Cost and Performance Estimation Approaches for the Individual Lagoon Tool and Small Lagoon Community Economic Streamlining Tool

Office of Science and Technology

Office of Water

U. S. Environmental Protection Agency

Washington DC 20460

820-B-24-003

August 2024, minor edits made March 2025

Acknowledgments

This work was made possible through the efforts of (in alphabetical order):

- Kelly Gravuer, Ph.D., Regional Branch, Standards and Health Protection Division, Office of Science and Technology, Office of Water.
- Gary Russo, Ph.D., National Branch, Standards and Health Protection Division, Office of Science and Technology, Office of Water.
- Mario Sengco, Ph.D., Regional Branch, Standards and Health Protection Division, Office of Science and Technology, Office of Water.
- Tetra Tech

Notices

This document has been drafted and approved for publication by the Standards and Health Protection Division, Office of Science and Technology, Office of Water, United States (U.S.) Environmental Protection Agency (EPA). Mention of trade names or use of commercial products does not constitute endorsement or recommendation for use.

This document and the tools described herein do not impose legally binding requirements on the United States Environmental Protection Agency, states, territories, authorized Tribes, or the regulated community, nor do they confer legal rights or impose legal obligations upon any member of the public. The Clean Water Act (CWA) provisions and the EPA regulations described in this document and in the tools contain legally binding requirements. The tools do not constitute a regulation, nor do they change or substitute for any CWA provision or EPA regulations. This document and the tools described herein are living documents and may be revised periodically without public notice. The adoption of a WQS variance is at the discretion of the state or authorized Tribe. <u>The use of these tools and resulting outputs is voluntary and does not guarantee the EPA approval of a WQS variance.</u>

Table of Contents

Introduction

The Individual Lagoon Tool (ILT) and Small Lagoon Community Economic Streamlining (SLCES) tool use mathematical models to estimate the cost of installing new or additional pollutant control technologies to meet Clean Water Act (CWA) Section 402 National Pollutant Discharge Elimination System (NPDES) permit requirements[1] based on the target ammonia criteria. This document describes the EPA's methodology for developing the cost estimation models and performance estimates for three pollutant control technologies to be used in the ILT and SLCES tool. For purposes of these tools, the cost estimation models assume the current wastewater treatment system is a lagoon-type system, and that meeting the target ammonia criteria[2] would in most cases require full replacement of the existing lagoon system, although it may be possible for some aerated lagoon systems to meet the target ammonia criteria with the addition of insulated floating covers. The EPA developed cost models to estimate the cost of replacing an existing lagoon wastewater treatment system with an oxidation ditch activated sludge system or sequencing batch reactor system, or by adding insulated floating covers to an existing aerated lagoon system.

1. Cost estimation approach

The EPA developed the cost models by estimating costs for selected design flows ranging from 0.01 to 2.00 million gallons per day (MGD) and then using regression techniques to develop cost models for any design flow within that range.

The EPA developed cost models by first designing an oxidation ditch activated sludge system and a sequencing batch reactor system using the software tool CapdetWorks[3]. CapdetWorks is a software tool often used for preliminary design and cost estimation of wastewater treatment plant construction projects based on the CAPDET program originally developed by the U.S. Army Corps of Engineers (USACE). CapdetWorks software allows users to design a combination of unit processes that provide certain effluent characteristics based on specified influent characteristics and then estimates the capital and operation and maintenance (O&M) costs of the design. The algorithms and cost indices in CapdetWorks provide information sufficient to develop Class 4 cost estimates as described by the Association for the Advancement of Cost Engineering International (formerly known as the American Association of Cost Engineers). Class 4 cost estimates are based on limited information and are usually used for purposes such as detailed planning, project screening at more developed stages, alternative scheme analysis, confirmation of economic and/or technical feasibility, and preliminary budget approval. The accuracy of the Class 4 cost estimates is in the range of -30 percent to +50 percent.

---

[1] NPDES permits are developed on a case-by-case basis in accordance with the CWA and implementing regulations. Compliance with those permits is a separate case-specific matter under the applicable CWA authorities. Any statements in this document about meeting NPDES permit limits are only for informational and illustrative purposes.

[2] As explained in *Applying the EPA's Economic Analysis Tools to a WQS Variance for Ammonia for Small Lagoon Communities*, for purposes of the SLCES tool and ILT, "…the EPA assumed the target ammonia criterion is commensurate with EPA's 2013 CWA section 304(a) recommended ammonia criteria. While the EPA made this assumption for the purposes of developing these two tools, nothing in this document, the SLCES Tool, or the ILT, dictates how states and authorized Tribes are to develop water quality criteria for ammonia."

[3] Mention of trade names or use of commercial products does not constitute endorsement or recommendation for use.

The EPA developed cost models for the oxidation ditch activated sludge system and the sequencing batch reactor system based on U.S. average cost estimates for year 2019, which was the most recent year of data available from the U.S. Census Bureau (hereafter referred to as "Census") when the EPA developed the cost models. When the ILT and SLCES tool estimate costs, the tools first calculate costs based on the regression models in year 2019 dollars. However, at the time the EPA was preparing these tools for public release, 2022 was the most recent year of Census data available. The EPA updated the tools to retrieve 2022 Census data and therefore needed to adjust the costs returned by the regression models to year 2022 dollars so that the cost estimates would be comparable to the economic data retrieved from the Census. To adjust the costs returned by the regression models (from year 2019 dollars to year 2022 dollars), the tools use cost ratios from the U.S. Army Corps of Engineers Civil Works Construction Cost Index System (USACE CWCCIS), the Bureau of Labor Statistics (BLS), and the U.S. Energy Information Administration. Finally, the tools adjust the year 2022 dollars cost estimates to account for state- and territory-specific differences in costs using ratios from the USACE CWCCIS. The cost adjustment methodology for the oxidation ditch activated sludge system and the sequencing batch reactor system are described in section 2.5.

The EPA developed a cost model for insulated lagoon covers by first estimating the price per square foot for a generic insulated lagoon cover using estimates from several lagoon cover vendors. The EPA then designed a generic lagoon wastewater treatment system in CapdetWorks and used CapdetWorks to estimate the area of the generic lagoon wastewater treatment system that could accommodate selected design flows ranging between 0.01 and 2.00 MGD. The EPA then calculated the estimated cost of the insulated lagoon covers for each design flow by multiplying the price per square foot of the generic insulated lagoon cover with the estimated areas of lagoons associated with each selected design flow. Because vendor costs of insulated lagoon covers were obtained during the year 2021, the EPA adjusted the estimated cost of the insulated lagoon covers for each design flow to 2019 dollars to be consistent with the base year of the oxidation ditch activated sludge system and the sequencing batch reactor system models. The EPA then used linear regression to develop a model of lagoon cover cost for any design flow between 0.01 and 2.00 MGD in year 2019 dollars. The ILT estimates the final cost of insulated lagoon covers by applying the regression equation to the specified design flow and then adjusting the resulting cost value to year 2022 dollars and accounting for state- and territory-specific differences using cost ratios from the USACE CWCCIS, in the same manner as the cost models for the oxidation ditch activated sludge system and the sequencing batch reactor system.

2. Full replacement of existing lagoon wastewater treatment system

Using CapdetWorks to estimate the cost of replacing a lagoon wastewater treatment system with an oxidation ditch activated sludge system or sequencing batch reactor required the selection of certain parameters. Details on the selection of those parameters are described below.

2.1. Capital Costs

Capital cost estimates for an oxidation ditch activated sludge system and sequencing batch reactor system depend on several factors including equipment cost, land cost, construction labor wages, and other direct and indirect construction costs. CapdetWorks allows the user to overwrite default values for the equipment cost indices, land cost, and construction labor rate used in the software. The EPA adjusted some those default values in CapdetWorks to provide

U.S. average cost estimates for year 2019. Below are details on the cost indices the EPA chose to use when estimating costs for equipment, land, and construction labor using CapdetWorks.

2.1.1. Equipment Cost Indices

CapdetWorks allows users to choose from multiple equipment cost databases. The EPA used the Hydromantis 2014 USA Average database for cost estimates. CapdetWorks accounts for changing costs over time by using several equipment-related cost indices to adjust costs to a target year. When using the Hydromantis 2014 USA Average cost database, CapdetWorks updates the costs using the Hydromantis Equipment Cost Index (HECI), Hydromantis Construction Cost Index (HCCI), and Hydromantis Pipe Cost Index (HPCI). At the time the EPA used CapdetWorks to develop the cost models, the software was updated to provide equipment costs as of the year 2020. However, as noted above, the latest socioeconomic data available from the Census at that time was for year 2019. Therefore, the EPA developed its cost models to reflect year 2019 dollars by requesting from Hydromantis a set of values for the HECI, HCCI, and HPCI that reflect year 2019 costs. Hydromantis provided index values for March, June, and October 2019. The EPA calculated the average of the 3 monthly values to generate average indices for year 2019 and used those indices to estimate equipment-related costs in year 2019 dollars. Table 1 shows these cost adjustment indices and the calculated average.

Table 1. Hydromantis Cost Indices for Year 2019

Index	March 2019	June 2019	October 2019	Average
Hydromantis Equipment Cost Index (HECI)	108.69	108.70	109.43	108.94
Hydromantis Construction Cost Index (HCCI)	113.74	114.09	114.54	114.12
Hydromantis Pipe Cost Index (HPCI)	111.54	111.23	108.97	110.58

2.1.2. Land Costs

Land costs are based on the average cost of farm real estate reported in the U.S. Department of Agriculture Land Values 2019 Summary (https://www.nass.usda.gov/Publications/Todays_Reports/reports/land0819.pdf). This report provides land values for farm real estate by region and by state for the 48 contiguous states. Cost of farm real estate was selected because lagoon wastewater treatment systems are often used in rural areas where land costs are lower compared to urbanized areas. The EPA used the average cost per acre of farm real estate in the United States for land cost based on data from the 48 contiguous states (the EPA could not find reliable data for Alaska, Hawaii, and Puerto Rico). The EPA determined that the impact of land costs on annualized project costs is relatively small compared to other unit costs because land costs represent a small portion of overall capital costs amortized over a typical financing period.

2.1.3. Construction Labor Costs

The EPA estimated construction labor rates by assuming a fully loaded rate of 2.1 times reported hourly wages to account for benefits, overhead, and other indirect costs. Wage rates for Construction Laborers were taken from the BLS Occupational Employment Statistics data (May 2019; https://www.bls.gov/oes/2019/may/oes472061.htm). The EPA used the median (50th percentile) wage rate for the entire United States as the base wage rate.

2.2. Operation And Maintenance Costs

The EPA estimated operation and maintenance (O&M) costs as the sum of operation, maintenance, material, chemicals, and energy costs. The EPA further divided operation costs by type of labor (wastewater treatment plant operator, administrative, and laboratory). The EPA adjusted parameters in CapdetWorks for labor rates and energy costs to provide cost estimates for the base year 2019.

2.2.1. Operation Costs

The EPA used CapdetWorks to estimate operation costs associated with labor hours for wastewater treatment plant operators, administrative staff, and laboratory staff. Labor rates were based on median hourly wages for the U.S. taken from the BLS Occupational Employment Statistics for 2019. The BLS provides median hourly wages for Water and Wastewater Treatment Plant and System Operators (https://www.bls.gov/oes/2019/may/oes518031.htm) and Chemical Technicians (https://www.bls.gov/oes/2019/may/oes194031.htm). For Administrative staff (e.g., plant managers and clerical staff), the BLS Occupational Employment Statistics do not provide wage data specific to wastewater treatment plants, but research conducted by Hydromantis suggests that the average wages of these staff are similar to Water and Wastewater Treatment Plant and System Operators. Therefore, CapdetWorks uses the wage rates for Water and Wastewater Treatment Plant and System Operators for Administrative staff. Hourly wage rates were multiplied by 2.1 to calculate fully loaded rates.

2.2.2. Maintenance Costs

Maintenance cost estimates in CapdetWorks consist solely of wastewater treatment plant operator labor. The wastewater treatment plant operator labor rate used in the CapdetWorks estimate of maintenance costs are based on U.S. median hourly wages for Water and Wastewater Treatment Plant and System Operators taken from the BLS Occupational Employment Statistics for 2019. The hourly wage was multiplied by 2.1 to calculate fully loaded rates.

2.2.3. Material and Chemical Costs

CapdetWorks estimates material and chemical cost for the modeled wastewater treatment systems. Costs represent U.S. average costs for the year 2019.

2.2.4. Energy Costs

Energy cost estimates are based on average electricity cost per kilowatt hour for the Commercial Sector obtained from Table 5.6.B in the U.S. Energy Information Administration's "Electric Power Monthly with Data for December 2019" (https://www.eia.gov/electricity/monthly/archive/february2020.pdf). The U.S. Energy Information Administration provides average electricity rates for the U.S. and electricity rates for all 50 states and Puerto Rico.

2.3. Cost Estimates

For each replacement option (oxidation ditch activated sludge system or sequencing batch reactor system), the EPA estimated costs in CapdetWorks for each cost component using selected design flows ranging from 0.01 to 2.0 MGD. Because there appeared to be nonlinearities at design flows below 0.5 MGD, the EPA estimated costs for design flows in smaller intervals below 0.5 MGD to better discern cost dynamics in that range of design flows. Figure 1 shows the CapdetWorks estimates for each cost component for the oxidation ditch activated sludge plotted against design flow, and Figure 2 shows the CapdetWorks estimates for each cost component for the sequencing batch reactor system plotted against design flow.

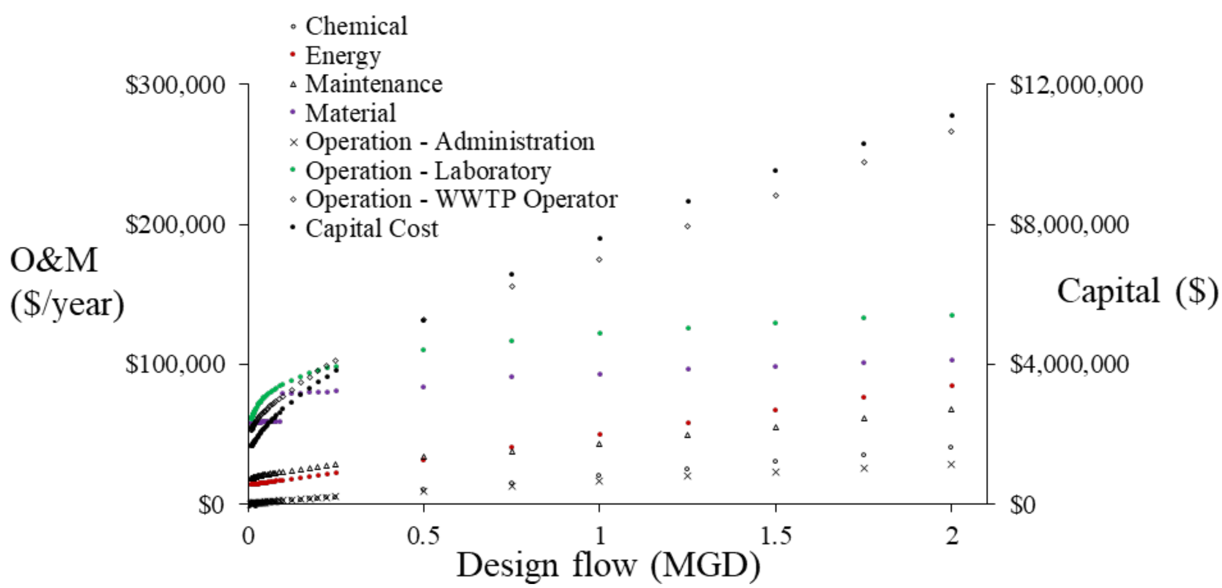

Figure 1. CapdetWorks estimates of capital costs and operation and maintenance costs for **oxidation ditch** activated sludge systems for design flows ranging between 0.01 MGD to 2.00 MGD. Scale for capital costs are on the right and scale for all other costs are on the left.

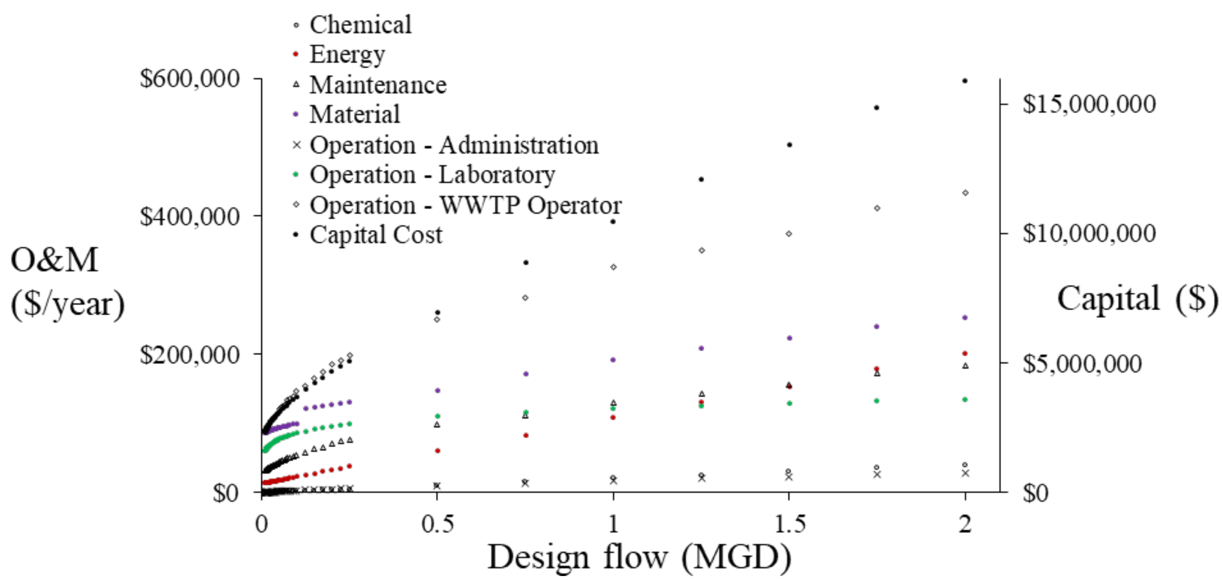

Figure 2. CapdetWorks estimates of capital costs and operation and maintenance costs for **sequencing batch reactor** systems. All conventions the same as Figure 1.

2.4. Regression Analysis

After the EPA estimated capital and O&M costs for each wastewater treatment system with design flows that ranged from 0.01 MGD to 2.00 MGD, the EPA use regression techniques to derive cost models based on design flow.

Visual inspection of Figures 1 and 2 shows that costs versus design flow is nonlinear for some but not all cost components. The EPA identified two main types of nonlinearities. One nonlinearity is an abrupt increase of $19,300 per year for material costs at 0.125 MGD for the sequencing batch reactor system and at 0.1 MGD for the oxidation ditch activated sludge system. The EPA determined the abrupt increase is due to an increase in sludge hauling and filling costs at design flows greater than 0.1-0.125 MGD. Because the increase is constant above a particular design flow for each system and such abrupt discontinuities are detrimental to most regression techniques, the EPA addressed the nonlinearity by subtracting $19,300 per year from material costs for the affected higher design flows, using regression to model material costs across all design flows, and then adding the $19,300 per year constant to the output of the regression model when estimating material costs for the higher design flows.

A second nonlinearity appears as a change in the rate of increase in cost for some cost components with increasing design flow. Such a change in the rate of increase often appears at a particular design flow. Because summing individual cost components for each design flow before regression would result in total cost having multiple discontinuities along the cost-design flow continuum that would likely complicate finding a suitable regression model, the EPA chose to find a single regression method suitable for all the individual cost components, derive regression coefficients for each cost component, use the regression coefficients to calculate costs for each individual cost component, and then calculate the sum of the individual components to estimate total cost for a particular design flow.

The EPA explored linear, logarithmic, polynomial, locally weighted, and segmented regression techniques to derive cost models. The EPA evaluated the performance of each regression technique using the coefficient of determination. After evaluating all regression techniques, the EPA chose segmented linear regression as the regression approach to derive cost models. Segmented linear regression, also known as piecewise regression or broken-stick regression, is a method of regression analysis where the independent variable is partitioned into intervals and a separate line segment is fit to each interval. The boundaries between the segments are called breakpoints. The EPA performed segmented regression using R version 4.1.0 and the R package "Segmented" version 1.3-4. The algorithm determines the number and location of breakpoints to best fit the data. The EPA chose segmented regression because it results in relatively simple models that adequately fit the data for all cost components. Figures 3 and 4 show scatter plots of flow capacity versus cost and the regression fits for each cost component.

Oxidation Ditch

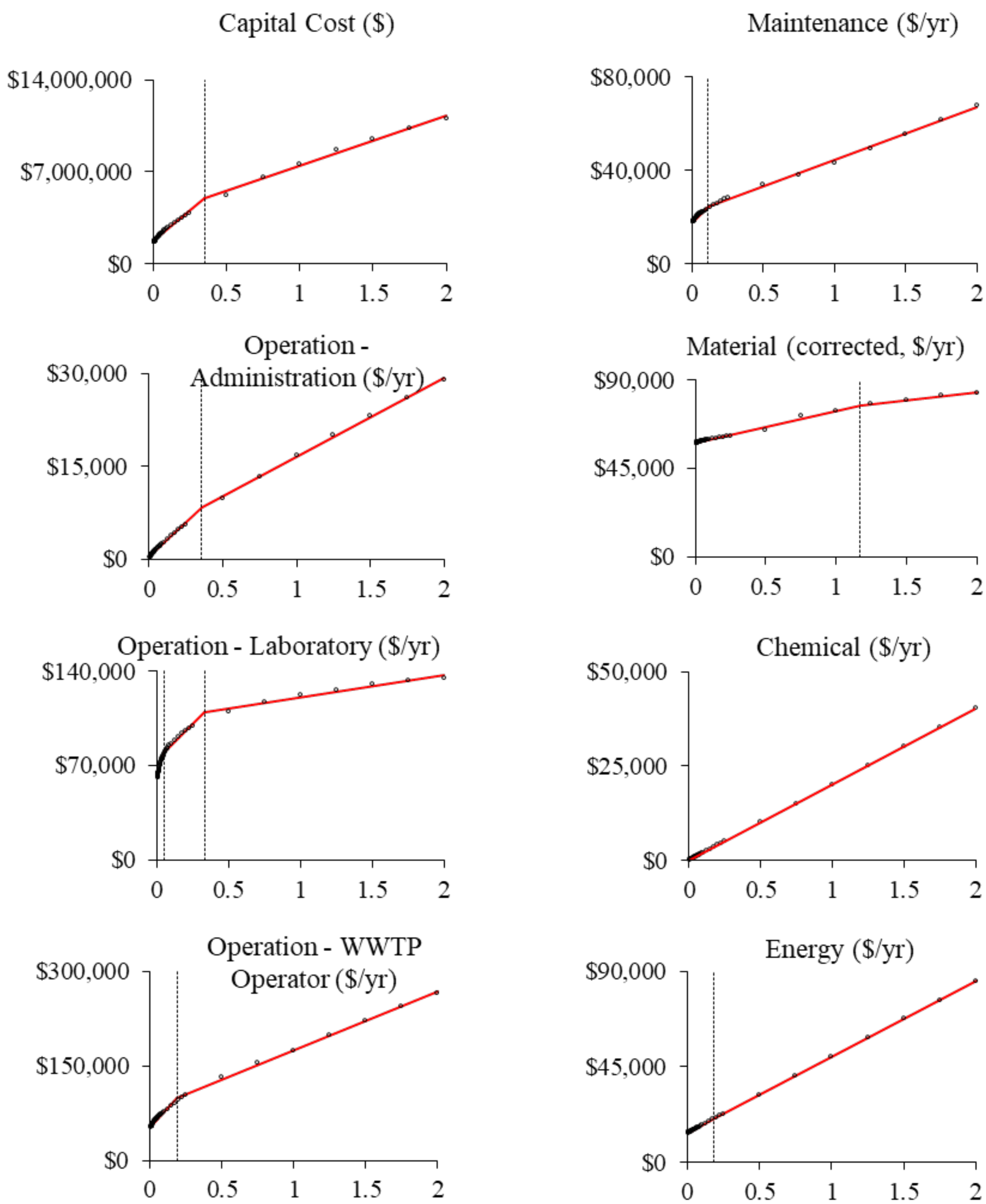

Figure 3. Regression fits for oxidation ditch activated sludge cost components using segmented regression. X-axis; design flow. Y-axis; annual cost (except for capital cost, where Y axis is total cost). Dashed vertical lines denote segment breakpoints. Note that the segmented regression algorithm found 3 segments best fit the cost componant "Operation – Laboratory" whereas the algorithm found a single segment best fit the cost componant "Chemical".

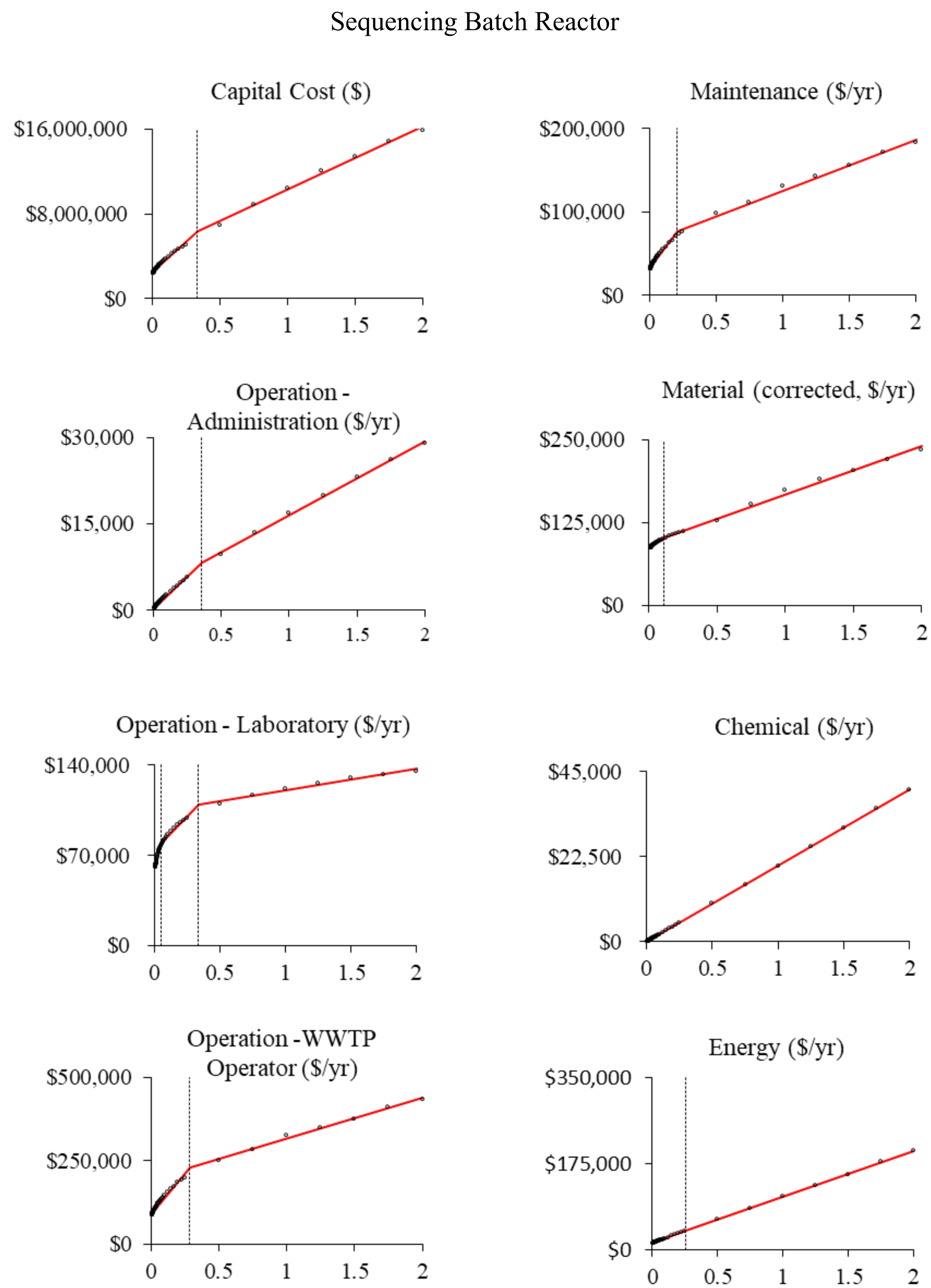

Figure 4. Regression fits for Sequencing Batch Reactor cost components using segmented regression. All conventions the same as Figure 3.

The segmented regression algorithm returned a single break point for Capital, Operation – Administration, Operation - WWTP Operator, Maintenance, Material, and Energy costs. Thus, the model for these costs can be expressed as:

IF Flow ≤ Breakpoint THEN Cost = Intercept_1 + (Slope_1 × Flow)

IF Flow > Breakpoint THEN Cost = Intercept_2 + (Slope_2 × Flow)

The segmented regression algorithm returned two break points for Operation – Laboratory costs. Thus, the model for this cost can be expressed as:

IF Flow ≤ Breakpoint_1 THEN Cost = Intercept_1 + (Slope_1 × Flow)

IF (Flow > Breakpoint_1 AND Flow ≤ Breakpoint_2) THEN Cost = Intercept_2 + (Slope_2 × Flow)

IF Flow > Breakpoint_2 THEN Cost = Intercept_3 + (Slope_3 × Flow)

The segmented regression algorithm returned no break points for Chemical costs. Thus, the model for this cost can be expressed as:

Cost = Intercept_1 + Slope_1 × Flow

Tables 2 and 3 show the regression coefficients and breakpoints for each cost component for the oxidation ditch activated sludge system and sequencing batch reactor systems, respectively. The regression coefficients are rounded to the nearest integer and the coefficients of determination are rounded to three decimal places.

Table 2. Oxidation ditch activated sludge system regression coefficients and coefficients of determination.

Cost Component	Slope_1	Intercep_1	Break point_1	Slope_2	Intercept_2	Break point_2	Slope_3	Intercept_3	R^2
Capital ($)	9,424,214	1,659,736	0.352	3,847,143	3,624,214				0.998
Chemical ($/y)	20,136	1							1.000
Energy ($/y)	38,355	13,608	0.185	35,621	14,115				1.000
Maintenance ($/y)	58,388	18,005	0.112	22,499	22,020				0.997
Material ($/y)	16,431	57,981	1.170	7,825	68,049				0.998
Operation - Administration ($/y)	22,405	372	0.356	12,727	3,815				1.000
Operation - Laboratory ($/y)	430,686	57,846	0.050	106,574	74,011	0.335	16,429	104,179	0.998
Operation - WWTP Operator ($/y)	238,497	53,166	0.190	93,766	80,676				0.997

Table 3. Sequencing Batch Reactor regression coefficients and coefficients of determination.

Cost Component	Slope_1	Intercept_1	Break point_1	Slope_2	Intercept_2	Break point_2	Slope_3	Intercept_3	R^2
Capital ($)	11,754,984	2,398,142	0.335	5,967,143	4,334,214				0.998
Chemical ($/y)	20,109	1							1.000
Energy ($/y)	99,017	13,004	0.256	93,504	14,415				1.000
Maintenance ($/y)	217,968	31,035	0.211	61,581	64,104				0.998
Material ($/y)	154,510	85,829	0.109	72,697	94,783				0.997
Operation - Administration ($/y)	22,405	372	0.356	12,727	3,815				1.000
Operation – Laboratory ($/y)	430,686	57,846	0.050	106,574	74,011	0.335	16,429	104,179	0.998
Operation - WWTP Operator ($/y)	491,843	88,879	0.286	122,000	194,643				0.999

2.5. Cost Adjustments

The regression models provide cost estimates in year 2019 dollars. Both the ILT and SLCES tool adjust regression model outputs to year 2022 dollars and account for state and territory-specific differences in two steps. The tools first adjust regression model cost estimates in year 2019 dollars to year 2022 dollars. The tools then adjust costs in year 2022 dollars to account for state and territory-specific differences in the cost of materials and labor. Puerto Rico is the only U.S. territory included in one of the tools (the ILT) because it is the only U.S. territory for which all the necessary Census data were available.

2.5.1. Capital Costs

The ILT and SLCES tool adjust capital cost estimates to year 2022 dollars using the USACE CWCCIS indices for Buildings, Grounds, and Utilities (https://www.usace.army.mil/Cost-Engineering/cwccis/). The tools calculate the ratio of the CWCCIS year 2022 Buildings, Grounds, and Utilities index to the CWCCIS year 2019 Buildings, Grounds, and Utilities index, and then multiply the capital cost regression output by this ratio. The tools then use the CWCCIS state adjustment factors to adjust capital costs due to differences in the cost of materials and labor among states by multiplying capital costs in year 2022 dollars by the 2022 CWCCIS state adjustment factor for that state. Neither tool adjusts capital costs for Puerto Rico (i.e., the ILT assumes a state adjustment factor of 1) because CWCCIS adjustment factors for Puerto Rico are not available.

2.5.2. O&M Costs

The EPA defines O&M costs as the sum of Operation (composed of Wastewater Treatment Plant Operator, Administrative, and Laboratory), Maintenance, Material, Chemicals, and Energy costs. The regression equations return average O&M costs for the United States in year 2019 dollars. The ILT and SLCES tools adjust O&M costs by first adjusting the estimates derived from the regression equations to 2022-year dollars and then further adjusting those estimates to account for differences in costs among states and territories. For O&M costs, adjustment factors for

Puerto Rico were available for Operation and Maintenance Labor and for Energy, but not for Material and Chemical Costs. For Material and Chemical Costs, the ILT assumes a state adjustment factor of 1 for Puerto Rico.

2.5.2.1. Operation and Maintenance Labor

The ILT and SLCES tool first adjust operation labor cost and maintenance labor costs to year 2022 dollars using median hourly wages from the National Occupational Employment and Wage Estimates for the United States included in the BLS Occupational Employment Statistics at: https://www.bls.gov/oes/tables.htm. The tools adjust labor costs to year 2022 dollars by calculating the ratio of year 2022 median wages to year 2019 median wages for the occupational titles Chemical Technicians and Water and Wastewater Treatment Plant and System Operators. The tools adjust Laboratory costs to year 2022 dollars by multiplying the estimated costs in year 2019 dollars derived from the regression equations with the year 2022 to year 2019 ratio calculated for the BLS occupational title Chemical Technicians. The tools adjust Wastewater Treatment Plant Operator, Administrative, and Maintenance costs to year 2022 dollars by multiplying the estimated costs in year 2019 dollars derived from the regression equations by the year 2022 to year 2019 ratio calculated for the BLS occupational title Water and Wastewater Treatment Plant and System Operators.

After adjusting labor cost estimates to year 2022 dollars, the ILT and SLCES tools adjust costs to account for state- and territory-specific differences in the cost of labor. The tools calculate the ratio of the year 2022 national median wage for occupational title Chemical Technicians, and for occupational title Water and Wastewater Treatment Plant and System Operators, to the year 2022 state-specific median wages for those same occupational titles. The tools then multiply the Laboratory costs by the state-specific ratio calculated for the BLS occupational title Chemical Technicians and multiply the Wastewater Treatment Plant Operator, Administrative, and Maintenance costs by the state-specific ratio calculated for the BLS occupational title Water and Wastewater Treatment Plant and System Operators.

2.5.2.2. Material and Chemical Costs

The ILT and SLCES tools adjust material and chemical cost estimates to year 2022 dollars and then adjust for state-specific differences using the same method used to adjust capital costs (see section 2.5.1 above for details).

2.5.2.3. Energy

The ILT and SLCES tools adjust energy costs to year 2022 dollars and adjust for state- and territory-specific differences in energy costs using energy price data from the U.S. Energy Information Administration (https://www.eia.gov/electricity/data/eia861m/xls/sales_revenue.xlsx). The tools first adjust the energy cost regression output (U.S. average costs in year 2019 dollars) to year 2022 dollars by calculating the ratio of the U.S. average commercial sector electricity rate for the year 2022 to the U.S. average commercial sector electricity rate for the year 2019, and then multiplying the energy cost regression output by this ratio. The tools then adjust this cost estimate to account for state- and territory-specific differences by calculating the ratio of the average commercial sector electricity rate for the state or territory in the year 2022 to the U.S. average commercial sector electricity rate in the year 2022, and then multiplying U.S. average energy costs in year 2022 dollars by this ratio.

2.6. Performance (Effluent Quality) Estimates for Full Replacement Systems

The EPA derived effluent ammonia concentration estimates for the full replacement systems (oxidation ditch activated sludge and sequencing batch reactor system) using CapdetWorks. The estimates are based on an influent ammonia concentration of 25 mg/L NH_3-N. The estimated effluent concentration varies based on winter and summer wastewater influent temperatures entered by the user (Figure 5). Based on the EPA technology fact sheets, the estimated effluent concentration values for the full replacement systems represent ammonia removal greater than or equal to 94%. However, it is worth noting that CapdetWorks documentation emphasizes that it is a cost estimation software program and not intended for modeling effluent quality. Figure 5 shows influent temperature versus effluent ammonia concentration for both full replacement systems (oxidation ditch activated sludge system and sequencing batch reactor system) modeled by CapdetWorks.

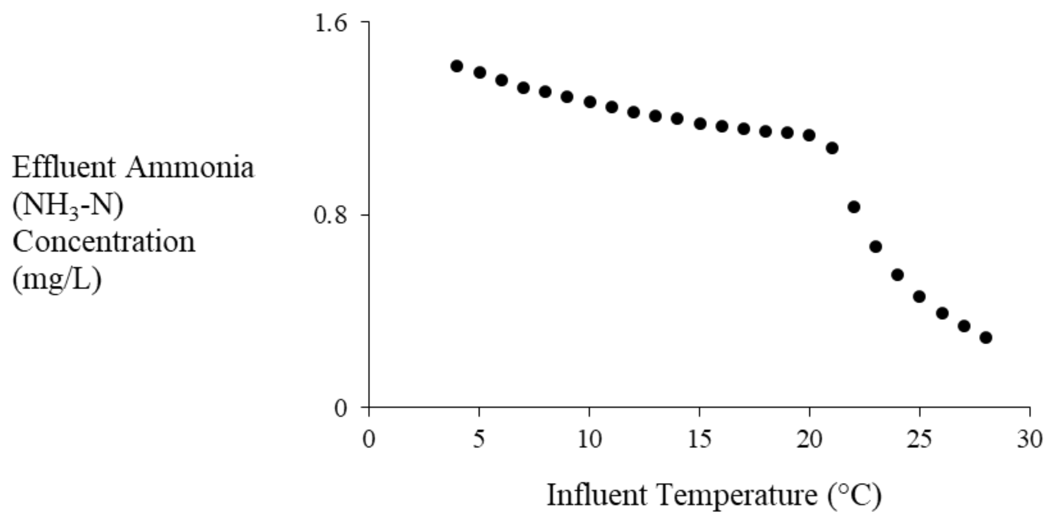

Figure 5. Influent temperature vs. effluent ammonia concentration for the full replacement systems.

3. Insulated Floating Covers

The ILT provides the option of evaluating whether installing insulated floating lagoon covers for an existing aerated lagoon would result in a substantial social and economic impact. The EPA developed a cost model for insulated lagoon covers using the following strategy:

1. Estimate the price per square foot of a generic insulated lagoon cover using estimates from several lagoon cover vendors. Vendors were identified via internet searches (as detailed below).
2. Design a generic lagoon wastewater treatment system in CapdetWorks.
3. Use CapdetWorks to estimate the surface area of generic lagoon wastewater treatment systems that have selected design flows ranging between 0.01 and 2.00 MGD.

4. Estimate the cost of insulated covers for lagoon wastewater treatment systems with each selected design flow by multiplying the estimated areas for each generic lagoon wastewater treatment system by the generic price per square foot.
5. Use regression to develop a model of lagoon cover cost for any design flow between 0.01 and 2.00 MGD.

3.1. Assumptions

Lagoon cover cost estimates assumed minimal fluctuations in lagoon level when operational, open access to all sides of the lagoon during installation, a dry lagoon during installation, and no necessary earthwork prior to installation. Two vendors requested additional information before providing cost estimates. In response to their questions, the EPA specified the following parameters:

- Lagoon walls have 30° slope.
- Lagoon location does not experience significant sustained wind.
- Water temperature ranges between 40°F and 80°F.
- There are no moving mechanical parts at the lagoon surface.
- The lagoon is located at the front range of the Rocky Mountains in Colorado.

When estimating lagoon area for different design flows, the EPA assumed lagoon systems with an average design flow of 0.5 MGD or less were single cell lagoon systems, and lagoon systems greater than 0.5 MGD were two-unit lagoon systems. In addition, cost estimates assumed coverage of the total surface area of the lagoon system.

3.2. Insulating Cover Properties

The EPA identified vendors from internet searches using the search terms: “insulated”, “floating”, “modular”, “cover”, “pond” and “lagoon.” Based on the search results, the EPA reviewed information from 12 vendors to determine if they supply the type of cover that could be used for lagoon wastewater treatment systems. The EPA contacted 8 vendors either through email or telephone to obtain additional information about an insulated floating cover for a hypothetical 1-acre (approximately 200 ft x 200 ft) lagoon wastewater treatment system. A 1-acre lagoon wastewater treatment system equates to an effluent flow of approximately 0.25 MGD. Of the 8 vendors the EPA contacted, 5 vendors claimed they could supply such covers. The EPA requested a cost estimate from each of these 5 vendors during the month of August 2021. The EPA received cost estimates from 4 vendors for 5 types of covers (one vendor did not provide a cost estimate). The ILT assumes no additional operation and maintenance costs after installation of lagoon covers.

The EPA received vendor cost estimates for insulated covers with varying insulating properties. For example, IEC (Industrial and Environmental Concepts, Inc.) and AWTT (Advanced Water Treatment Technologies) both claimed an insulation R-value of 17. The Layfield Group claimed an insulation R-value of 4. The Lange Containment Systems Inc. (Lange) described its high-density polyethylene (HDPE) cover as insulated but made no claims regarding its insulating properties.

3.3. Vendor Cost Estimates

Vendors provided cost estimate information that ranged from detailed proposals based on many assumptions to rough estimates provided over the phone based on few assumptions. Vendors ranged from small companies operating out of a single office to large firms with multiple offices nationwide. The estimate from IEC was based on a company supplied site supervisor overseeing work performed by local labor and rental equipment. Other quotes were based on installation by crews supplied by the vendor. The AWTT covers have minimal installation costs because the product consists of thousands of floating hexagonal tiles deposited into the lagoon and allowed to slowly spread across the surface. Table 4 summarizes the cost estimates provided by the vendors.

Table 4. Vendor Cost Estimates for Floating Insulated Lagoon Covers

Supplier[4]	Product	Insulation Factor	Cost/ft^2	Includes Installation	Includes Shipping
IEC	R17 lagoon cover	R17	\$5.05	X[1]	X
AWTT	Hexprotect Max R17	R17	\$5.65	X	X
Lange Containment	HDPE Cover with Foam Insulation	NA	\$7.25		
Lange Containment	UV Stable XR-5 Reinforced Geomembrane	NA	\$8.50	X	
Layfield Group	EL 6050 45 mil floating cover	R4	\$4.00	X	X
Mid-point of range			\$6.25		

[1]Based on Minnesota local labor costs and one company supplied supervisor.

Cost estimates range between \$4.00/ft^2 (including shipping and installation) and \$8.50/ft^2 (including installation but not shipping). The mid-point of the range of vendor cost estimates is \$6.25/ft^2.

To provide additional verification of the vendor cost estimates, these costs were compared to the costs published in a 2017 report from the Colorado Department of Public Health and Environment (CDPHE) entitled: "User Guide for Selection of Lagoon Treatment Technology for Ammonia Removal" (CDPHE 2017). The CDPHE 2017 report provides categorical cost estimates (low, middle, and high) for the year 2017. To compare the CDPHE 2017 cost estimates to the EPA's cost estimates obtained from vendors in 2021, the EPA adjusted the CDPHE 2017 cost estimates to year 2021 dollars using the U.S. Army Corps of Engineers (USACE) Civil Works Construction Cost Index System (CWCCIS) annual (fiscal year) cost indices for Buildings, Grounds, and Utilities. The EPA also adjusted the CDPHE 2017 cost estimates to year 2019 dollars (the base year of the full replacement cost models developed using CapdetWorks) using the USACE CWCCIS. CDPHE 2017 estimates installation costs as 15-25% of material costs. The EPA estimated installation costs by applying 15%, 20%, and 25% of material costs to

[4] As noted above, mention of trade names or use of commercial products does not constitute endorsement or recommendation for use.

the low, middle, and high categorical estimates, respectively. Table 5 summarizes estimated costs for modular floating insulated covers by CDPHE (2017).

Table 5. Estimated costs for modular floating insulated covers by CDPHE 2017 as reported and adjusted to year 2021 dollars

Cost category	Cost/ft^2 (2017 - year of CDPHE report).	Cost per ft^2 (adjusted to year 2021 dollars)
Low	\$4.60	\$5.16
Middle	\$5.70	\$6.39
High	\$6.88	\$7.71

The middle cost category from CDPHE 2017 in 2021 dollars including installation is \$6.39/ft^2, which is close to the \$6.25/ft^2 mid-point between the highest and lowest cost estimates the EPA obtained from vendors in 2021.

3.4. Regression Analysis

The EPA used CapdetWorks to estimate the surface area of generic lagoon wastewater treatment systems with selected design flows ranging between 0.01 and 2.00 MGD. The EPA then estimated the cost of insulated lagoon covers for each of these generic lagoon wastewater treatment systems by multiplying the estimated surface area of each generic lagoon wastewater treatment system by the estimated unit cost in dollars per square foot. The EPA then used regression techniques to develop a model of lagoon cover cost for any design flow between 0.01 and 2.00 MGD.

The EPA received cost estimates from vendors in the year 2021. Thus, the mid-point of the range of vendor cost estimates shown in Table 5 (\$6.25/ft^2) is in year 2021 dollars. However, the EPA's cost models for the oxidation ditch and sequencing batch reactor systems are in year 2019 dollars with the ILT subsequently adjusting the output of the oxidation ditch and sequencing batch reactor system cost models to the "update year" of the tool (year 2022 at the time of this writing). To simplify future updating of the ILT to years beyond 2022, the EPA adjusted the unit cost of insulated lagoon covers to year 2019 dollars (the same year as the output of the oxidation ditch and sequencing batch reactor cost models) by calculating the ratio of the CWCCIS year 2019 Buildings, Grounds, and Utilities index to the CWCCIS year 2021 Buildings, Grounds, and Utilities index, and then multiplying the mid-point of the range of vendor cost estimates (\$6.25/ft^2) by this ratio. Thus, the EPA used \$5.97/ft^2 as the unit cost of insulated lagoon covers to develop the insulated covers cost model.

Visual inspection suggests a linear relationship between cost and average design flow. Figure 6 shows the cost of lagoon covers (in year 2019 dollars) for each evaluated design flow and the linear regression fit using ordinary least squares regression.

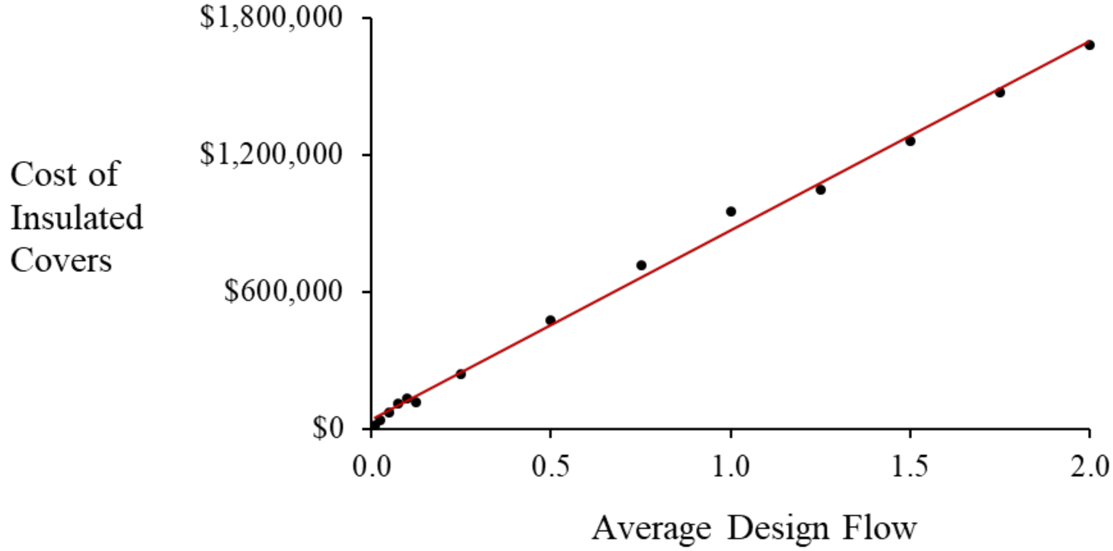

Figure 6. Regression of insulated lagoon cover cost on flow using ordinary least square linear regression.

Lagoon cover costs are highly correlated with average design flow from 0.01 MGD to 2 MGD (Pearson correlation coefficient r = 0.998). Thus, cost was estimated using the ordinary least squares linear regression model:

$$\text{Cost (\$)} = \$39{,}855 + \$828{,}412 \times \text{Flow (MGD)}$$

The ILT uses this formula to estimate lagoon cover costs for a lagoon with the average design flow value specified by the user, and then adjusts that cost estimate to the update year of the tool (year 2022 at the time of this writing) and to account for state-specific differences in costs.

3.5. Cost Adjustments

The ILT estimates the cost of insulated lagoon covers in year 2019 dollars by applying the regression equation above and then adjusts the resulting cost value to year 2022 dollars using CWCCIS as described in Section 2.5.1. The ILT then adjusts the resulting national average value to accommodate location-specific differences using CWCCIS state-specific adjustment factors as described in Section 2.5.1.

3.6. Performance (Effluent Quality) Estimates

The estimated effluent ammonia concentrations provided by the ILT are static. The tool estimates effluent ammonia concentrations of 20 mg/L in winter and 4 mg/L in summer regardless of the winter and summer wastewater temperatures entered into the tool. These effluent concentrations correspond to the expected level of ammonia removal cited in CDPHE (2017) for lagoon wastewater temperatures of 10°C and 25°C. Note that the influent wastewater temperature and the temperature in the lagoon (which may have long hydraulic retention time and is assumed to be completely mixed) may be different.