Statewide Water Supply Initiative Update Technical Memorandum

Prepared for:
Colorado Water Conservation Board

Project Title:

Colorado Water Project Cost Estimating Tool

Subject: B: Cost Curves Development
Date: December 1, 2018
To: Russ Sands, Colorado Water Conservation Board
From: CDM Smith
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Appendix B: Colorado Water Project Cost Estimating Tool Unit Costs and Cost Curves Development

Cost curves were derived from various sources of data for each of the project modules as discussed in the following sections. Where data was not available in terms of year 2017 dollars, the values were converted from the year available to 2017 using Equation B.1.

Equation B.1. $F = \mathrm{P}(1 + i)^n$

Where F = future cost or year 2017 cost

P = present cost or available cost from a given year

i = inflation rate

n = difference in years from year of available data to 2017

SWSI selected an inflation rate of 3.5% based on the rolling average of historical prices.

Not included are curves for water rights or user-specified projects as those modules rely on user input only.

B.1: Pipelines Module Application of Cost Data

Cost curves for the Pipelines Module are included for pipelines, pump stations, and storage tanks. Cost for pipelines are in dollars per linear foot (LF) for a given diameter in inches. For pipelines, costs curves from a previous CWCB costing tool, the Texas Unified Costing Model (UCM) and Denver Water were all converted to 2017 dollars and compared. All compared similarly; therefore, the Denver Water source was used as it was most applicable to Colorado projects.

The selected curves considered costs for undeveloped or rural areas and developed or urban areas. The Pipelines Module refers to the construction environment as Urban or Rural. An Urban environment is already developed, and construction is more difficult resulting in a higher cost compared to Rural where construction is assumed to cost less. The cost curves are shown in Figure B-1Error! Reference source not found..

Pump station and storage tank cost curves are based on the curves in the Texas UCM for intake and booster pump stations and ground storage tanks (with roofs). Then the curves were escalated from 2013 to 2017 dollars. The pump station cost curves are shown in Figure B-2 and are based on pump station power in horsepower. The storage tank cost curve shown in Figure B-3 is based on storage volume in million gallons.

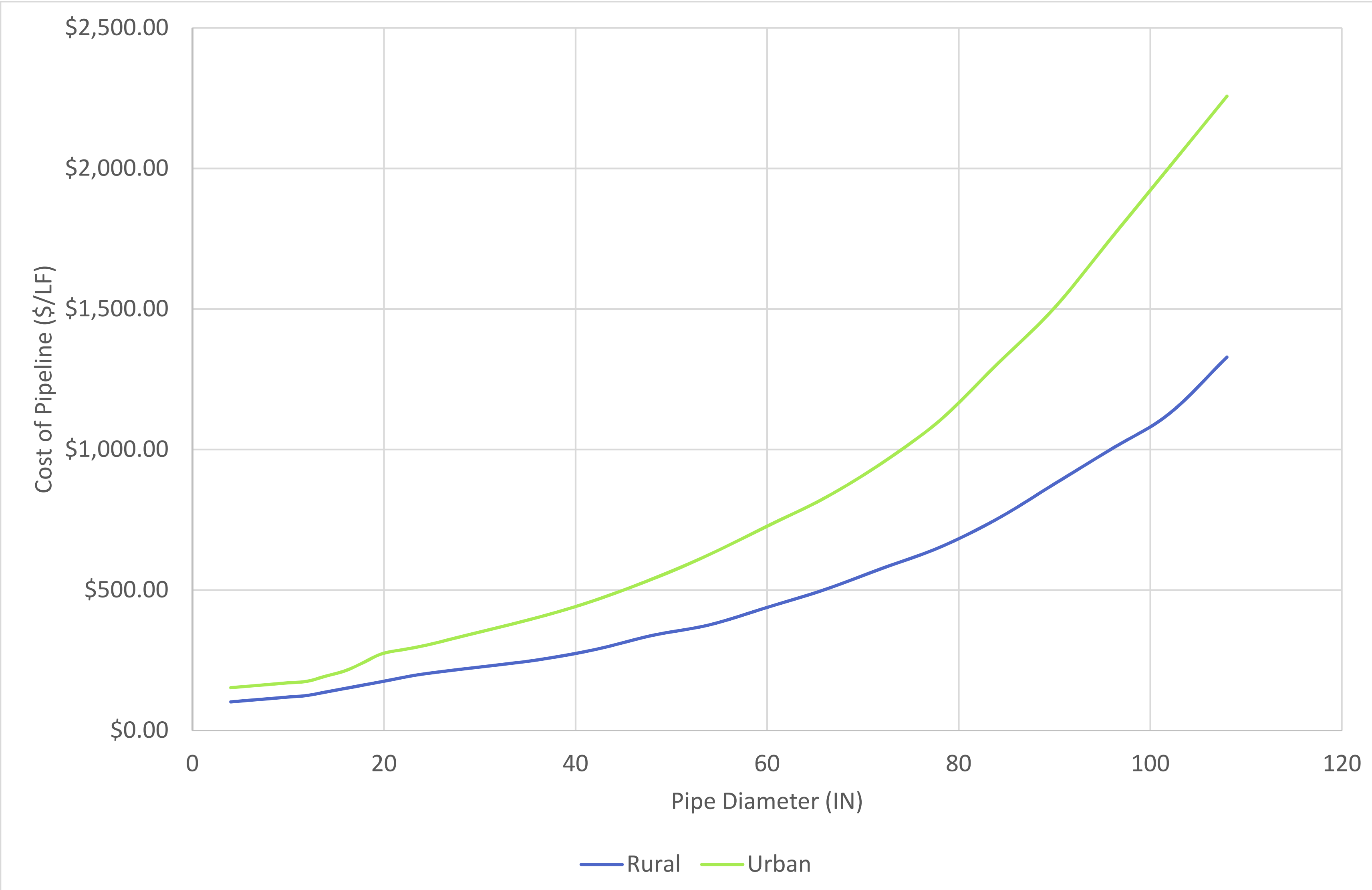

Figure B-1 Pipelines Cost Curve

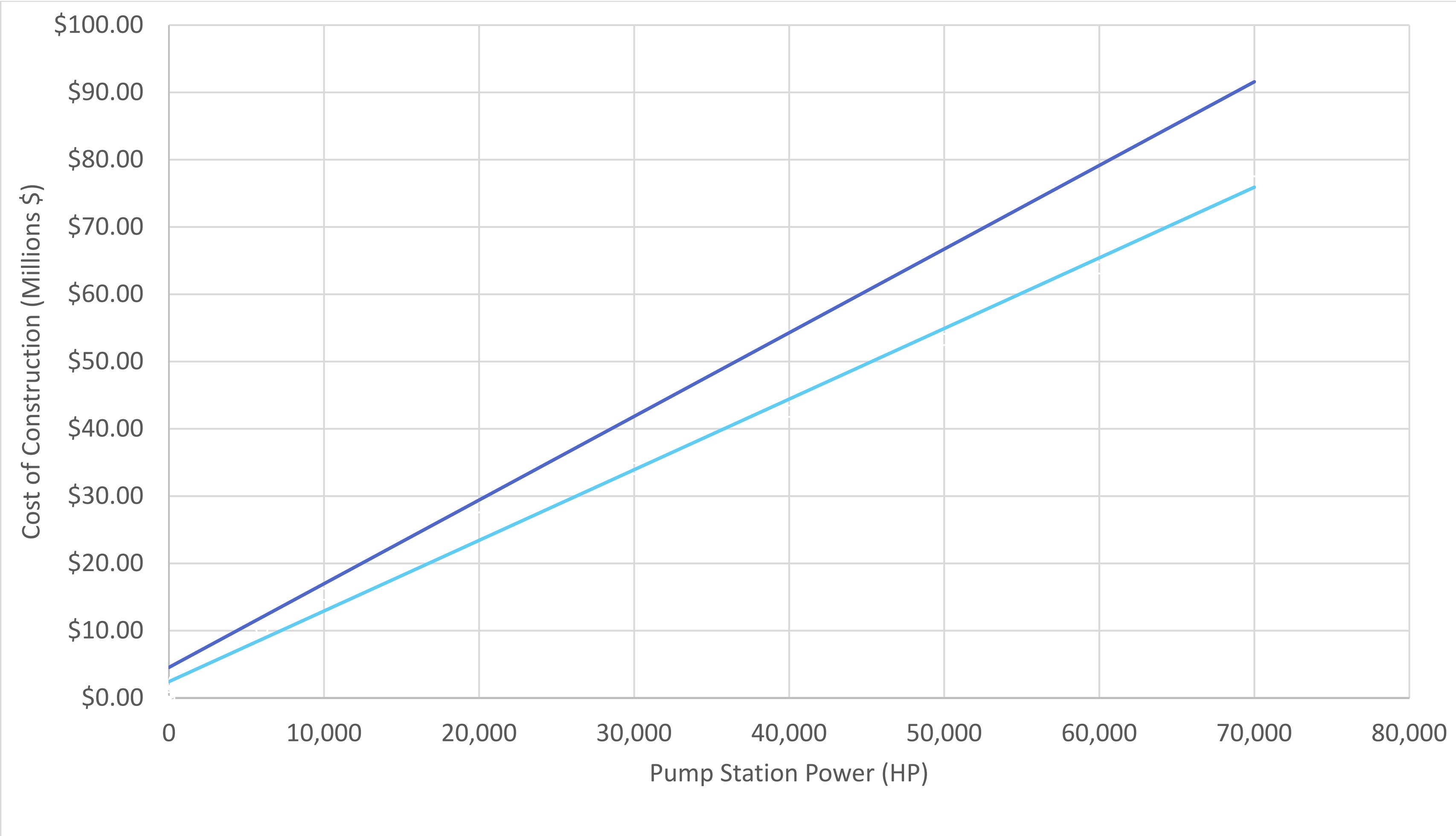

Figure B-2 Pump Station Cost Curves

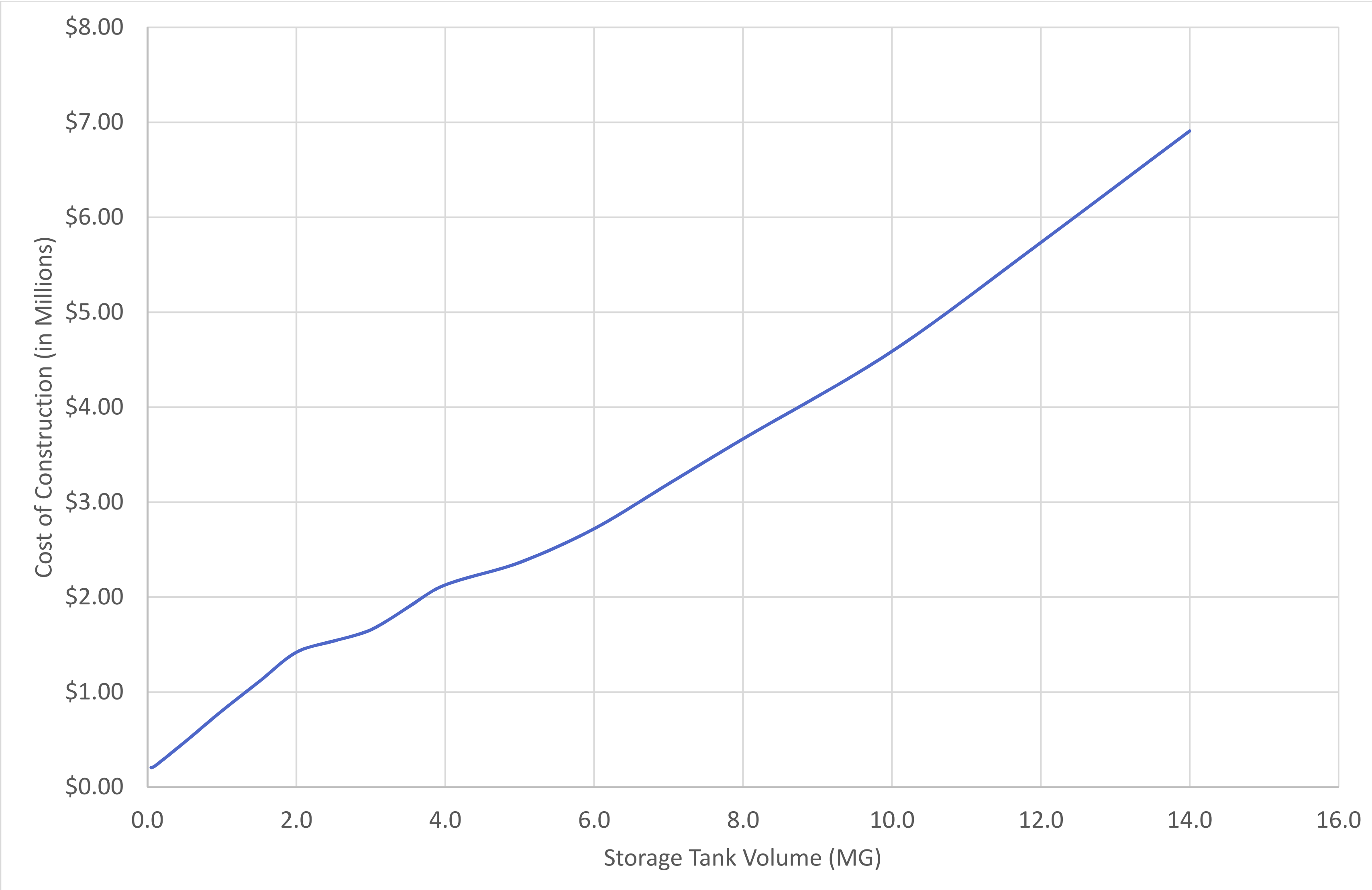

Figure B-3 Booster Pump Station Storage Tank Cost Curve

B.2: Well Fields Module Application of Cost Data

Cost curves for varying well capacities from 150 gpm to 1800 gpm were developed for each of the three well types: public supply, aquifer storage and recovery and irrigation. To derive the capital cost for well construction, the well capacity and depth are applied to the curve for the specific well type to return a capital cost for construction of individual wells. The cost curves are shown in Figure B-4Error! Reference source not found., Figure B-5 and Figure B-6Error! Reference source not found.. The cost for each well is summed in the Costing Module to return the cost for construction of the entire well field. The cost curves represent only the cost for construction of a well, and do not include pumping or piping costs from the well to the transmission line or to the delivery point. The cost of water conveyance through the transmission line is accounted for in the Costing Module by referencing the pipelines and booster pump station cost curves.

The cost curves for the Well Fields Module were developed based on the cost curves from the Texas UCM. The cost curves from the Texas UCM were adjusted to represent 2017 dollars. Project costs from recent well field construction projects throughout the southwest were included in the development of the cost curves to verify the Texas UCM-based curves and adjust data to be more representative of the region and time period.

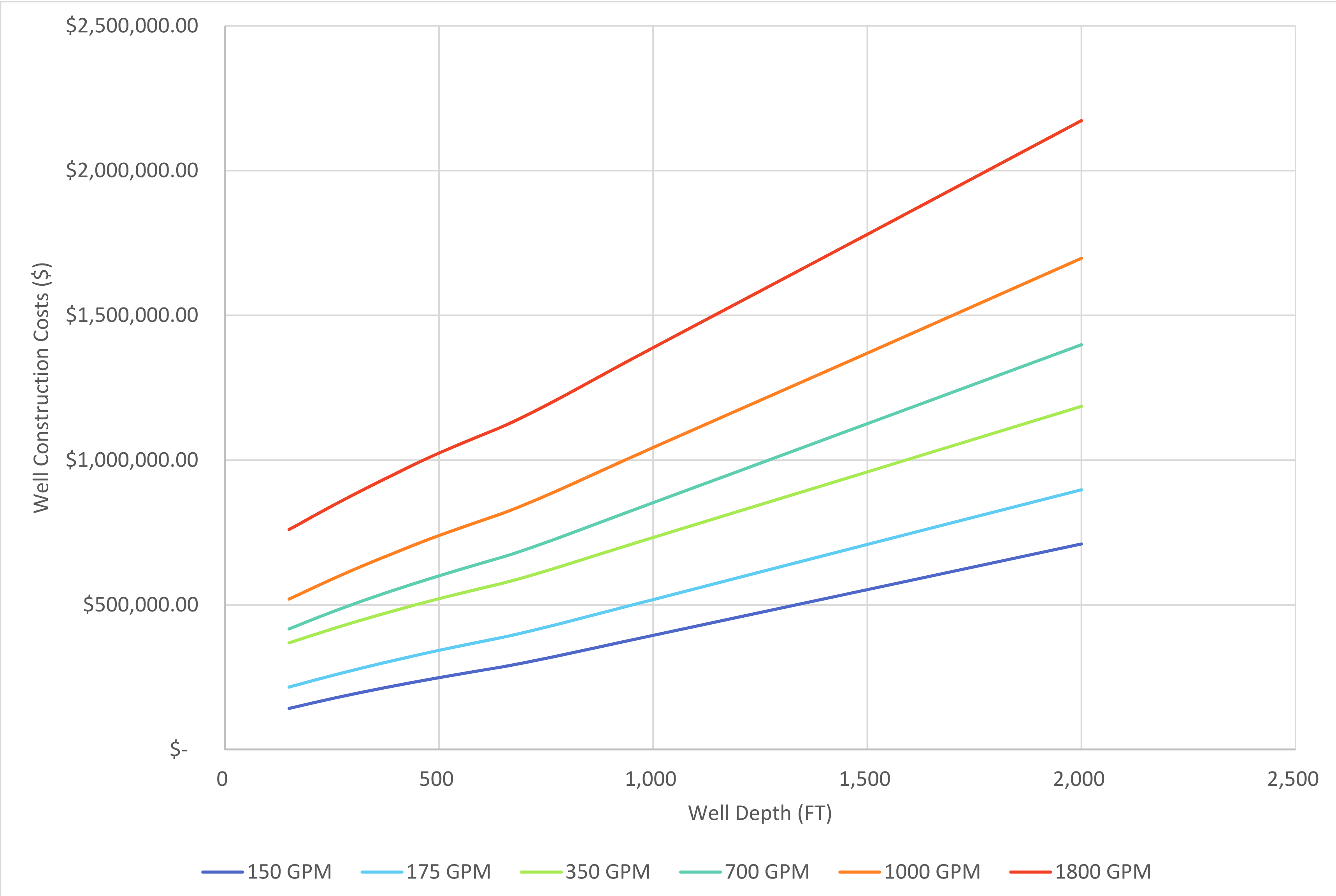

Figure B-4 Public Supply Well Cost Curves

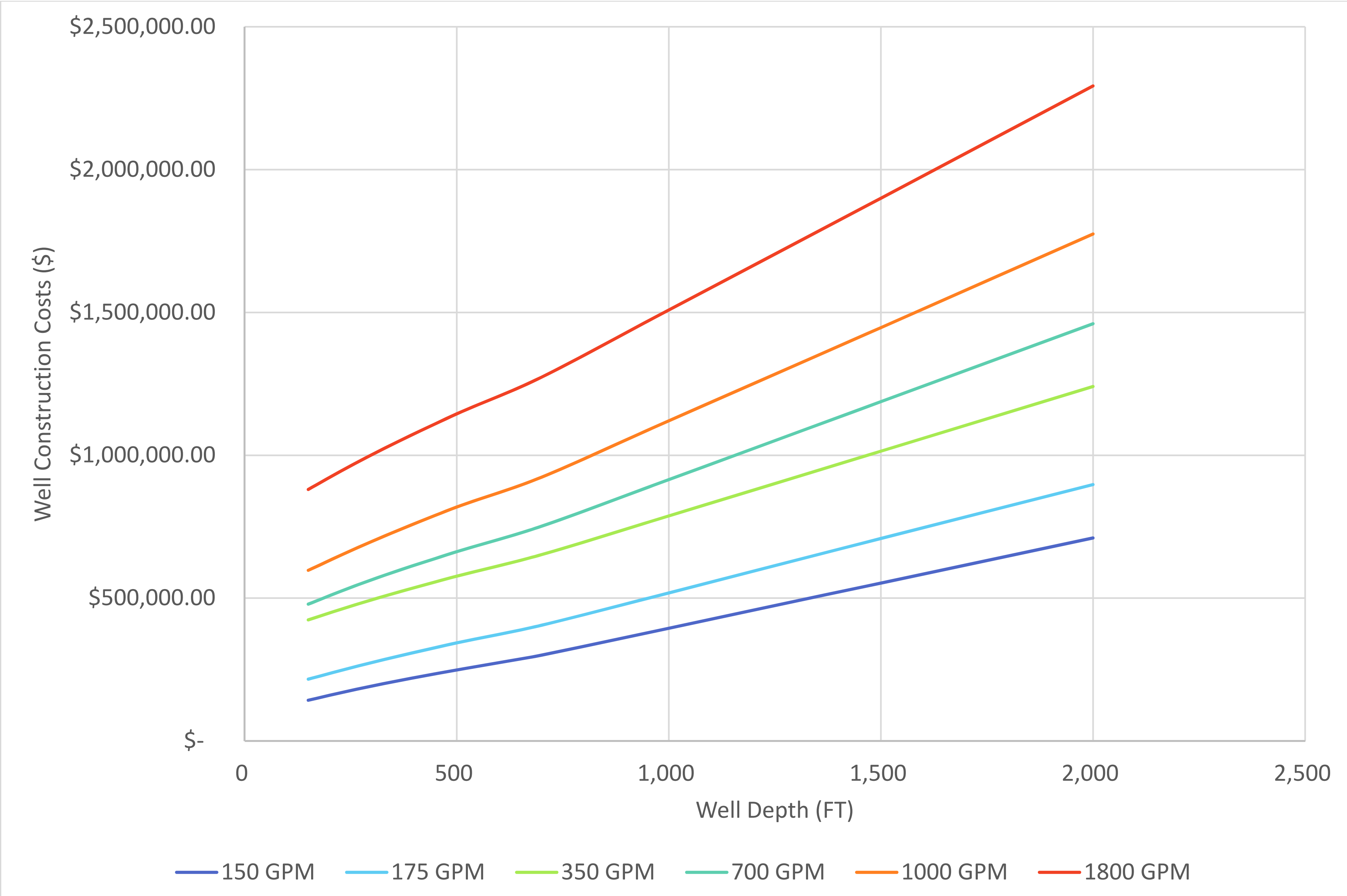

Figure B-5 Aquifer Storage and Recovery Well Cost Curves

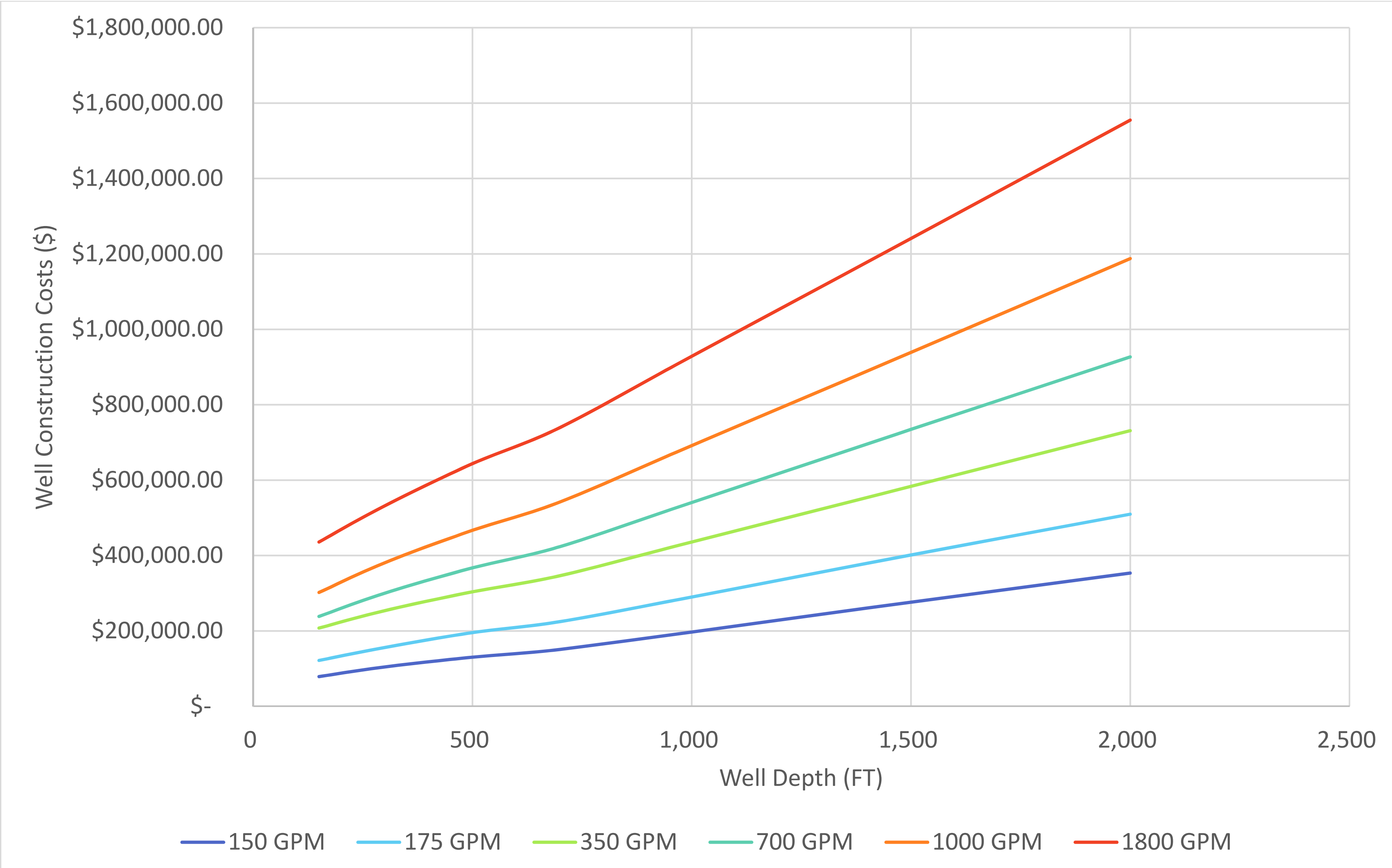

Figure B-6 Irrigation Well Cost Curves

B.3: Reservoir Module Application of Cost Data

To convert reservoir storage into costs, cost curves were developed for new reservoirs and reservoir expansions. Cost data from recent projects were provided by the Colorado School of Mines (Burrow, 2014) and used to develop the curves. A linear trend was fit to the data provided for new reservoirs based on storage volume and the resulting cost curve is shown in

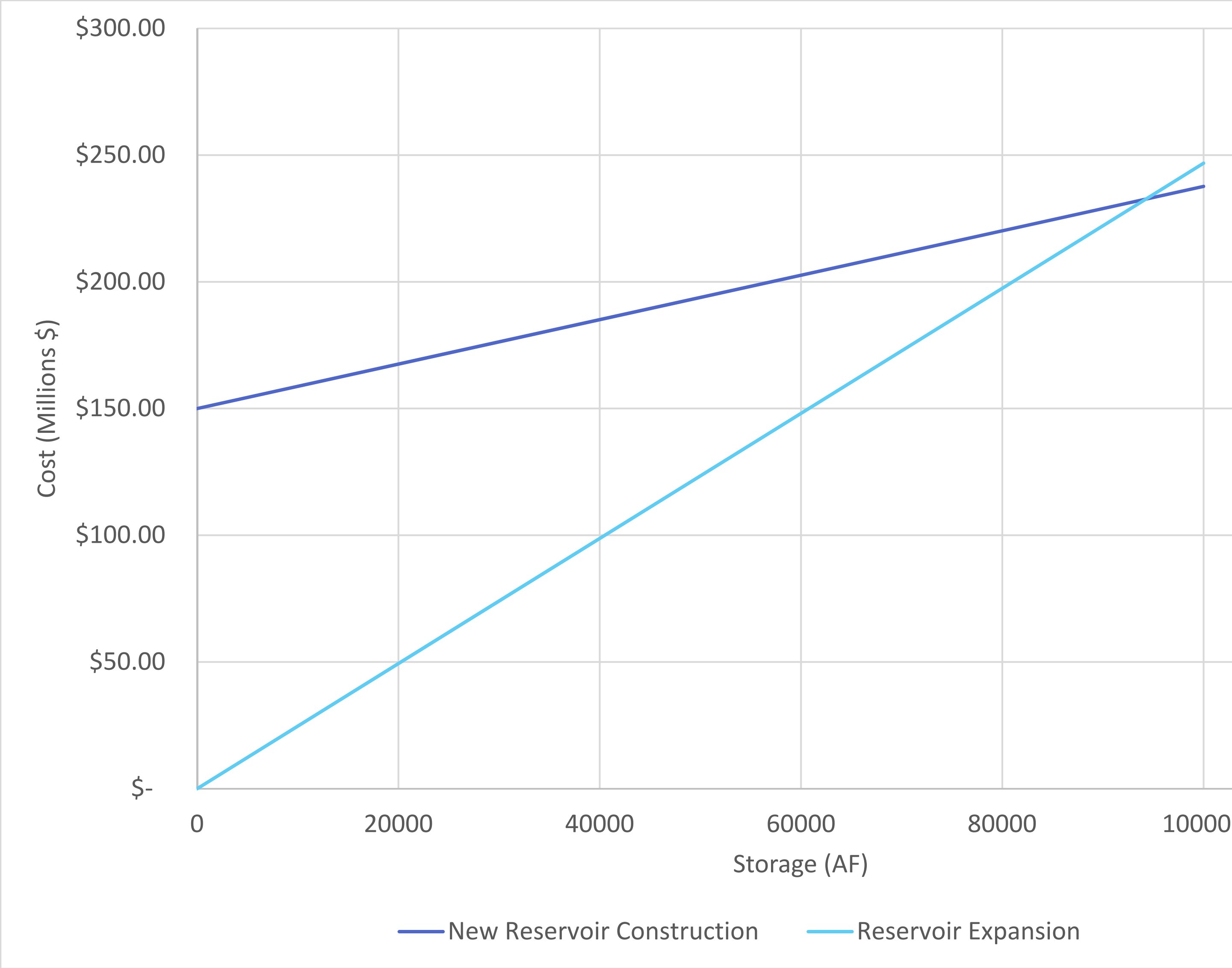

Figure B-7Error! Reference source not found.. Due to the limited data available for reservoir expansions, the median cost per acre-foot of storage was used to develop the cost curve shown.

The cost of reservoir rehabilitation (dam, spillway, outlet piping, etc. improvements) is highly variable, depending on the geometry and mechanics of the outlet works. Cost data detailed enough to provide cost curves representing reservoir rehabilitation for varying geometries and outlet works was not available. For this reason, the reservoir rehabilitation cost data is a direct input by the user. However, recognizing that while cost data provided in the Basin Implementation Plans and other sources was not detailed enough to develop a cost curve, the data may still be useful to help users estimate costs.

During review of the April 2015 BIPs, Projects and Methods, and IPPs were documented and categorized. The list of projects provided in Error! Reference source not found. represent projects that were (1) categorized as Reservoir Rehabilitation or Dam Improvements and (2) provided some level of rehabilitation cost estimate. Therefore, this list does not include all projects listed in the BIPs that may include reservoir rehabilitation. The user should take note that these projects may have limited detail on rehabilitation specifics and a professional engineer in the field of reservoir outlet works should be consulted for final project cost estimation.

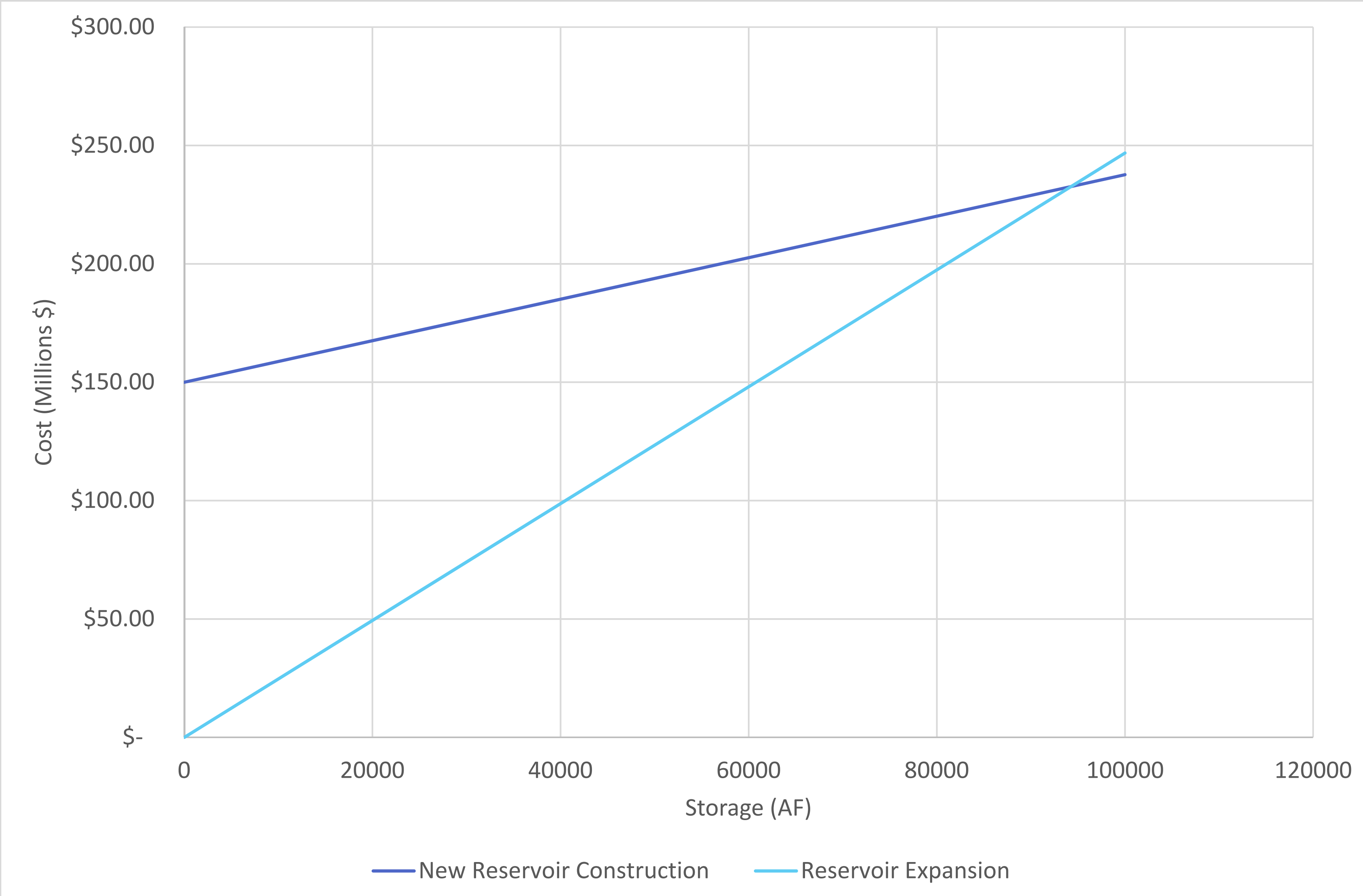

Figure B-7 New Reservoir Construction and Reservoir Expansion Cost Curves

Table B-1 Estimated Reservoir Rehabilitation Costs from 2015 Basin Implementation Plans

Basin	Project Name	BIP Project Description	Estimated BIP Cost	Notes
Gunnison	Paonia Reservoir Sediment Removal and Outlet Modification Project (Part 2)	Paonia Reservoir was designed to store 21,000 AF of water which is used for irrigation, flat-water recreation, fishing, augmentation, and improved late season flows to the North Fork of the Gunnison. Over the last fifty years, the reservoir has lost 24% of its total capacity due to sedimentation build up. The goal of this project is to investigate long-term sediment management options with the intent of minimizing future losses and possibly restoring current capacity losses.	$ 8,000,000	
Gunnison	West Reservoir #1 Outlet Pipe Replacement	West Reservoir is currently under a no-fill restriction from the State Engineers Office because of concerns about a deteriorating outlet pipe. The owners propose to replace the existing pipe and restore the reservoir to use, thus helping preserve a pre-1922 water right.	$ 426,317	
Gunnison	Lake San Cristobal Controlled Outlet Structure (Part 1)	Hinsdale County and the Upper Gunnison River Water Conservancy District (UGRWCD) explored the feasibility of constructing a new permanent control structure at the outlet of Lake San Cristobal. The new structure allows for more controlled releases to regulate the lake level and prevent failure of the structure during flood events. The additional stored water resulting from the project will be used primarily as augmentation water within the Lake Fork of the Gunnison River other beneficial uses include agriculture, recreation and releases for instream flows.	$ 40,000 *	
Gunnison	Lake San Cristobal Outlet Structure Modification (Part 2)	No detailed rehabilitation activities	$ 120,960 *	
Gunnison	Engineering for Lake San Cristobal Outlet Modification (Part 3)	No detailed rehabilitation activities	$ 75,265 *	
Gunnison	Juniata Reservoir Spillway Modification	No detailed rehabilitation activities	$ 97,000 *	
Gunnison	Hanson Reservoir Outlet Rehabilitation	No detailed rehabilitation activities	$ 50,000 *	

Basin	Project Name	BIP Project Description	Estimated BIP Cost	Notes
Gunnison	Lake San Cristobal Outlet Structure (Part 4)	No detailed rehabilitation activities	$ 150,000 *	
Gunnison	Hartland Dam Improvements	No detailed rehabilitation activities	$ 200,000 *	
Gunnison	Lining Outlet Pipe for Grand Mesa Reservoir #6	No detailed rehabilitation activities	$ 19,840 *	
Gunnison	Relief Ditch Diversion Dam Design	No detailed rehabilitation activities	$ 800,000 *	
Gunnison	Tunnel Reconstruction Project	No detailed rehabilitation activities	$ 730,110 *	
Gunnison	Dam Outlet Structure Repair	No detailed rehabilitation activities	$ 31,372 *	
Rio Grande	Mountain Home Reservoir Dam Repair	Rehabilitation of the Mountain Home Reservoir dam outlet works will improve dam safety and reliable water level management of the reservoir. The State is now requiring TIC to repair or upgrade the gates and to restore full operating capability at Mountain Home Reservoir. The Project will also provide improved water storage management and reduced storage loss (which currently amounts to 1,350 to 2,250 AF annually). Finally, improved outlet works will provide protection of the CPW conservation pool and enhancement of environmental, recreational, and wildlife habitat assets.	$ 500,000	Prelim Design: $20,000 Final Design: $20,000 Construction: $350,000 Admin, etc.: $100,00 Contingency: $10,000

Projects listed are not inclusive of all Reservoir Rehabilitation projects provided in the 2015 BIPs, but only represent those projects with an estimated cost for Reservoir Rehabilitation.

**Estimated cost reflects only WSRA requested funds. It is unknown if this cost represents the actual total cost of the rehabilitation, or only the funding amount requested from WSRA.*

B.4: Water Treatment Facility Module Application of Cost Data

To derive the capital cost for treatment facility construction, the calculated design capacity is applied to the cost curve for the selected treatment type. The cost curves for the Treatment Module were developed using the Cost Estimating Manual for Water Treatment (McGivney & Kawamura, 2008). The cost curves from the manual were adjusted to represent 2017 dollars and adjusted geographically based on Colorado-based water treatment projects, as data were available.

Different cost curves were developed for each of the eight conventional treatment types. The curves were developed based on treatment plants serving small or rural populations, assuming large municipal areas would develop more detailed engineering designs and cost estimate. However, while the curve is only developed for plants 20 mgd or smaller, if a larger plant capacity is input by the user, the tool will extrapolate a cost based on the curves shown in Figure B-8 and Figure B-9. A check for geographic sensitivity of treatment costs was performed, the curves were compared against average cost of construction for the eight treatment types provided by subject matter experts. It was determined that the national-scale cost estimates from the Cost Estimating Manual for Water Treatment were acceptable median estimates for Colorado-based projects. The cost curves for estimating water treatment capital construction costs are shown in Figure B-8.

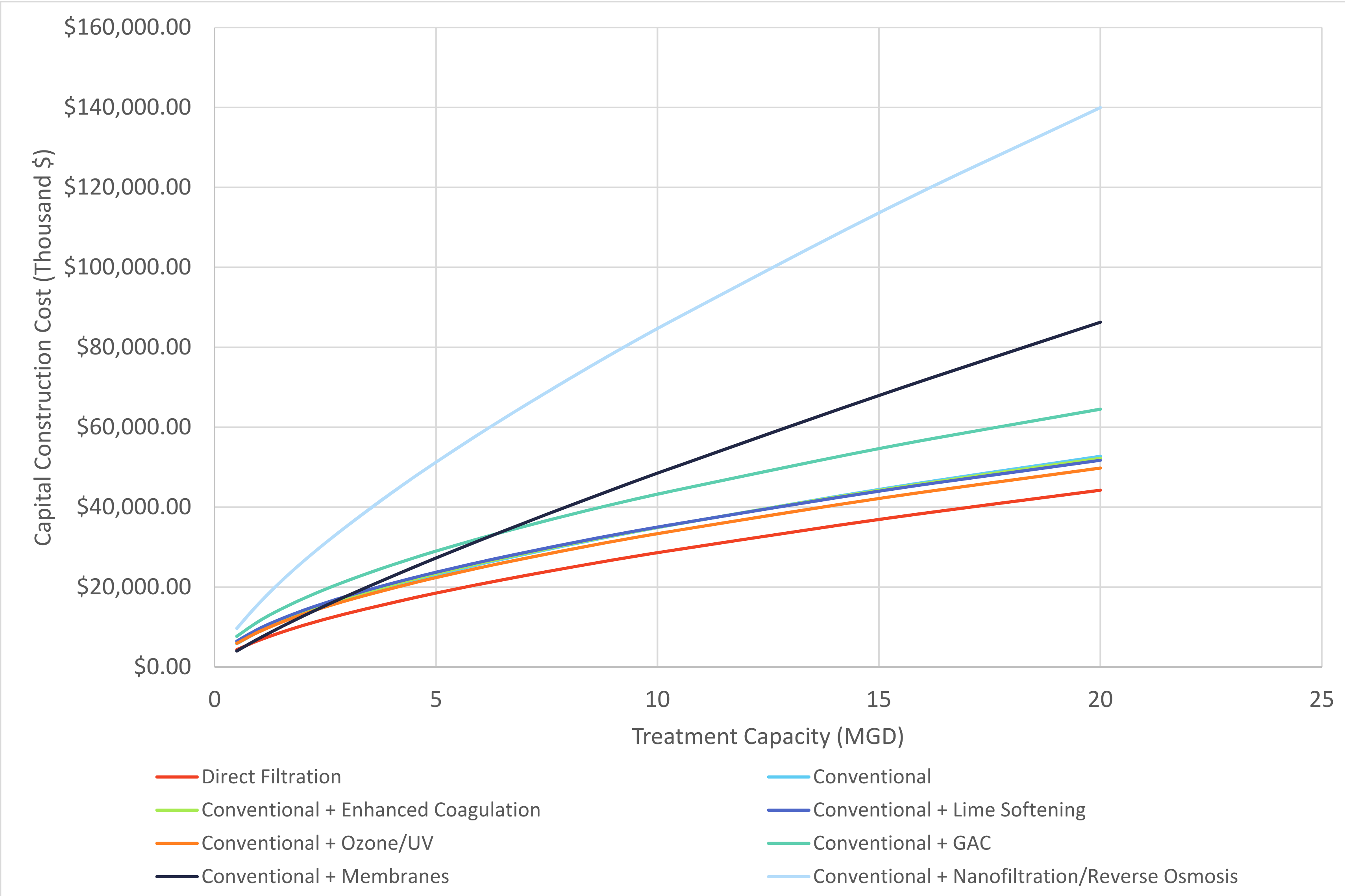

Figure B-8 Water Treatment Technology Capital Construction Cost Curves

A challenge in developing cost curves for treatment is the variability in plant processes. The treatment types were chosen to represent common treatment processes; however, in real-life applications processes may be added or removed to meet community needs. Therefore, where appropriate, adjustments were made to the Cost Estimating Manual curves for the treatment types using available costing data. For treatment types where costing data was lacking, values were interpolated between known cost curves. For example, the Cost Estimating Manual does not have a cost curve for conventional plus enhanced coagulation treatment, but costs are expected to fall between conventional and conventional plus lime softening; therefore, costs were interpolated between the two known treatment types. The estimated costs for these curves are similar and provided in Figure B-9 for clarity.

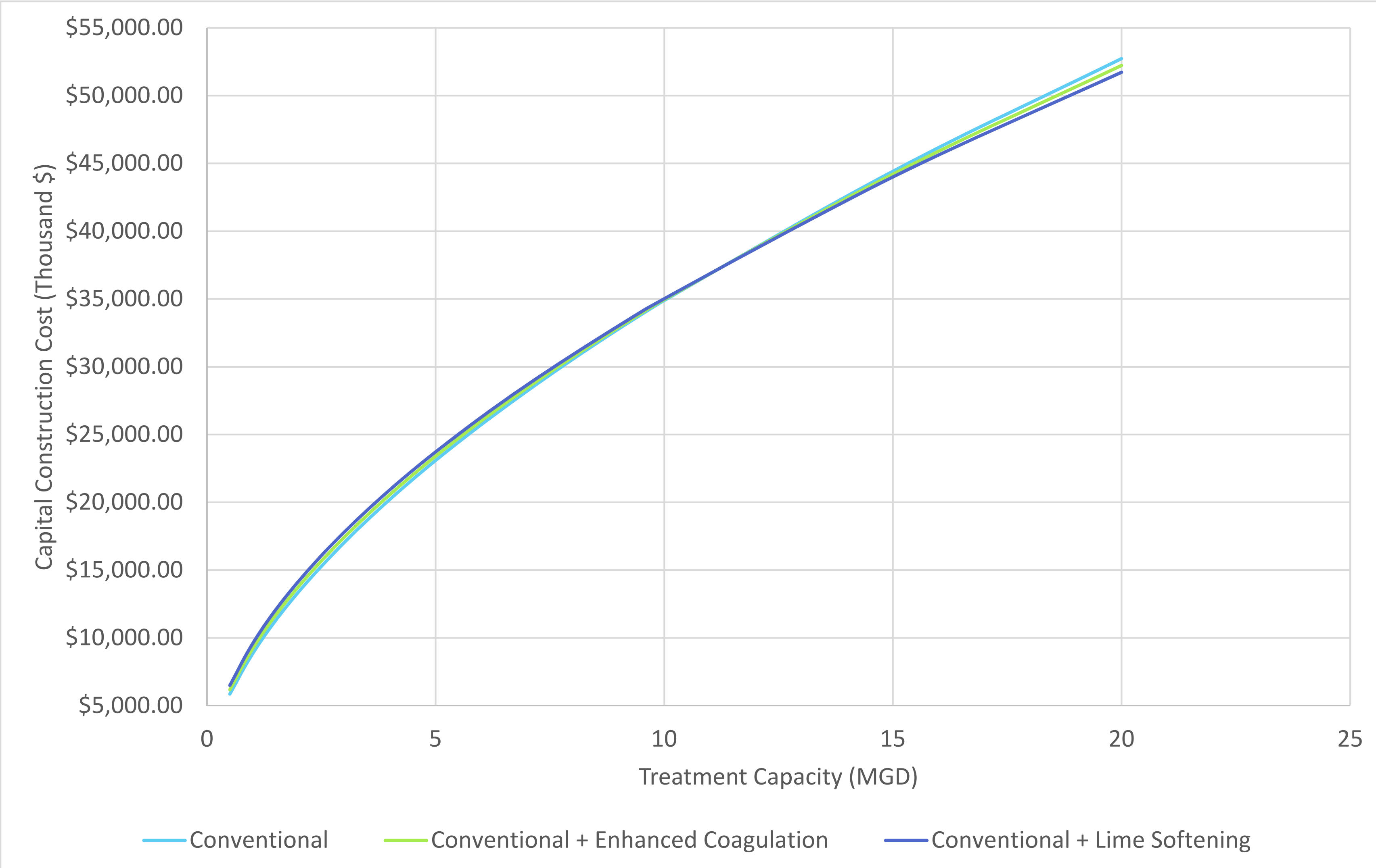

Figure B-9 Interpolated Cost Curves for Conventional plus Enhanced Coagulation Treatment

The manual combines costs of ozone and granular activated carbon (GAC) treatment; because the Cost Estimating Tool separates these two processes the individual line item costs used to develop the manual cost curves were evaluated to determine what percent each process contributed to the total construction cost. For ozone treatment, the percent of the construction cost attributed to GAC was calculated and uniformly subtracted from the ozone + GAC costs leaving only what was associated with ozone treatment. The same process was followed for GAC. While it is understood this method does not account for economies of scale, relative to other treatment types, the curves represent expected costs. This process was repeated for O&M costs.

Another adjustment from the Cost Estimating Manual was the combination of the Nano/Ultra Filtration and Reverse Osmosis cost curves, where the manual provides separate. The two cost curves were plotted together and the +50% and -30% confidence intervals also plotted. The median curve between the +50% and - 30% curves was calculated and used to represent costs for the three treatment types. Although it is recognized this method may over or underestimate some costs, it is appropriate for planning level capital and O&M costs. Figure B-10Error! Reference source not found. shows the plotting of these curves together with the selected cost curve for Nano/Ultra Filtration and Reverse Osmosis.

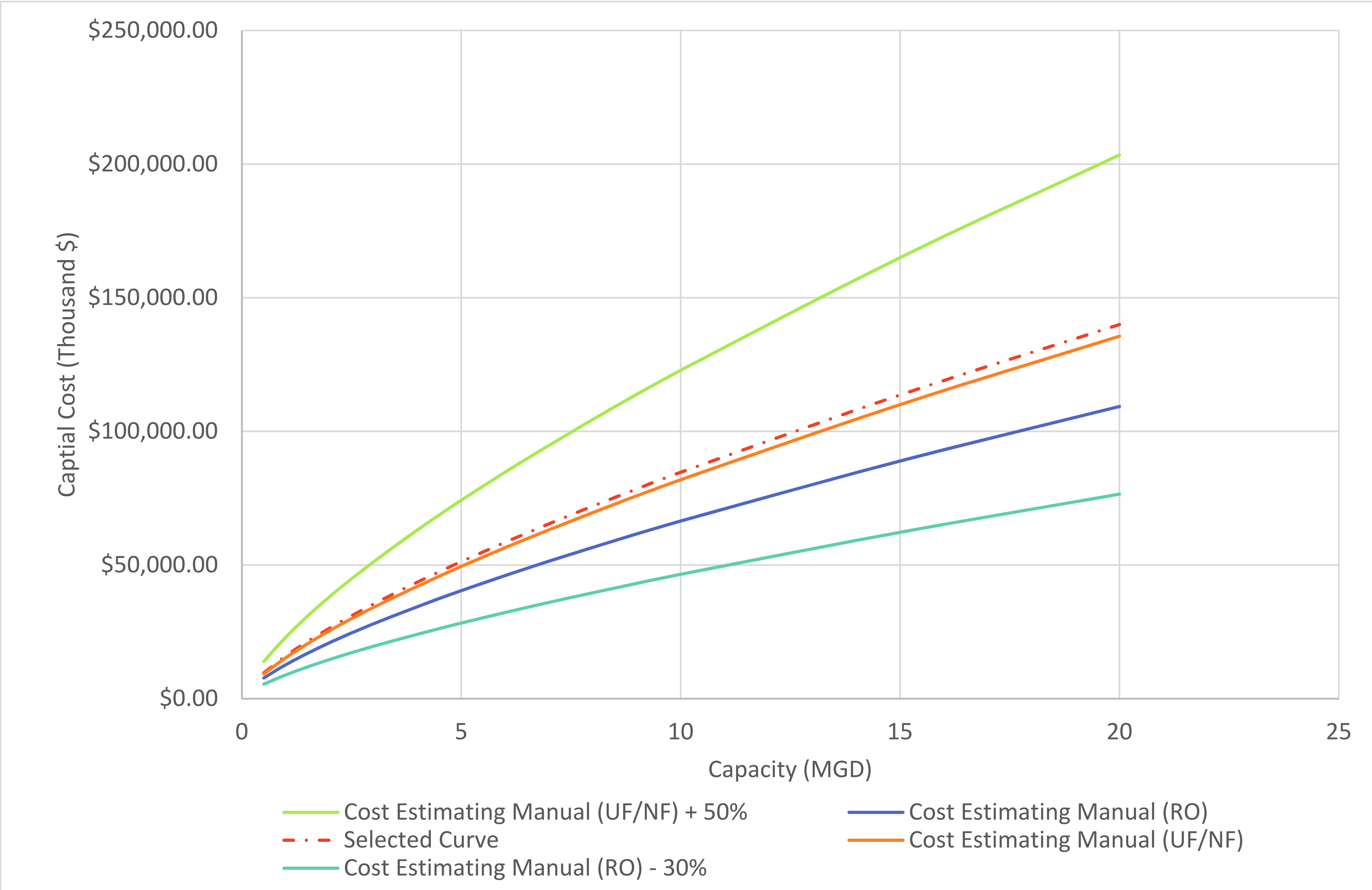

Figure B-10 Analysis of Ultra/Nano Filtration and Reverse Osmosis Capital Construction Cost Curves

Water treatment facilities typically require continual monitoring and staffing; therefore, the cost for operations and maintenance is a significant portion of the cost to be considered. To address this, separate cost curves for annual operations and maintenance costs were developed for the Treatment Module. It should be noted that these curves also consider energy demands for facility operation. These energy costs are not derived from peak day capacity, but rather the average daily production because O&M energy use must be assessed over the year.

Treatment O&M costs were also derived for treatment facility capacities from 0.5 to 20 MGD from cost curves provided in Cost Estimating Manual for Water Treatment Facilities (McGivney & Kawamura, 2008). The ENR CCI Index is not intended to provide geographic adjustments; therefore, the Cost Estimating Manual curves were checked against a recent benchmarking study of water treatment O&M costs performed for four plants located throughout the western United States and historic EPA cost curves. These costs were plotted as $1000/MGD to provide O&M cost curves for each treatment type. The final cost curves for operations and maintenance of the various treatment technologies are provided in Figure B-11.

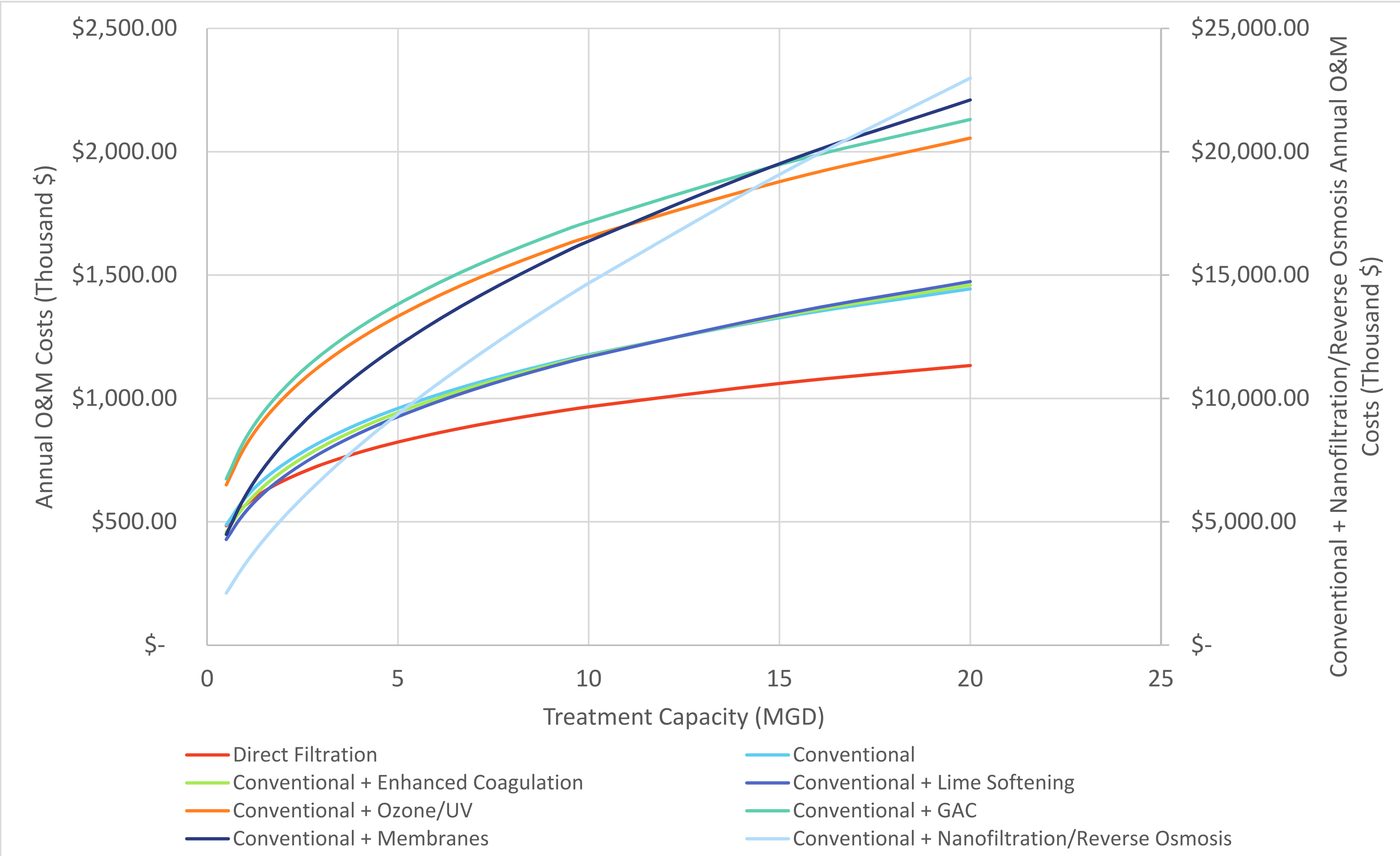

Figure B-11 Water Treatment Technology Annual O&M Cost Curves

*Note: Conventional + Nanofiltration/Reverse Osmosis Annual O&M Costs are plotted on a secondary axis

B.5: Ditch and Diversion Module Application of Cost Data

To convert Ditch and Diversion Module parameters into costs, curves were developed for new ditch construction and ditch rehabilitation. Project costs depend significantly on the type of ditch lining installed; therefore, a curve was also developed for each ditch lining type based on cost of lining per linear foot installed. The cost curves for new ditch construction and ditch rehabilitation are provided in Figure B-12Error! Reference source not found. and Figure B-13Error! Reference source not found., respectively.

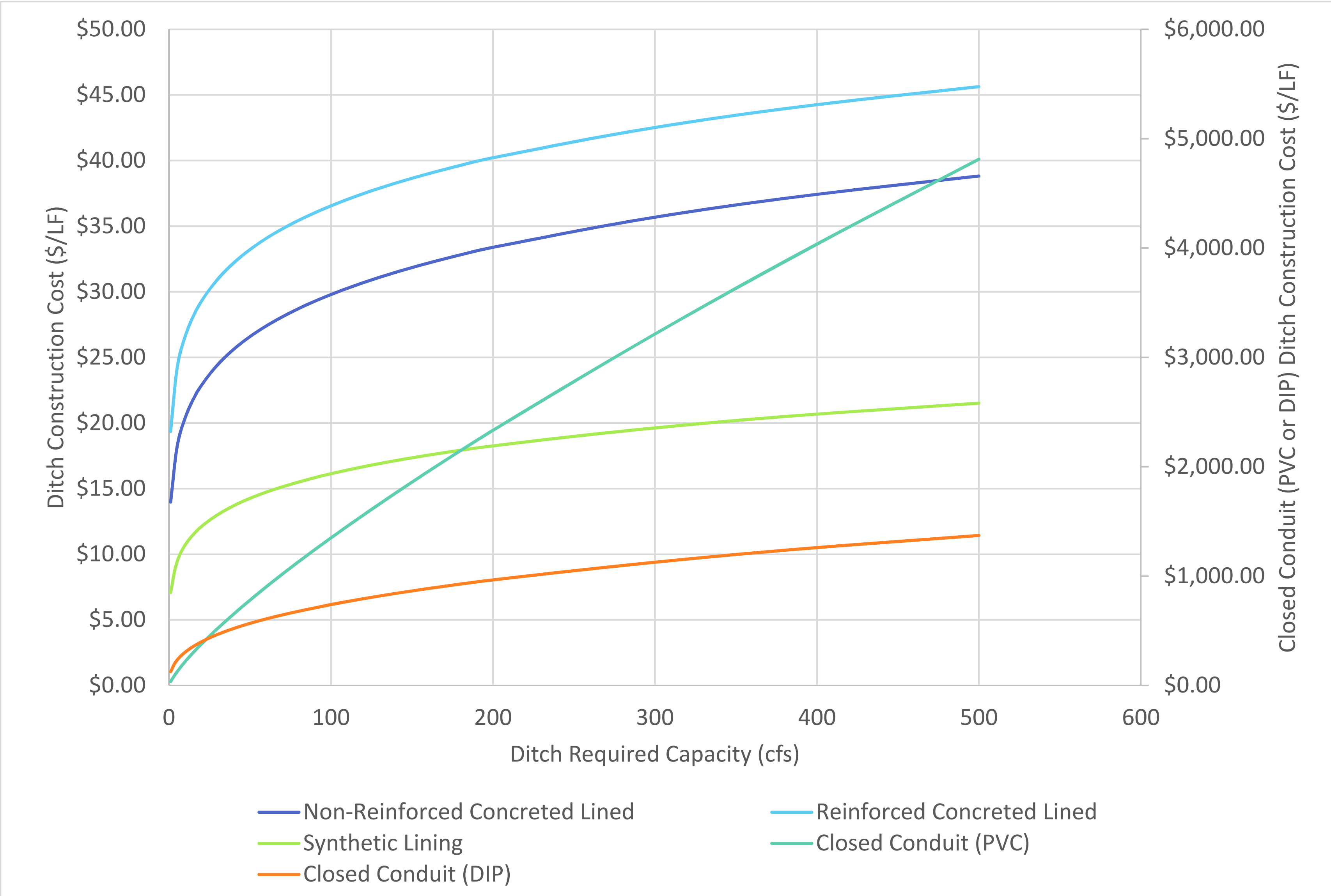

Figure B-12 New Ditch Construction Cost Curves

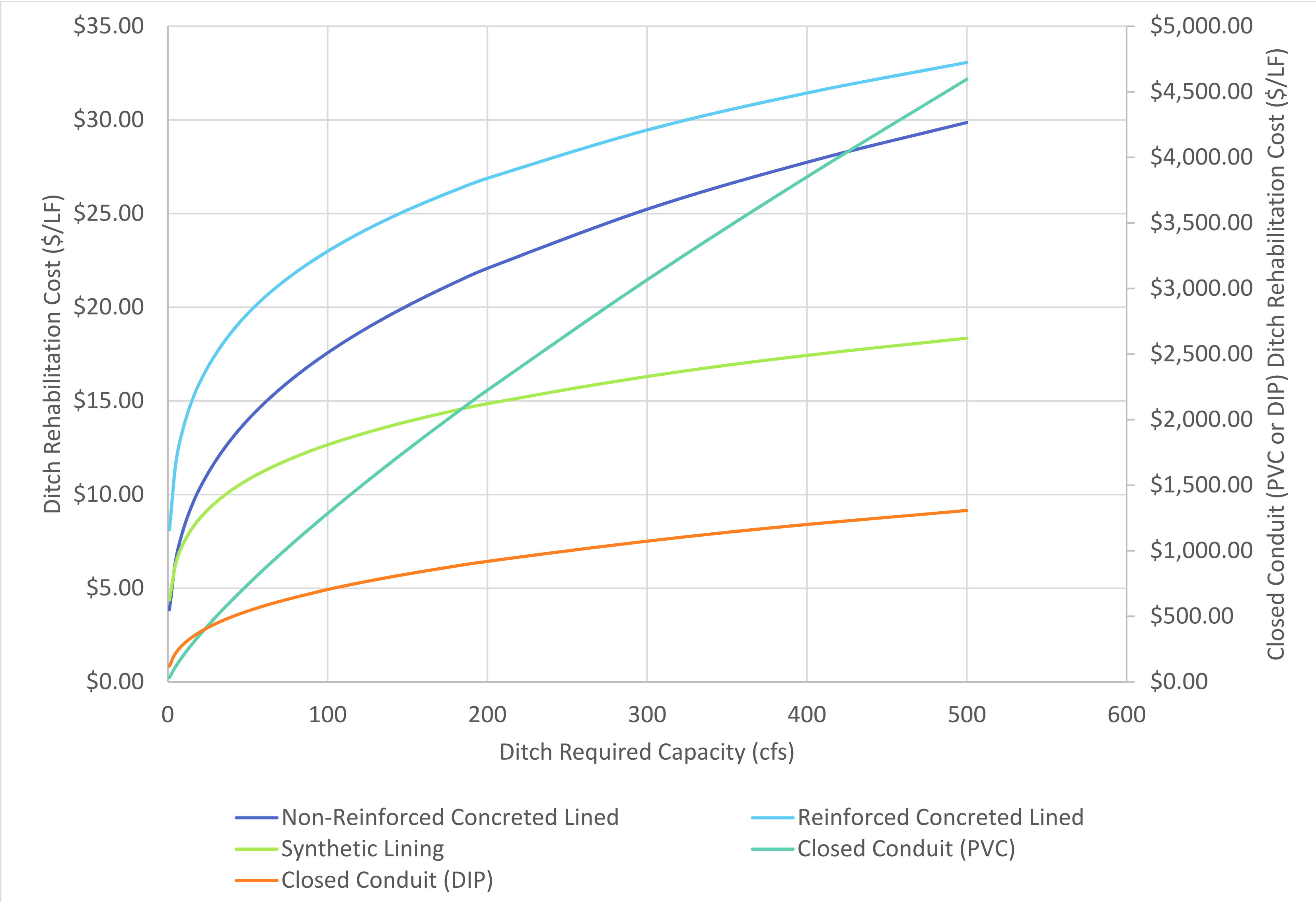

Figure B-13 Ditch Rehabilitation *Cost* Curves

The cost curves for new ditches and ditch rehabilitation were derived from costing information for ditch construction provided by the NRCS. The tool developed by the NRCS provides cost estimates for ditch construction utilizing cost data for materials within the Colorado/Utah/Idaho region. Construction costs in the tool account for earthwork, labor and associated costs for new ditch construction. The most common type of ditch rehabilitation is installation of a new ditch lining, therefore ditch rehabilitation utilizes the NRCS tool estimates for ditch lining costs, but removes the costs associated with earthwork for new ditch construction. These data were adjusted to represent 2017 dollars. The tool was utilized to develop cost curves of ditch capacity (discharge) versus cost per linear foot of lining. In order to develop cost curves in this manner, several assumptions were made regarding ditch geometry (refer to Water Cost Estimating Tool Technical Memorandum, Section Error! Reference source not found.). These assumptions were applied to the NRCS tool so that only the ditch capacity and length variables altered project costs to obtain the cost curves shown in Figure B-12 and Figure B-13. This process was repeated for each lining type. (NRCS, 2011)

The NRCS tool does not include costs for appurtenant construction such as a diversion structure. Costs for installation and construction of a diversion structure vary depending on stream size, environment and ditch capacity. Data on several diversion structure projects completed throughout the state were provided by Colorado DNR and included in a cost analysis. However, the projects varied widely in the level of detail specific to diversion structure design, construction and capacity. For instance, a project may have included a diversion structure as part of a larger stream restoration or ditch construction project, but the cost of just the diversion structure could not be ascertained, or any details about the diversion geometry, type or capacity. The projects were refined to those with a project cost where the diversion structure was the main component of the project. For those projects where a diversion capacity was not provided, the capacity of the diversion was estimated as the peak monthly diversion discharge recorded in the Diversion Records on the Colorado Decision Support (CDSS) website.

The cost curve resulting from this analysis is provided in Figure B-14. This curve is used in the tool to estimate the Recommended Cost of Diversion Structure Cost Curve; however, because this curve was developed based on limited data and several assumptions, the user should use discretion before entering the recommended cost in the Selected Diversion Structure Cost field. To help the user determine if the recommended cost is reasonable for their project, a reference table (

Table B-2) of the data points used to develop Figure B-14 is provided including a description of activities included in the project cost. The user should review these project descriptions and compare to the recommended cost and adjust the Selected Cost as is reasonable.

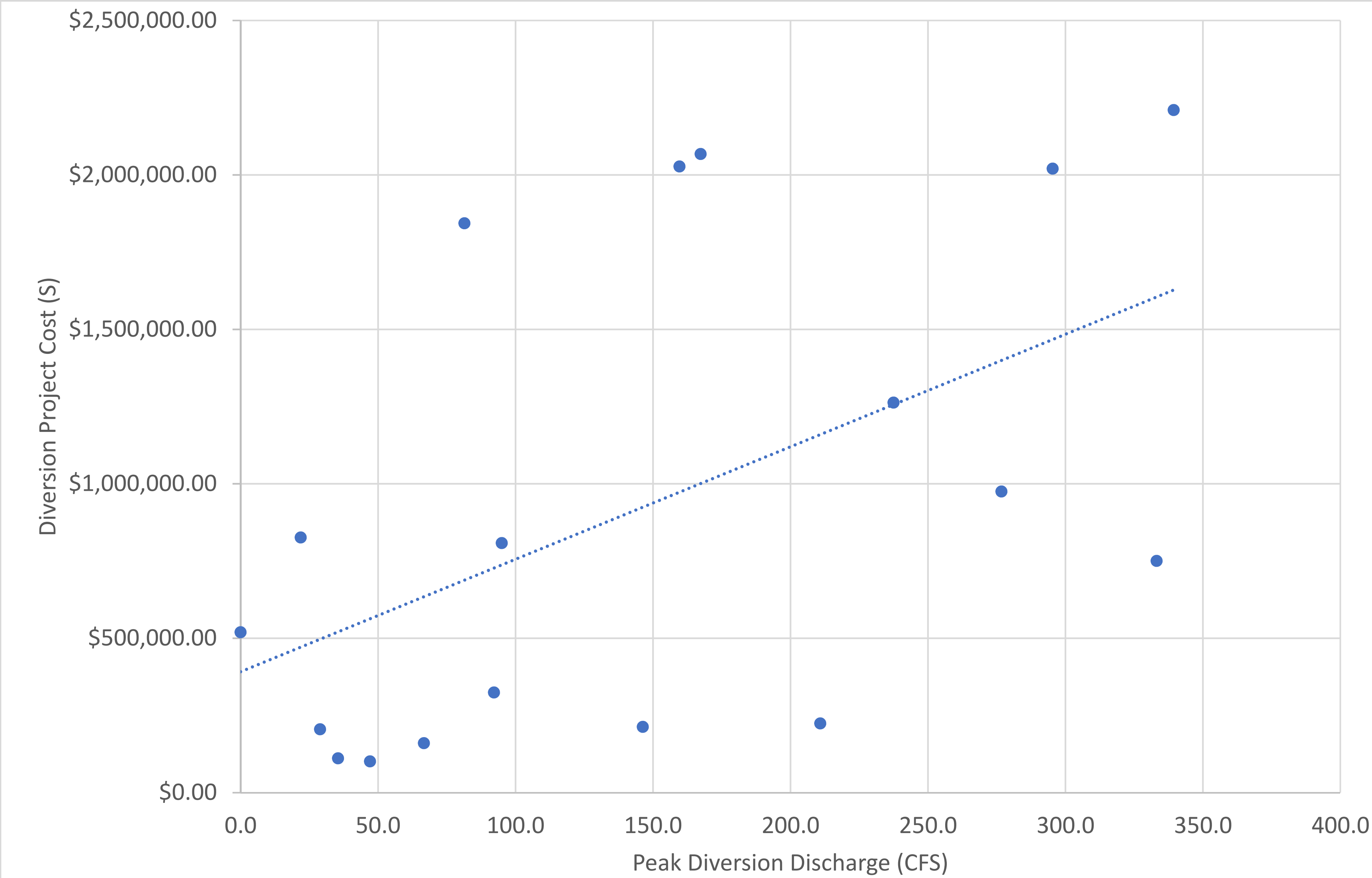

Figure B-14 Recommended Cost of Diversion Structure Cost Curve

Table B-2 Diversion Structure Costs from Various CO DNR Projects

Project ID	Project Stream	Project County	Diversion Structure Type	Maximum Diversion Capacity (CFS)	Approximate Diversion Structure Cost	Description of Project Costs
1	Saint Vrain	Boulder	Grouted Boulder Dam	92.2	$324,210	--
2	Arkansas	Chaffee	Earthen Dike	29.0	$205,000	--
3	South Platte	--	Adjustable-Height Check Dam	295.4	$2,020,000	Demolition of existing structures and reconstruction of headworks; Channel stabilization
4	--	--	--	0.0	$519,140	Diversion dam and headgate repair, Parshall flume, ditch embankment rebuild
5	South Platte	Logan/ Sedgwick	Parshall Flume	210.9	$224,000	Bypass of residual flows, dewatering, excavation, constructing new weir, riprap, removal of old structure
6	Conejos River	--	Automated Headgate	146.3	$213,000	Remove and replace diversion and headgate structures
7	Little Thompson	Larimer	--	95.0	$808,000	Headgate rehabilitation, siphon construction, flood clean up
8	Conejos River	--	Automated Headgate	47.1	$101,000	Diversion dam, headgate, sluice gates, 5 flumes, 5 stilling wells, telemetry
9	South Platte	Logan	--	167.4	$2,067,470	Replacement of river diversion structure, replacement of ditch headgate structure, installation of hydraulic bladders and controls
10	South Platte	Adams	--	159.7	$2,027,070	Construction and installation of gantry crane grate cleaning system, rehabilitate trash rack, replace diversion gates and operators
11	Saint Vrain	Boulder	--	333.2	$750,000	Diversion dam and trash rack construction
12	Rio Grande	South Fork/ Alamosa	Radial Gates with Automation	21.9	$826,000	88 ft diversion dam with fish and boat passage; 2 radial gates with automation; 1,054 LF of 36" HDPE pipe
13	Saint Vrain	Boulder	--	237.5	$1,262,500	Diversion structure, sluice and flume gates, headgates, and fish ladder

Project ID	Project Stream	Project County	Diversion Structure Type	Maximum Diversion Capacity (CFS)	Approximate Diversion Structure Cost	Description of Project Costs
14	Rio Grande	Rio Grande	--	276.8	$975,000	120 LF grouted boulder diversion dam, trash rack structure, 4 slide headgates and structure, 1 radial sluice gate, structure and channel, headgate automation
15	Saint Vrain	Boulder	--	81.4	$1,843,250	Diversion dam with fish ladder, headgates, conveyance ditch, river turnout structure
16	Clear Creek	Adams/ Jefferson	Slide Gate	339.4	$2,209,597	Diversion dam and headgate rehabilitation including SCADA installation, rehabilitation of two siphon structures, and replacement of a storm drain pipe
17	Little Thompson	Boulder/ Larimer	--	66.7	$160,000	Removing debris from the dam and diversion structure; forming and pouring new wing wall; rechanneling river
18	Clear Creek	Denver	--	35.5	$110,781	Repair Fisher Ditch headgate, install sand-out gate and pipeline, replace 650 LF of damaged CMP with RCP

B.6: Stream and Habitat Module Application of Cost Data

To convert Stream and Habitat Module parameters into costs, cost curves were developed for rural and urban environments. The curves represent cost per width class and dollars per linear foot of restoration length. The user inputs for environment type and level of restoration determine which curve is referenced. The width class selected is then referenced to the appropriate curve and a unit cost per linear foot of restoration length is returned. Similar to the Ditches and Diversions Module, the cost per linear foot is multiplied by the user-supplied restoration length to return a total project cost. The cost curves for rural and urban streams and habitat projects are provided in Figure B-15 and Figure B-16, respectively.

These curves were developed from actual steam and habitat restoration projects previously submitted to CWCB and other publicly available stream restoration projects throughout Colorado. Each project was reviewed for levels of restoration involved, length, and average stream width then costs for each level of restoration were converted into an average cost per linear foot.

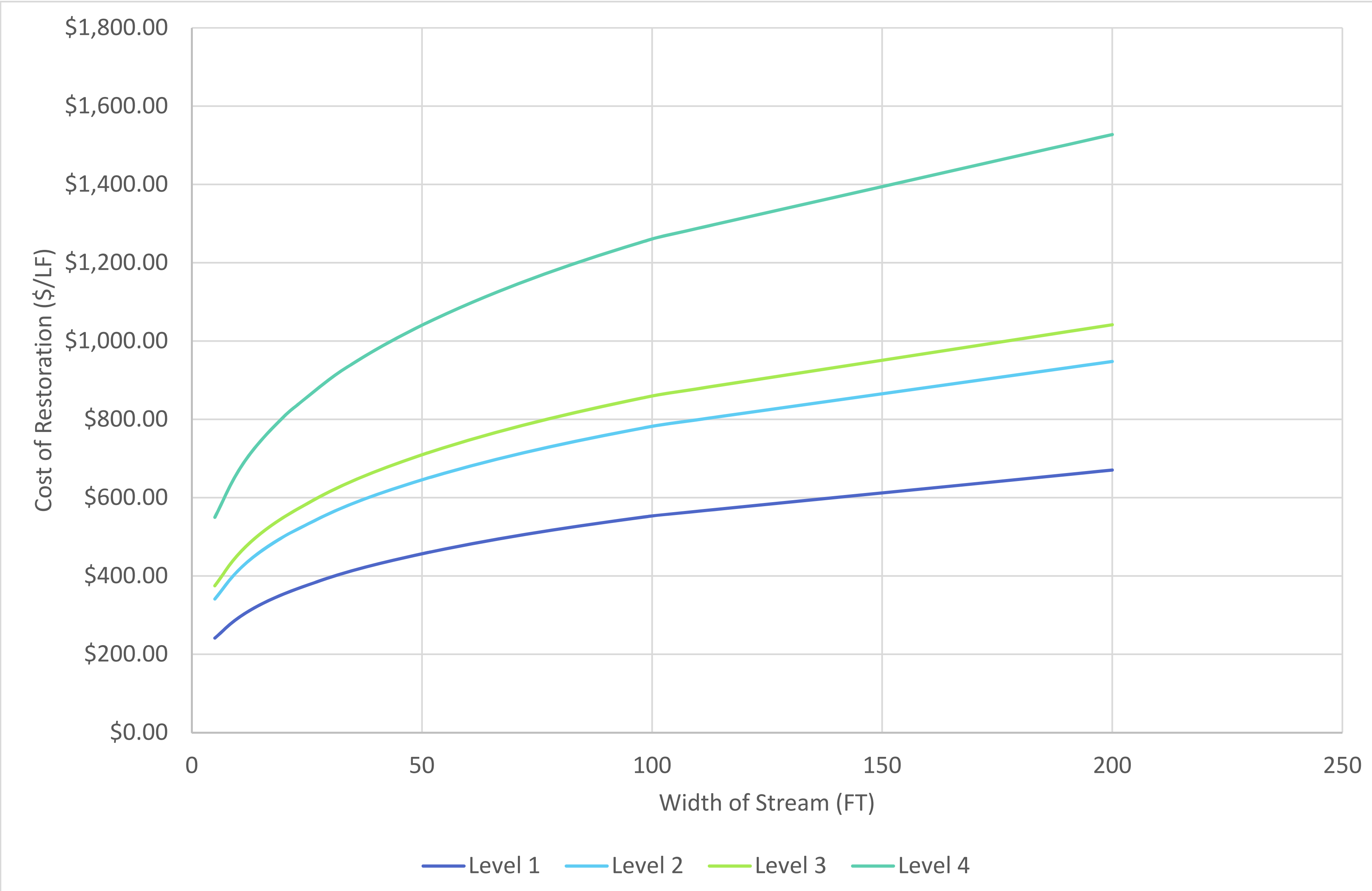

Figure B-15 Rural Streams and Habitat Project Cost Curves

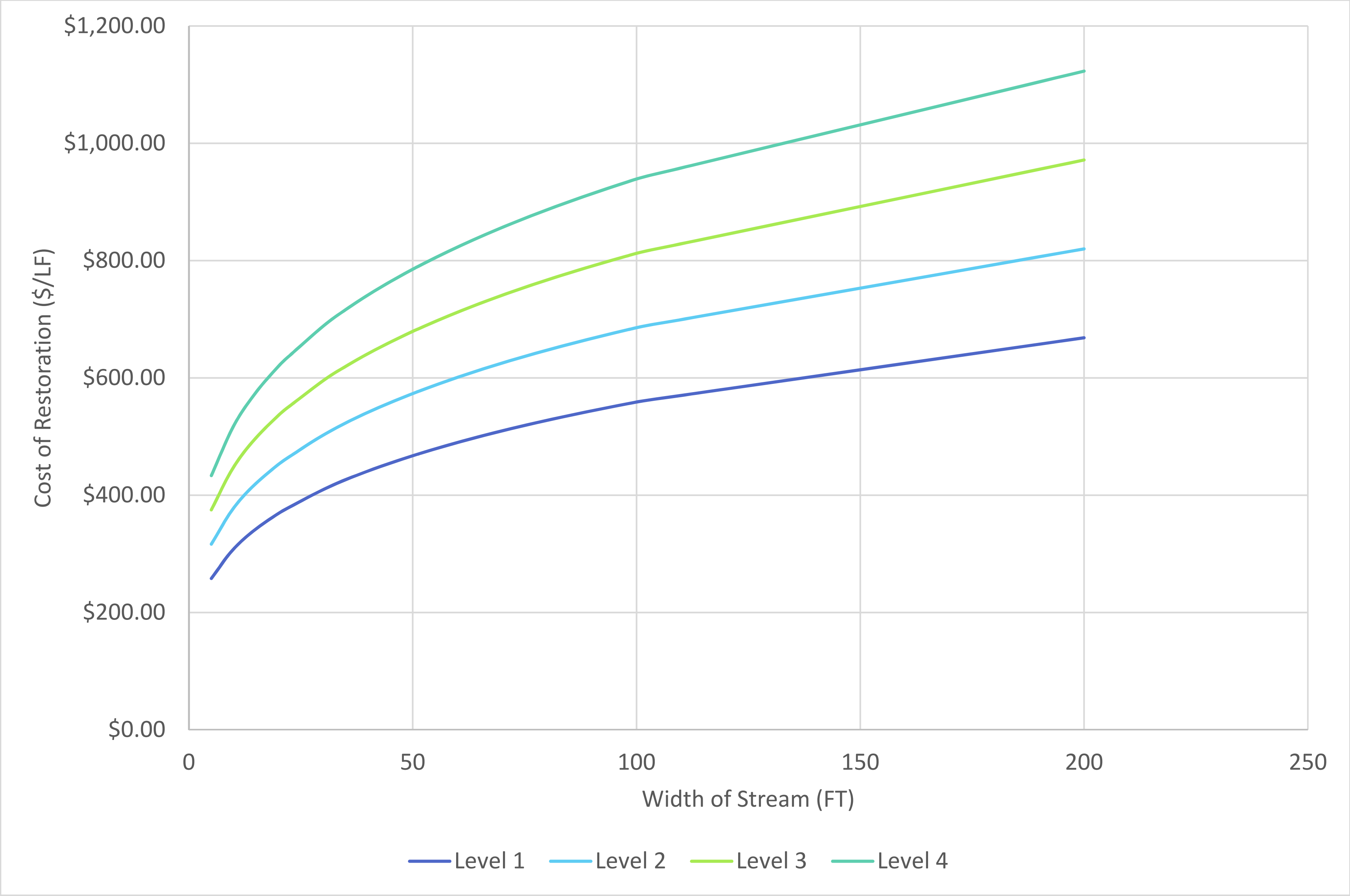

Figure B-16 Urban Stream and Habitat Project Cost Curves

Analysis showed that project costs increased with each level of restoration, as expected. Although cost per width class generally increased as stream size increased, due to limited data in each stream width class for the four levels of restoration, costs varied. Therefore, average total project cost for each width class, regardless of level of restoration, was calculated for rural and urban projects (see Table B-3Error! Reference source not found. and

Table B-4, respectively).

Table B-3 Average Total Cost and Percent Difference for Rural Stream and Habitat Projects

Width	Average Rural Total Project Cost	Percent Difference in Average Total Project Cost
5 to 20	$ 821,734.63	
21 to 50	$ 1,608,993.98	65%
51 to 100	$ 1,702,273.09	6%
>100	$ 2,162,828.69	24%

Table B-4 Average Total Cost and Percent Difference for Urban Stream and Habitat Projects

Width	Average Rural Total Project Cost	Percent Difference in Average Total Project Cost
5 to 20	$ 907,645.60	
21 to 50	$ 1,663,713.50	59%
51 to 100	$ 1,781,901.83	7%
>100	$ 2,189,815.16	21%

As Table B-3 Average Total Cost and Percent Difference for Rural Stream and Habitat ProjectsTable B-3Error! Reference source not found. and

Table B-4Error! Reference source not found. show, during analysis of restoration cost data, it was found that costs for restoring streams within the 20- to 50-foot width class and the 50- to 100-foot width class were similar, likely due to a lack of data for projects between 50 and 100 feet in width. Due to this finding, the cost curves for the two classes were combined, therefore costs for streams between 20 and 100 feet in width will be the same, however the classes were preserved for future data collection.

The percent differences between the width classes were then applied to the cost-per linear foot estimates for each level of restoration to provide cost per linear foot, level of restoration and width class. The user specifies a level of restoration and stream width, which dictates which curve the tool selects. When multiplied by total length of restoration, cost total cost for restoration for the specified level or restoration and stream width is returned.