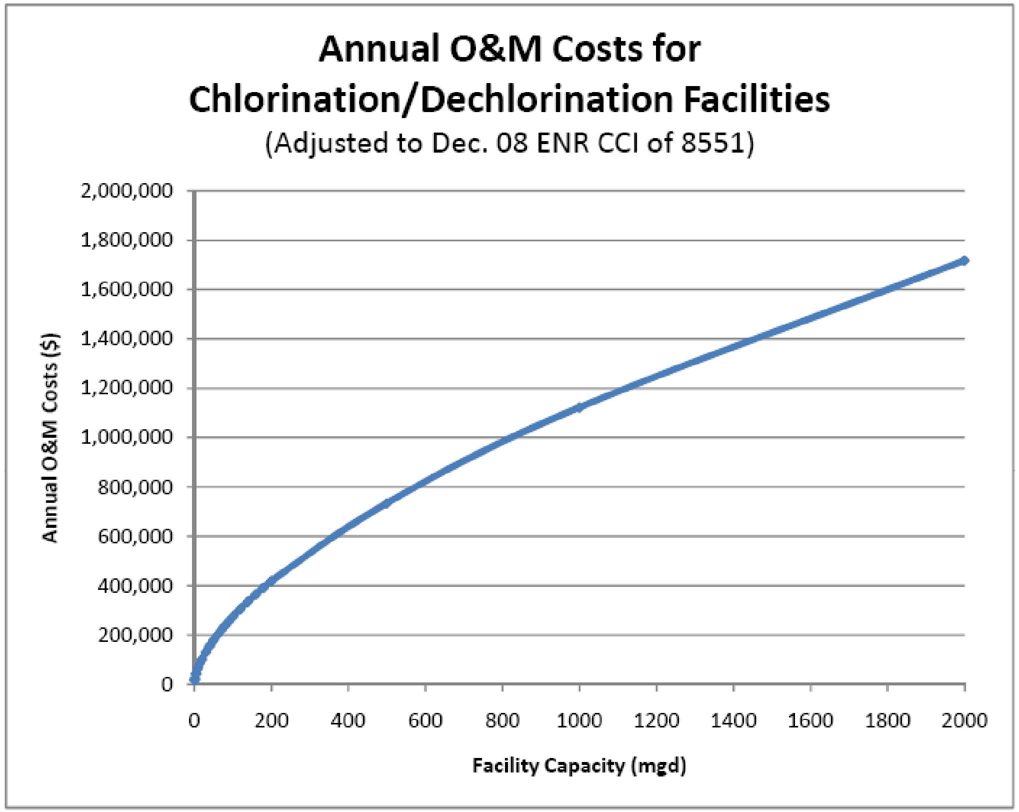
Where y equals construction cost in dollars, and x equals facility capacity in MGD.

[2] *Cost Estimating Procedures for Raw Sewage Overflow Control Alternatives Evaluation.* City of Indianapolis, September 2003.

Base ENRCCI: 8,551

Cost Table for New CSO Chlorination/Dechlorination Disinfection Treatment Facilities

Facility Capacity (mgd)	Annual O&M Cost ($)
1	16,149
2	24,716
5	43,383
10	66,398
15	85,167
20	101,622
30	130,348
40	155,531
50	178,370
60	199,498
70	219,303
80	238,040
90	255,893
100	272,994
120	305,331
140	335,642
160	364,320
180	391,643
200	417,817
500	733,366
1000	1,122,415
2000	1,718,000



The cost table above is based on the following conditions:

1. Annual O&M costs are derived from the USEPA construction cost curves using the current ENRCCI, which is an acceptable estimate between a range of 1 and 2000 mgd.
2. Curve defined by the equation below is based on the use of sodium hypochlorite and sodium bisulfite.

Annual O&M Cost Equation:

Cost ($Thousands) = (Current ENRCCI / 6635) * 12.531 * $Q^{0.614}$

*6,635 was the ENRCCI from March 2003.

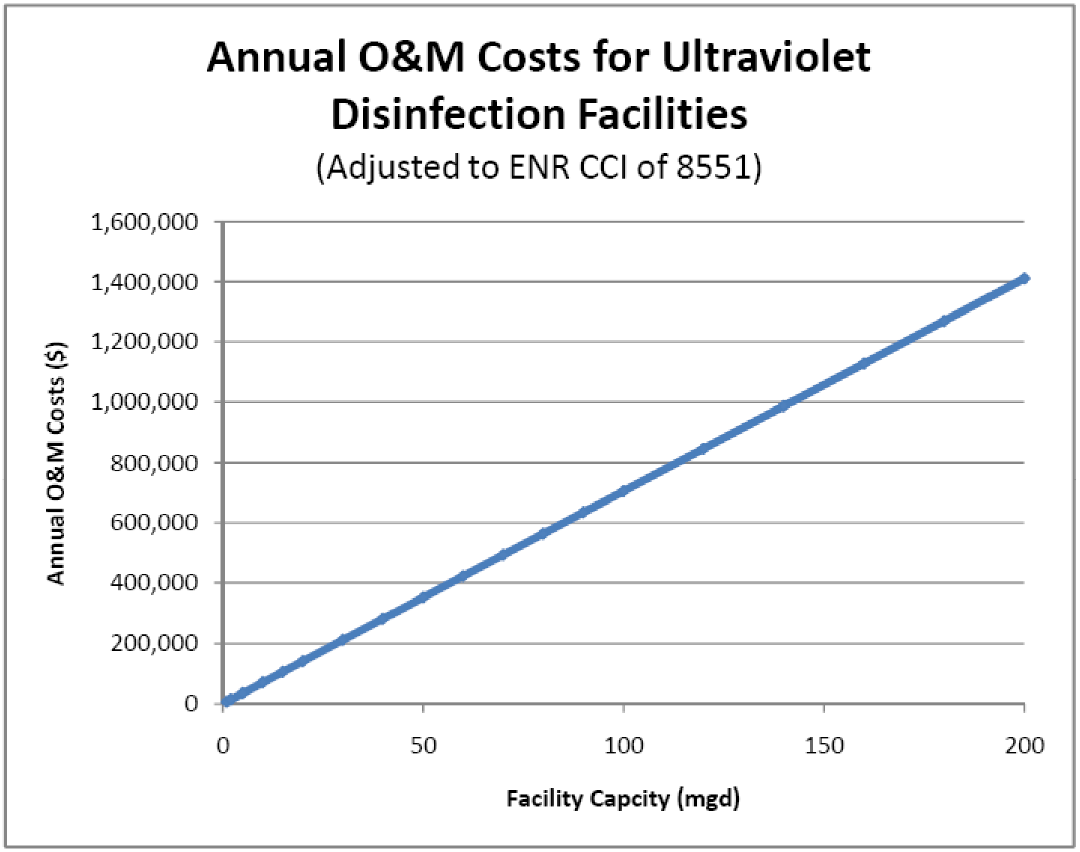
*Q = Facility Capacity (mgd)

Source: USEPA Cost Curves as Reported in Indianapolis CSO Control Cost Estimating Procedures Memo

Figure 2.3.15-2 O&M Cost Curve for Chlorination / Dechlorination Facilities [ENRCCI 8551; RS MEANS 100]

Base ENRCCI: 8,551

Cost Table for New CSO UV Disinfection Treatment Facilities	
Facility Capacity (mgd)	Annual O&M Cost ($)
1	7,056
2	14,112
5	35,280
10	70,560
15	105,840
20	141,120
30	211,681
40	282,241
50	352,801
60	423,361
70	493,922
80	564,482
90	635,042
100	705,602
120	846,723
140	987,843
160	1,128,964
180	1,270,084
200	1,411,205



The cost table above is based on the following conditions:

1. Annual O&M is estimated between a range of 1 and 100 mgd based on recent author references (Cotton et al.) as cited in Indianapolis CSO Program documentation.

Annual O&M Cost Equation:

Cost ($M) = (Current ENRCCI / 6635) * 5475 * Q

*6,635 was the ENRCCI from March 2003.

*Q = Facility Capacity (mgd)

Figure 2.3.15-4 O&M Cost Curve for Ultraviolet (UV) Disinfection [ENRCCI 8551; RS MEANS 100]

3.0 LIFECYCLE COSTS

3.1 Introduction to Lifecycle Costs

The user will be evaluating alternative control elements (e.g., storage vs. satellite treatment) and control alternatives. Control alternatives are arrays of control elements (e.g., a relief interceptor and one 5-mg storage tank at the bottom of the sewershed vs. two 2-mg tanks along the existing interceptor) to provide the same level of watershed-wide wet-weather control.

The various control elements and control alternatives will be compared economically based on comparative life cycle costs. Lifecycle costs are the total costs of building, operating and maintaining a control element for the planning period of the WWP.

3.2 Planning Period and Temporal Framework

The ACT allows for user-specified construction end dates and construction duration periods for each control implemented.

3.3 Present Worth Analysis

Lifecycle costs of alternative control elements will be compared based on their respective present worth. The ACT will calculate the present worth of control elements based on the design parameters entered by the user.

Present worth is the value, expressed in present dollars of the capital costs and the stream of future O&M costs generated by a control element. Calculating the present worth of alternative control elements allows for comparisons between various mixes of capital and O&M costs over the planning period.

The ACT calculates present worth for capital costs, O&M and replacement costs in three different ways. For analysis of alternatives, The City of Philadelphia's Long Term Control Plan Update describes costs and benefits derived using method 2.

> **Method 1** – **Current Year Costs –** Costs are not inflated under Method 1. Capital costs are expressed in current dollars. O&M costs are expressed in current dollars. The current year value of the future stream of O&M payments are discounted back to the current year, as are future replacement costs. This methodology is simplistic but obviates the complexities involved in predicting inflation rates and the mid-point of construction.
>
> **Method 2** (default in ACT)– Under Method 2, current year capital costs are inflated to the mid-point of construction at the input capital costs inflation rate and then deflated back to current year using the discount factor. O&M costs are inflated to the years of implementation and the inflated stream of costs is discounted back to the current year. Replacement costs are inflated to the replacement year and then discounted back.
>
> **Method 3** – Method 3 recognizes the reality of bond financing for major capital projects such as wet weather controls and addresses the current value of the future stream of

debt service payments. Capital costs are inflated to midpoint of construction. Debt service payments, based on the inflated capital costs are then discounted as a stream of future payments back to current year. O&M costs are inflated to the years of implementation and the inflated stream of costs is discounted back to the current year. Replacement costs are inflated to the replacement year and then discounted back.

An example of the results of these three methodologies is shown below on Figure 4.3-1 excerpted from the ACT Schematic diagram, provided in Appendix A to this document.

Present Worth

Basis of PW Calculation	Inflate	% PW	Current Year or Inflated Costs?
Present Worth Inputs			
Annual O&M Costs PW Inputs			
Annual O&M Costs (current $)	$649,440		From O&M Cost Calculation Module
O&M First Year of Operation	$1,179,344		
First Year of Operation	2027		
Last Year of Planning Period	2046		
Capital Cost PW Inputs			
Current Year Capital Costs	$56,871,000		
Capital Costs Inflated to Midpoint	$86,582,390		
Total Capital Costs	$157,962,523		Sum of projected debt service payments

Present Worth Outputs	Capital	O&M	Replacement	Total	Notes
PW Method 1 - Current Year Costs	$56,871,000	$2,609,720	$0	$59,480,720	Current year capital costs and discounted stream of current year dollar O&M costs
PW Method 2 - PW of Inflated Capital Costs	$36,127,806	$6,205,104	$0	$42,332,910	Current year capital costs are inflated and then discounted to 2009, O&M costs inflated and discounted.
PW Method 3 - PW of Debt Service Payments	$31,737,954	$6,205,104	$0	$37,943,058	Present Worth of debt service payments and discounted stream of inflated O&M costs
				To Knee of Curve Analysis	

Figure 4.3-1 – Example of Present Worth Methodologies within the ACT

Land Costs

Land acquisition costs will be entered into the present worth calculations at current (2009) values and will be inflated by the ACT if the inflation function is activated. As discussed more fully in Section 2.1.4 of this document, estimated land acquisition costs will be provided by the user due to the location specific nature of the potential cost, and inputted by the user into the ACT for the specific alternative run. Where the control element may reasonably be contained within an existing ROW or if the land requirements for various alternatives are substantially identical, it might be reasonable to omit land acquisition costs from the present worth analysis.

Salvage Value

The ACT does not account for the salvage value of control elements.

3.4 Replacement Costs

Because of the long planning period, mechanical equipment and depending on the initiation of operation, potentially structural facilities will be at the ends of their respective useful lives prior to the end of the planning period. Therefore, replacement costs for equipment or structural facilities requiring replacement or substantial rehabilitation prior to 2048 must be included in the present worth analysis.

The user has the option of inputting a replacement cost and a renewal/replacement frequency for applicable equipment in an alternative. The ACT calculates the present value of these replacement costs given the user input values and the default planning period.

4.0 References

The Association for the Advancement of Cost Engineering. 2005. Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for the Process Industries (AACE International Recommended Practice No. 18R-97).

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