Analysis and Technical Update to the Colorado Water Plan

Technical Memorandum

Prepared for:

Colorado Water Conservation Board

Project Title:

Colorado Water Project Cost Estimating Tool Documentation

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List of Acronyms

ac-ft	Acre-feet
ASR	Aquifer Storage and Recharge or Recovery
BIP	Basin Implementation Plan
BRT	Basin Roundtable
CCI	CDM Constructors, Inc.
CDSS	Colorado Decision Support System
cfs	Cubic feet per second
CO DNR	Colorado Department of Natural Resources
CWCB	Colorado Water Conservation Board
DIP	Ductile Iron Pipe
E&R	Environment and Recreation
ENR CCI	Engineering News-Record Construction Cost Index
EPA	Environmental Protection Agency
fps	Feet per second
ft	Feet
ft-msl	Feet above mean sea level
GAC	Granular Activated Carbon
GIS	Geographic Information Systems
gpm	Gallons per minute
Horse Power	Hp
hr	Hour
in	Inches
kW	Kilowatts
lf	Linear feet
MF	Membrane Filtration
MG	Million gallons
mgd	Million gallons per day
NF	Nanofiltration
NRCS	Natural Resources Conservation Service
NWQMC	National Water Quality Monitoring Council
O&M	Operations and maintenance
PF	Peaking Factor
psi	Pounds per square inch

PVC	Polyvinyl Chloride
RO	Reverse Osmosis
STORET	EPA STOrage and RETrieval
SWSI	Statewide Water Supply Initiative
TOC	Total Organic Compounds
TSS	Total Suspended Solids
UCM	Texas Unified Cost Model
UF	Ultrafiltration
USDA	United States Department of Agriculture
USGS	United States Geologic Survey
UV	Ultraviolet
yr	Year

Executive Summary

The Colorado Water Project Cost Estimating Tool (Cost Estimating Tool) was developed for the Statewide Water Supply Initiative (SWSI) update to provide a common framework for the basin roundtables (BRTs) to develop planning-level project cost estimates. The tool may be used to develop costs for the following types of projects:

- Water transmission pipeline projects for transporting raw or treated water supplies
- Well field projects for public water supply, irrigation or aquifer storage and recovery (ASR)
- New reservoir or reservoir expansion projects
- Water treatment projects
- New ditches or ditch rehabilitation projects with or without a diversion structure
- Stream and habitat improvement or restoration projects

The Cost Estimating Tool is available to assist the BRTs in the development of Basin Implementation Plans (BIPs). The tool provides a baseline cost estimate for use in the planning process and serves as a mechanism to collect useful information for additional planning and tool refinement in future iterations. Its targeted use is for project concepts for which cost estimates have not yet been developed.

The tool development and use are documented herein with the following sections:

- **Section 1: Introduction** – This section discusses why the tool was developed, how it is to be used and provides further description of the report organization.
- **Section 2: Methodology** – Each component of the tool is described including calculations, user inputs and outputs, and assumptions. This is the main documentation of the overall tool development.
- **Section 3: Implementation** – Included in this section are recommendations for future updates and improvements. Also discussed are some of the data limitations that could be improved upon with future iterations.
- **Appendix A: User Guide** that can be provided as a stand-alone document with the tool.
- **Appendix B: Documentation** of the various data sources used for developing the cost curves for each type of project

Section 1: Introduction

This memorandum presents the objective, development documentation, user guide and cost data for the Colorado Water Project Cost Estimating Tool (Cost Estimating Tool) developed for the Statewide Water Supply Initiative (SWSI) update. The intent of the Cost Estimating Tool is to provide a common technical framework for the basin roundtables (BRTs) to develop planning-level project cost estimates. The cost estimates developed with the tool may be used to support decision-making and to provide consistent project data to the Colorado Water Conservation Board (CWCB). The Basin Implementation Plans (BIPs) submitted in 2015 provided cost data for basin water projects that varied greatly in detail and consistency.

1.1 INTENDED USE

The Cost Estimating Tool was developed out of a need to have planning-level project cost estimates for all proposed projects. During BIP development, BRTs were tasked with identifying completed, ongoing, and proposed projects and methods for addressing water supply needs. While all basins but one identified project cost as a key component of project execution, presentation of estimated costs for projects was not consistent among basins. **Table 1-1** provides a summary of projects with listed costs by basin.

Table 1-1 Basin Project Cost Summary

Basin	Number of Projects	Projects with Costs	Percent of Projects with Costs
Arkansas	185	17	9%
Colorado	31	14	45%
Gunnison	214	112	52%
North Platte	77	1	1%
Rio Grande	110	30	27%
South Platte & Metro	214	0	0%
Southwest	217	1	0%
Yampa	48	4	8%
Total	**1,096**	**179**	**16%**

As **Table 1-1** shows, only 16% of presented projects throughout the eight BIPs provided any estimate of project costs. This demonstrated a need for an accessible costing tool for basins to use during subsequent development of BIPs to determine potential funding needs. This information is also useful to CWCB for determining available funds through programs such as the Water Supply Reserve Fund (WSRF). Of the 1,096 inventoried projects, 117 identified the WSRF program as a current or planned funding source.

The resulting Cost Estimating Tool serves two functions: 1) it provides a tool for basins to estimate and report planning-level costs for proposed projects, and 2) allows CWCB to make like-for-like comparisons of proposed project costs across the state. The BRTs may also use the tool for financial reporting of project cost estimates during the next round of BIPs.

It is important to understand the purpose and limitations of this tool:

- The tool does **NOT** replace cost estimates that have already been developed for projects.
- The tool should **NOT** be used in place of more detailed cost estimates that could be developed if enough information is available.
- The tool is **NOT** an automated process. Review and understanding of the costs calculated is needed.
- The tool **IS** to be used by BRTs when developing cost estimates for project concepts that are to be included in a BIP so that CWCB has an approximate cost to use in planning.
- The calculated costs are very high-level and **only useful for planning purposes**. More detailed cost estimates based on site-specific information will yield different results.

1.2 TOOL AND REPORT ORGANIZATION

The Cost Estimating Tool is organized by Project Modules, with each module representing a different type of water supply project. The organization of this report correlates with the Project Modules; each having its own section. **Section 2** describes the overarching methodology used to develop the tool and details the methodology for creating the individual Project Modules and associated costs. Section 2 is organized uniformly for each module as described below:

- **Section 2.X** gives an overview of the specific Project Module
- **Section 2.X.1** presents the calculations and tools or models that are used in the Project Module
- **Section 2.X.2** discusses module inputs, outputs and costing data
- **Section 2.X.3** describes significant assumptions

Data from each Project Module is synthesized in the Costing Module and Cost Summary Sheets to develop the overall cost estimate.

It is understood that the Cost Estimating Tool is a dynamic resource that should be revisited and updated; therefore, **Section 3** discusses considerations for future updates to the tool's functionality and cost data. To assist the BRTs to best use the tool, a User Guide was developed and is included as **Appendix A.** Details regarding the development of the cost curves for each type of project are available in **Appendix B**.

Section 2: Cost Estimating Tool Methodology

The Cost Estimating Tool is an excel-based tool that guides users through a process for developing planning-level cost estimates for water supply projects within Colorado. The tool consists of the following main components: 1) eight Project Modules that collect project information significant to project costs from the user, and 2) a Costing Module that uses the output from the Project Modules and calculates construction costs by applying unit costs or cost curves developed for each project type. A Cost Summary Sheet synthesizes the cost information calculated in the Costing Module for easy reporting and includes ancillary project costs for project development and annual costs.

For ease of navigation, the tool components are presented on an Overview Page which provides links to all Project Modules and some tool instructions and disclaimers. **Figure 2-1** is a schematic of the tool organization shown on the Overview Page.

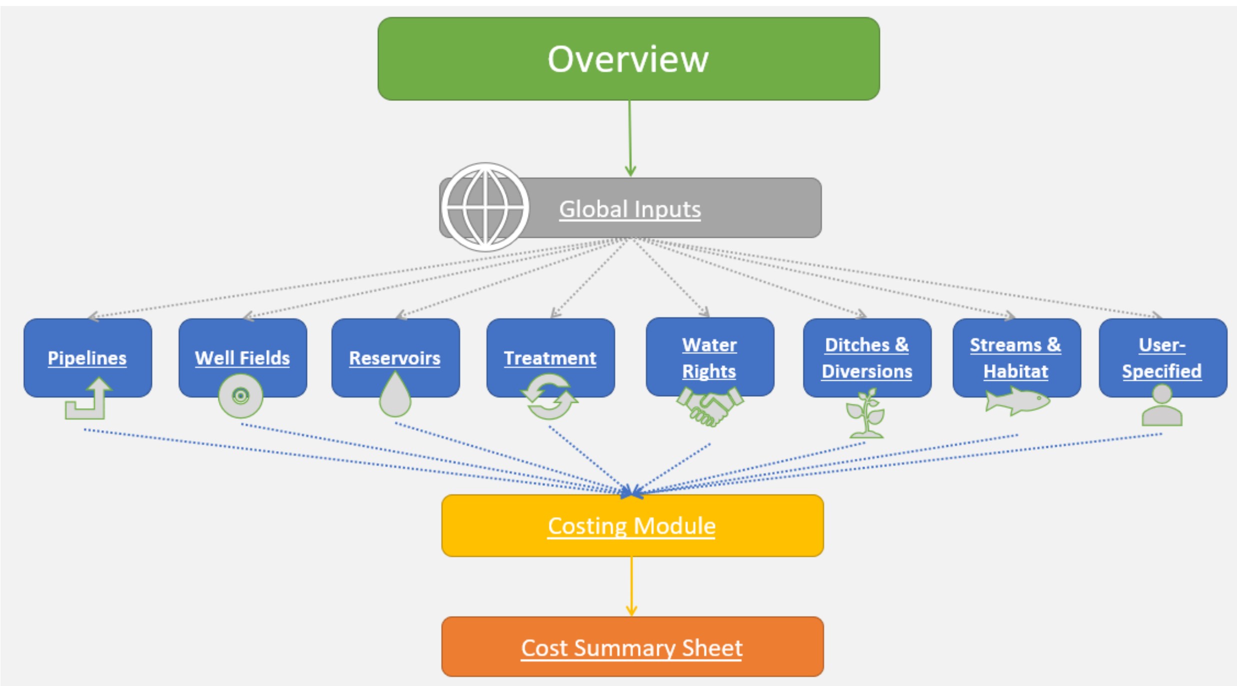

Figure 2-1 Cost Estimating Tool Schematic

To avoid duplicative entry of information, and garner basic details about projects, a Global Inputs tab collects general project information that is used for project development costs and most notably, cost escalation for future projects. More detailed instructions are provided in the Cost Estimating Tool User Guide, which is included as **Appendix A**.

The individual Project Modules prompt the user to input the necessary information to estimate construction costs using the tool. Module complexity varies by project type due to the number of elements a project requires to estimate costs. **Table 2-1** summarizes each Project Module by the type of project and the general inputs used to characterize project components that affect cost.

Table 2-1 Summary of Project Modules

Project Module	Types	Components	General User Inputs
Pipelines	Raw, Treated	Pipelines, Pump Stations, Storage	Project Yield and Peaking Factor, Pipeline Profile Components, Pipe Size and Length, Pump Type
Well Fields	Public Supply, Aquifer Storage and Recovery, Injection, Irrigation Wells	Wells, Booster Pumps, Pipe Network	Water Table Characteristics, Project Yield and Peaking Factor, Transmission Pipeline Profile Components, Number of Wells and Average Production, Well Depth and Capacity, Transmission Pipe Size and Length, Booster Pump Capacity
Reservoirs	New Reservoir, Reservoir Expansion, Reservoir Rehabilitation	Reservoir, Reservoir Rehab, Hydropower Production	Project Type, New Storage Volume, Reservoir Rehab Project Description, Cost of Rehabilitation, Height of Falling Water, Discharge through Hydropower Station
Treatment	Various Treatment Types	Treatment	Average Day Demand and Peaking Factor, Treatment Type
Water Rights	Instream Flow Requirements, Recreational In-Channel Diversion, Water Supply	Cost	Total Capital Cost of Water Right Purchase
Ditches and Diversion	New Ditch, Ditch Rehabilitation	Diversion Structure, Headgate Structure, Ditch	Type of Diversion Structure, Type of Headgate Structure, Maximum Diversion Discharge/Ditch Capacity, Type of Ditch, Ditch Length
Streams and Habitat	Stream Restoration, Conservation, Habitat Restoration/Species Protection, Acid Mine Drainage Water Treatment	Land Acquisition, Channel Improvements, Channel Structures, Channel Realignment	Stream Width Range, Length of Restoration, Level of Restoration
User-Specified Project	Project Types not represented by other modules	User-specified	Project Description, Total Capital Costs, Total Operations & Maintenance Costs

The inputs provided by the user are used to calculate cost-significant project elements. The module outputs are carried over into the Costing Module where unit costs or cost curves, developed for each module, are applied. The development of the cost curves for the eight Project Modules are based on the best available data for that project type. When available, costing information from recent Colorado projects were used to develop cost curves. All cost curves are representative of 2017 dollars. More information on cost curve development is available in Appendix B.

Other project costs, including project development and annual costs, are calculated and presented in the Cost Summary Sheet.

2.1 PIPELINES MODULE METHODOLOGY

The Pipelines Module may be used to cost different types of projects that include a pipeline component. Types of pipeline projects may include transmission of finished or raw water for potable or non-potable uses. The main components of a pipeline project include the pipeline itself, pump stations, and storage at the pump stations. The user may develop parameters for up to three pipe segments of differing diameter, length and project yield.

The inputs include information about the pipeline profile and anticipated project yield, which is used to calculate the pipeline diameter and pumping requirements. The outputs for developing the costs are the pipeline diameters and lengths and the pump station power and energy use. The following sections provide additional details on the process, user inputs, outputs, and assumptions.

2.1.1 CALCULATION PROCESSES

The module calculates pipeline and pump station parameters relevant to establishing construction and operations and maintenance (O&M) costs. Units for each value are converted in the module as needed.

Peak flow is calculated using **Equation 1**. If the pipeline is providing uniform delivery (i.e., the peaking factor is equal to 1), a percent downtime for maintenance is applied to the peak flow to account for a greater maximum flow needed throughout the year to meet the project annual yield.

Equation 1. $$q_{peak} = q_{average} * PF$$

where q_{peak} = peak flow in cubic feet per second (cfs)

$q_{average}$ = average day flow in (cfs) corresponding to the total project annual yield

PF = peaking factor

Pipeline diameter is calculated using the Continuity equation expanded and rearranged to solve for diameter. The resulting equation is shown as **Equation 2**.

Equation 2. $$D = \left(\frac{4q}{V\pi}\right)^{1/2}$$

where D = diameter in feet (to be converted to inches),

q = flow in cubic feet per second (cfs), and

V = velocity in feet per second (ft/s)

Total dynamic head and flow are needed to determine the necessary pump station power. Total dynamic head is the static head (total lift) plus the friction head. The friction head is calculated using the Hazen-Williams equation rearranged to solve for the friction head. The equation for total dynamic head is shown as **Equation 3**.

Equation 3. $$h_t = h_s + \frac{10.4LQ^{1.85}}{C^{1.85}D^{4.8655}}$$

where h_t = total dynamic head in feet (ft)

h_s = static head in ft

L = pipe length in ft

Q = flow in gallons per minute (gpm)

C = the Hazen-Williams friction factor

D = pipe diameter in inches (in)

Total required power is calculated in terms of Horse Power (Hp) using the desired flow rate and total dynamic head as shown in **Equation 4**.

Equation 4. $$P = \frac{(h_t)Q}{3960\mu}$$

where P = power in Hp

h_t = total dynamic head in ft

Q = flow in gpm

μ = efficiency as a fraction

The number of pump stations needed is estimated based on the maximum allowable pipeline pressure. An additional pump station is needed when the total pumping head exceeds the maximum allowable pipeline pressure.

Finally, pumping energy required to pump the annual flow rate is calculated to determine the annual cost of pumping. Energy use is assumed to be constant over the year except for specified pump downtime. Total pumping energy per year is calculated by converting Hp to kilowatts (kW) and multiplying by the hours of pumping in the year.

2.1.2 INPUTS, OUTPUTS AND SOURCE DATA

The Pipeline Module requires several inputs that are either required to be supplied by the user, adjustable by the user, or optionally supplied by the user. There are no inputs that are hard-coded. Default typical values are included for those inputs that are adjustable by the user. There are also lists of typical values and ranges of values from which the user can select. This puts the responsibility on the user to appropriately design the pipeline system that is being costed.

The outputs used to develop construction costs include pipe diameter, pipe length, pump station(s) power, and storage volume. This information is applied to the cost curves, which were mostly developed from Denver Water cost data.

Specifics of the inputs and outputs are described in tables in the Pipelines Module section of Appendix A. Details regarding development of the cost curves are available in Appendix B.

2.1.3 ASSUMPTIONS

The Pipelines Module assumes the following:

- Use of multiple segments is not required and only necessary if there is a change in project yield, peaking factor or diameter along the pipeline length. Multiple segments may also be used if the user wants to control the number and distribution of pump stations along the project. Inputs or calculations do not transfer from one segment to another. They can, however, be used as independent calculations that combine into a single, total cost estimate.
- Based on typical water composition, terrain, and use in Colorado, ductile iron pipe is assumed for all pipeline costs.
- Calculations and costs assume an average of 6 feet of cover over the length of the pipeline.
- Calculations and costs assume an average of 2,500 feet between valves in the pipeline. Bends are not considered.
- The number of pump stations needed is estimated based on the total dynamic head over the entire pipeline divided by the maximum allowable head, and the power required is evenly divided over the number of pump stations.
- If user selects "Intake" as pump type, the first pump is assumed to be intake and any additional required pumps for the segment are assumed to be booster pumps
- Storage requirements are provided by the user, but a recommended value is 10% of the average daily flow.

2.2 WELL FIELD MODULE

The Well Field Module includes wells, pumps, and the main transmission line through a well field. Types of well field projects include public water supply, irrigation, or aquifer storage and recharge or recovery (ASR). Rehabilitation of wells or a well field or conversion of existing wells to ASR wells are not included for this module. Those types of projects require more detailed information for which more detailed cost estimates could be developed.

The types of user inputs for this module include well hydraulic information, well production parameters, and well field transmission pipeline information. These inputs are used to calculate the number of the wells, depth and capacity of each well, transmission pipeline diameter, and transmission pumping needs. The Well Field Module outputs for developing the costs are the individual well capacity and depth, pipeline diameter and length, transmission system pumping requirements (total dynamic head and capacity), and total well field power and energy use (well and transmission). The following sections provide additional details on the process, inputs, outputs, and assumptions.

2.2.1 CALCULATION PROCESSES

This section describes each calculation used in the Well Fields Module. The first set of calculations are for the well field and related hydraulics. Figure 2-2 depicts a simplified schematic of the well hydraulics inputs and calculations. Elevation is in feet above mean sea level (ft-msl). Units are converted in the module as needed and not explicitly documented here.

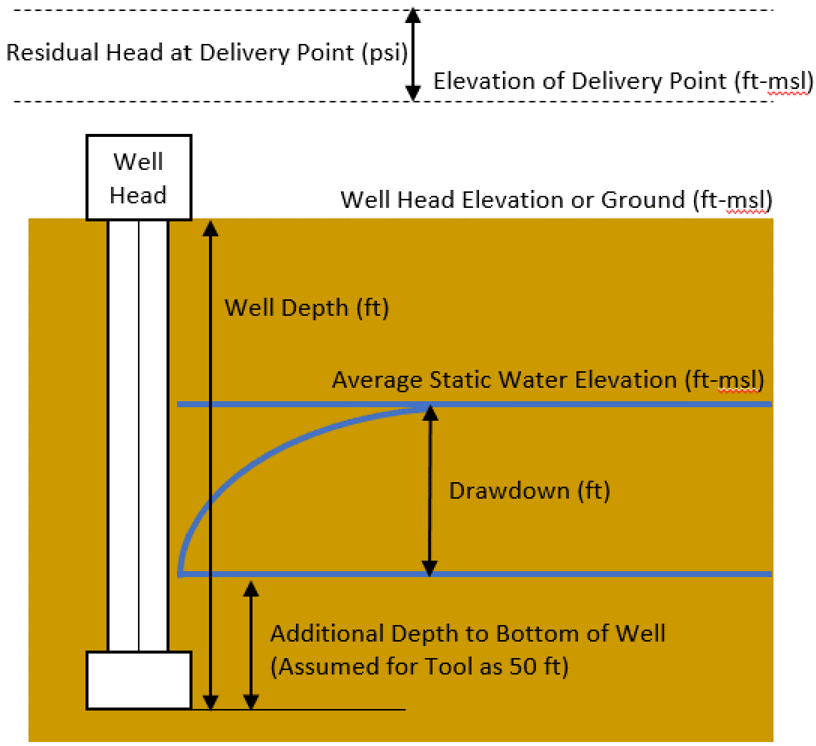

Figure 2-2 Well Hydraulics Schematic

Peak flow is calculated using **Equation 1** (previously presented in the Pipelines Module). The number of required active wells are calculated per **Equation 5**.

Equation 5. $$N_{wells} = \left\lceil \frac{q_{peak\,yield}}{q_{peak\,well}} \right\rceil$$

where N_{wells} = total number of wells needed, rounded up to the nearest whole number

$q_{peak\ yield}$ = total project yield converted to a peak yield (**Equation 1**) in gpm

$q_{peak\ well}$ = peak flow per well in gpm

The module then lists each well in the "Calculated Well Parameters" where the user must supply the well head elevation (or approximate ground elevation) in ft-msl for each well. The well depth is then calculated per **Equation 6**.

Equation 6. $$d_{well} = (z_{well\ head} - z_{static\ water}) + d_{drawdown} + 50ft$$

where d_{well} = the average depth of a well in ft

$z_{well\ head}$ = the well head elevation in ft-msl

$z_{static\ water}$ = the average static water elevation in ft-msl

$d_{drawdown}$ = drawdown depth in ft

An assumed additional depth of 50 feet is added for calculating the total depth. The peak capacity is calculated assuming the same peak flow per well in gpm. The user may keep the calculations for the number of wells, the depth per well and peak capacity as calculated, or the user can input specific information for each well.

The operating time is the fraction of the operating time over a year of operation calculated per **Equation 7** and is used to estimate annual energy use.

Equation 7. $$t_{fraction} = \frac{q_{average\ yield}}{(N_{wells}) * q_{peak\ well}}$$

where $t_{fraction}$ = fraction of time during a year that the entire well field is operating

$q_{average\ yield}$ = total project average annual yield in gpm

N_{wells} = total number of wells in the well field

$q_{peak\ well}$ = peak flow per well in gpm

Average values were calculated for the overall well field to simplify some of the hydraulic equations. For example, the user inputs a well head elevation for each of the wells, but an average of those inputs is used in the calculations for estimating energy use for all the wells in the well field. The average (i.e., average over the well field) total dynamic head for the well field is expressed using **Equation 8**.

Equation 8. $$TDH_{well\ field} = (Z_{well\ head} - z_{static\ water}) + d_{drawdown} + h_{well\ column}$$

where $TDH_{well\ field}$ = the average well field total dynamic head under peak flow conditions in ft

$Z_{well\ head}$ = the average well field head elevation in ft-msl

$z_{static\ water}$ = the average static water elevation in ft-msl

$d_{drawdown}$ = drawdown depth in ft

$h_{well\ column}$ = the average well column frictional losses in the well column in ft

The well column losses (or $h_{well\ column}$ in **Equation 8**) are calculated by rearranging Equation 2 and Equation 3 (refer to Pipelines Module) as shown in **Equation 9**.

Equation 9. $$h_{well\ column} = \frac{10.4 D_{well}\, q_{peak\ well}{}^{1.85}}{C^{1.85}\left[\frac{12\ in}{ft}\left(4\frac{q_{peak\ well}}{V\pi}\right)^{1/2}\right]^{4.8655}}$$

where $h_{well\ column}$ = the average well column frictional losses in the well column in ft

D_{well} = average well depth from the well head elevation to the well bottom in ft

$q_{peak\ well}$ = peak flow per well in gpm

C = the Hazen-Williams friction factor

V = velocity in ft/s

An estimate of total required power is calculated in terms of Hp using the average day flow and total dynamic head per well as shown in Equation 4, previously presented in the Pipelines Module. Then, energy use is calculated per well and for the entire well field to determine the annual cost of well operation. Energy use is assumed to be constant over the year. Total pumping energy per year is calculated by converting Hp to kW and multiplying by the hours of pumping in the year.

The remainder of the module includes calculations for the main transmission line and booster pump stations. These calculations are the same as in the Pipelines Module. Differences in how the pipeline outputs are developed include the following:

- A well field transmission pipeline is set up to determine diameters for multiple segments that account for the connectivity of the well field.
- Pumping related to each well is included in the cost of the well, but the need for additional booster pumps is included along the transmission line. Based on those calculations the user then chooses the number of pumps to include, their capacity and total dynamic head.
- Each well is assumed to be in series along the transmission line, so the required TDH is calculated between each well based on the user-specified well head elevation and head loss through the pipeline.

2.2.2 INPUTS, OUTPUTS AND SOURCE DATA

The Well Fields Module process requires several inputs that are supplied by the user or adjustable by the user. Default values for Well Column Velocity, Mechanical and Electrical Efficiency, and Hazen Williams C values are provided in the tool, but are adjustable by the user. In addition to the required user inputs that feed the calculations, the user has the option to use calculated values for well and booster pump parameters that feed the Costing Module, or they can enter their own specific information. This provides flexibility and puts the responsibility on the user to appropriately design the system that is being costed.

The outputs used to develop construction costs include the same items as in the Pipelines Module. In addition to these, well depth and capacity for each well are used and applied to the cost curves, which were mostly developed from cost data from the Texas Unified Cost Model (UCM) adjusted with information on recent well field projects in the southwest.

Specifics of the inputs and outputs are described in tables in the Well Fields Module section of Appendix A. Details regarding development of the cost curves are available in Appendix B.

2.2.3 ASSUMPTIONS

The Well Fields Module assumes the following:

- Operational parameters are not considered.
- The well field layout is simplified and assumes a main transmission line with wells connecting individually to that line. The pipelines from the well to the main transmission line are assumed short enough to be negligible in the costs. If the user requires costs for these lines, the Pipelines Module may be used, or additional external costs may be added in the Costing Module.
- The calculations for booster pumps include one at each transmission line node (or where a well is added) unless the power needed is zero.
- Calculated well depth assumes an additional 50 feet below the drawdown level; this value is hard-coded in the calculations and is not adjustable by the user.
- Calculations regarding capacity and depth per well assume uniformity across the well field, but the user may input more detailed information if available.

- ASR well fields are included and assumed to be constructed like other well fields. Greater cost curves are used to differentiate the cost of an ASR project. Additional assumptions for ASR well fields include the following:
  - Transmission of the water to be injected from the source to the well field is not included. This may be costed separately using the Pipelines Module.
  - The tool only includes the costs for new wells. Retro-fitting existing wells to be used for ASR has a lower cost and should be considered on a case-by-case basis.
  - Pre- or post-treatment costs are not included. User may consider using the Treatment Module for additional treatment costs.
  - Recharge is assumed as a gravity feed into the well. Additional cost of pumps and operations would need to be added if recharge water must be pumped into the well under pressure.

2.3 RESERVOIRS MODULE

The Reservoirs Module includes projects for construction of a new reservoir, reservoir expansion and reservoir rehabilitation. Hydropower generation may be calculated but the cost of the infrastructure required is not necessarily included in the cost estimate. This module only includes costs related to the reservoir itself and does not include variations for on- or off-channel reservoirs. Conveyance or transmission of water to and from a reservoir is not included, and the Ditches and Diversions or Pipelines Module may be used for that aspect of a reservoir project.

As reservoir rehabilitation can vary greatly depending on the condition, age, location, use and water/soil composition of the reservoir, input data describing these characteristics and corresponding calculations were not included for these types of projects. Future iterations of the tool should consider collecting a larger data set of reservoir rehabilitation projects and costs to develop this module element further.

2.3.1 CALCULATION PROCESSES

This module includes a basic-level process that incorporates cost curves using inputs on the type of reservoir project and reservoir volume. The cost curves include the cost of the dam, spillway, outlet works, and costs related to the impacted area. No calculations are involved. The user inputs are supplied directly to the Costing Module where cost is calculated based on reservoir volume using the appropriate cost curve for reservoir project type (new reservoir or expansion).

Hydropower calculations are optional for estimating energy production. Power production is calculated using **Equation 10**.

Equation 10. $$P = \frac{(h_W)Q}{3960\mu}$$

Where P = power in Hp

h_w = height of falling water in ft

Q = flow in gpm

μ = efficiency as a fraction

The power generated is converted to an annual amount of energy produced based on user input regarding the frequency of production over a typical year. Energy production per year is calculated by converting Hp to kW and multiplying by the hours of generation in the year.

2.3.2 INPUTS, OUTPUTS AND SOURCE DATA

The Reservoirs Module process requires minimal inputs. Inputs required to be supplied by the user include the project type (new reservoir or expansion) and the new or additional storage volume. If the user is rehabilitating an existing reservoir, they are encouraged to provide details regarding the rehabilitation activities taking place and the estimated cost. Other inputs are optional for the user to supply. Values related to hydropower efficiency are included as defaults that are adjustable by the user.

The outputs used to develop construction costs are the inputs, which apply directly to the cost curves. The cost curves are based on data provided by the Colorado School Mines (Burrow, 2014) and the South Platte Storage Study Final Report (Stantec & Leonard Rice, 2015).

Specifics of the inputs and outputs are described in tables in the Reservoirs Module section of Appendix A. Details regarding development of the cost curves are available in Appendix B.

2.3.3 ASSUMPTIONS

The Reservoirs Module assumes the following:

- Module does not include cost variations for on- or off-channel reservoirs. For off-channel reservoirs the Pipelines or Ditches & Diversions modules may be used to estimate costs for conveyance to an off-channel reservoir.
- Transmission of water from a natural source to the basin is not included. Users may cost out a project requiring reservoir transmission by combining costs from the Pipelines Module with the cost of reservoir construction.
- Land acquisition is estimated by the user in the Global Inputs Module. Most reservoir projects will require land acquisition. The user should include an estimate of land area required in the Global Inputs Module.
- Only New Storage Volume is used for cost estimation.
- Hydropower does not affect total project cost.

2.4 TREATMENT MODULE

Water treatment projects may be operated to provide water for potable or non-potable uses. The principal guidelines for determining the appropriate water treatment technology is the source water quality and required effluent water quality, which is dictated by the intended effluent use. The Treatment Module was designed to address these two factors through a qualitative self-assessment of source water characteristics by the user as a tool for determining the best-suited treatment type.

Colorado is characterized by both high-density urban centers and rural communities. With a myriad of environments and industries, water quality in these areas may vary from pristine to significantly impaired. The eight conventional treatment technologies included in the Treatment Module were selected based on their representation of the broad range of source waters and socioenvironmental settings found in Colorado. This module allows for a wide variety of source water quality to be considered using a table of indicator parameters identified as drivers/thresholds for treatment.

2.4.1 CALCULATION PROCESSES

The two main components of the Treatment Module are treatment type and capacity. Selecting the appropriate water treatment type of a community is dictated by source water quality, effluent use, and required capacity. The treatment types included in the module are summarized in **Table 2-2** in terms of source water types.

Table 2-2 Source Water Characterization versus Applicable Treatment Types

Treatment Type	Source Water Quality Characterization
Direct Filtration	Pristine water quality
Conventional	Moderate-high water quality
Conventional + Enhanced Coagulation	High natural organic matter (NOM) May result in disinfection by-products (DBPs)
Conventional + Lime Softening	High hardness ($CaCO3$) Commonly includes high NOM and turbidity source water
Conventional + Ozone/UV	High NOM Presence of pathogens Bromide and taste and odor issues Potentially includes contaminants of emerging concern (CECs)
Conventional + GAC	High NOM Low risk of pathogens Bromide and taste and odor issues Potentially includes contaminants of emerging concern (CECs)
Conventional + Membranes	High NOM High risk of pathogens
Conventional + Nanofiltration/Reverse Osmosis	Treats all characteristics listed for other treatment types, plus salinity removal (Note: less effective for taste and odor)

The second component of the module is treatment plant capacity. This module calculates the required capacity using **Equation 11**.

Equation 11. $$Q_{required} = Q_{average} * PF$$

where $Q_{required}$ = required peak day capacity in million gallons per day (mgd)

$Q_{average}$ = average day demand in (mgd)

PF = peaking factor

2.4.2 INPUTS, OUTPUTS AND SOURCE DATA

The Treatment Module requires minimal inputs including treatment type, the planned treatment average day demand, and peaking factor. There are no default values or optional inputs.

Treatment type and required capacity are the output used to determine the appropriate point on the cost curve to return a construction cost for the treatment facility type. In addition, the capacity is applied to the O&M cost curve of the treatment technology. In lieu of calculating the required energy for the proposed plant capacity per treatment type, cost curves were developed that account for energy costs in annual maintenance costs.

The cost curves for the Treatment Module were developed using the Cost Estimating Manual for Water Treatment (McGivney and Kawamura, 2008).

Specifics of the inputs and outputs are described in tables in the Treatment Module section of **Appendix A** along with reference material to aid in the selection of treatment type. Details regarding development of the cost curves are available in **Appendix B**.

2.4.3 ASSUMPTIONS

The Treatment Module assumes the following:

- There are eight water treatment technologies provided in the tool. While the tool provides references to aid the user in determining the appropriate technology, it is assumed the user will be able to identify the appropriate technology for their community. The reference table is not intended for final treatment technology decision-making, but as a guiding tool for planning-level cost estimating.
- Reference Table treatment thresholds were developed assuming end use of treated water is for potable uses. The tool may be used for the purposes of planning a non-potable reuse project; however, the water quality requirements for non-potable uses vary significantly depending on the industry. The most typical use of water treatment facilities is to meet municipal water need, and therefore was assumed to be the end-use for the purposes of this tool.
- O&M Costs are calculated for each type of treatment and include an estimation of energy requirements, therefore energy for treatment is not calculated separately
- Treatment costs were created assuming a range of accuracy of +50% and -30%.

2.5 WATER RIGHTS MODULE

The Water Rights Module requires user input on the cost of acquiring a water right. This may include water rights for any type of use including water supply, instream flow requirements, or recreational in-channel diversions. Although no calculations are included, this module exists to provide an input for what can be a significant cost when using the tool to develop costs for other components of a water supply project. **Appendix A** provides some additional resources regarding water rights and water right administration in Colorado.

This module assumes the water rights costs entered by the user are all-inclusive. The cost input in the tool should include all capital, legal, administrative and labor costs involved in the process of negotiating and purchasing the water right. The cost should also be entered in the same year dollars desired by the user for the total project costs. In other words, the tool does not adjust these costs in any way.

2.6 DITCHES AND DIVERSIONS MODULE

The Ditches and Diversions Module is intended for diversion structures and irrigation ditches for agricultural use. Types of ditch and diversion projects may include:

- Ditch or canal construction
- Ditch or canal rehabilitation
- In-channel diversion structures

The most common type of ditch and diversion project among the current BIPs involves rehabilitation or improvements to existing ditches and canals through ditch relining. Historically, many irrigation ditches were earthen or concrete lined. Earthen ditches can easily erode and lose diverted water through infiltration. Recent improvements in ditch lining materials have led agricultural producers to re-line existing channels with synthetic, closed conduit or improved concrete liners. Cost estimating options are included for various lining types and include associated earthwork and labor if a new ditch is being constructed. Development of these costs is discussed in Appendix B.

Diversion projects are reliant on several variables including channel geometry, discharge through the diverting stream and required ditch capacity (i.e. variables that are very project-specific and can vary widely). To aid users in developing their diversion structure costs, a list of existing diversion structure projects, diverted quantity and approximate diversion structure cost is provided in Appendix B and as a reference in the tool. Future iterations of the tool should consider further data collection to refine development of diversion costs, as discussed in Section 3.

In some cases, a ditch and/or diversion project may be one component of a larger water supply project; therefore, it may be appropriate to utilize additional modules such as Streams and Habitat, Reservoirs and Well Fields.

2.6.1 CALCULATION PROCESSES

This module incorporates cost curves using inputs regarding diversion structure type, ditch type, project type (new or rehabilitation), length and capacity. Each user input, except length, is supplied directly to the Costing Module to determine the appropriate cost curve in terms of dollars per linear foot. Cost is then calculated by multiplying length by the unit cost. There are no other calculations.

2.6.2 INPUTS, OUTPUTS AND SOURCE DATA

The Ditches and Diversions Module requires inputs that are mostly informational and are the outputs supplied to the Costing Module to determine the appropriate cost curve (described in Appendix B). The module focuses on characterizing the ditch or diversion project by requesting information on the components included in construction (diversion structure, ditch, or both), type of project (new ditch or rehabilitation) and type of ditch lining. For capacity, the user inputs the maximum desired diversion capacity, which is also assumed to be the capacity of the diversion structure and headgate. Ditch length is used as a multiplier as the cost curves are in dollars per linear foot. The cost curves were developed using a ditch construction cost estimating tool developed by the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS, 2011).

Because diversion and headgate structure costs are highly variable based on the characteristics of the diverted stream, a reliable cost curve could not be developed. The user is directed to provide inputs; however, these are either optional or informational and are intended to capture information useful in future tool iterations. Specifics and further guidance for ditch and diversion inputs and outputs can be found in the Ditches and Diversions Module section of Appendix A.

2.6.3 ASSUMPTIONS

The Ditches & Diversions Module assumes the following:

- Ditch Rehabilitation projects are characterized by installation of upgraded or improved lining material and do not incorporate changes to ditch capacity. If the user intends to increase ditch capacity in the process of channel lining installation, the New Ditch project type should be selected.
- Recommended Diversion Structure Cost is developed based on limited data points, varying diversion structure types and geometries, and diversion structure capacities are estimated based on peak diversion structure capacity from the Colorado Decision Support System (CDSS) website. These costs are only recommended and require discretion before using the recommended cost. The user should review the Reference Table for actual project costs used to develop the curve to determine if the cost is appropriate for their proposed project.

- A tool developed by the NRCS was used to develop costing curves for ditch discharge versus cost of material per linear foot. The use of this tool required the following assumptions:
  - For ditches with trapezoidal geometry: (1) Ditch side slopes are consistently 2 ft/ft, (2) Trapezoidal ditches include a 0.5-foot freeboard, and (3) The average slope over the length of the ditch is 0.15 percent.
  - For closed conduit ditches: (1) Conduits have 4 feet of soil cover, and (2) The average slope over the length of the conduit is 0.15 percent.
  - Manning's roughness values are as follows:
    - Concrete: 0.013
    - Synthetic: 0.022
    - Ductile Iron Pipe: 0.013
    - PVC: 0.009

2.7 STREAMS AND HABITAT MODULE

The Streams and Habitat Module includes projects related to improving the environment, preserving or improving flow regimes, and sustaining an area for recreational purposes. These types of projects may vary greatly, which makes developing a cost estimating tool to fit all projects complicated. To address this, projects were tiered into four levels of restoration essentially starting with work outside of the channel banks and working inward toward the channel centerline. This is discussed further in **Section 2.7.2** and **Appendix A**.

Examples of stream restoration projects, or projects where stream restoration may provide a benefit, include fire protection or post-fire mitigation, improvement of water quality or invasive species removal. Stream restoration projects are most beneficial when specific environmental attributes served by the stream are identified and considered during project design.

2.7.1 CALCULATION PROCESSES

This module incorporates cost curves using inputs regarding stream width, environment, length of restoration and level of restoration. Each user input, except length, is supplied directly to the Costing Module to determine the appropriate cost curve in terms of dollars per linear foot. Cost is then calculated by multiplying length by the unit cost. There are no other calculations.

2.7.2 INPUTS, OUTPUTS AND SOURCE DATA

Module inputs focus on characterization of the stream environment and restoration level to determine the appropriate cost curve. Users should be aware that inputs for this module may require, at a minimum, an aerial analysis of the project area to determine the stream environment as urban or rural.

Cost of stream restoration projects can vary greatly depending on project location, size (mainstem vs. tributary) and condition; therefore, the tool defines stream restoration at varying levels. Costs for each level of restoration are described below:

- **Level 1 - Riparian habitat restoration:** Addresses ecological-based improvements within the riparian buffer such as vegetation reestablishment, improvement of soil conditions, and regrading to restore natural hydrologic conditions in the floodplain.

- **Level 2 - Level 1 plus bank stabilization:** Includes riparian habitat restoration and addresses work along banks such as bank erosion prevention or bank rebuilding using regrading, armoring, or bioengineering.
- **Level 3 - Levels 1 and 2 plus in-channel restoration:** Includes bank stabilization and riparian and aquatic habitat restoration through in-channel structures such as riffles, rock vanes, or weirs. Such structures can create habitats for aquatic life, improve water quality through stream mixing, and prevent unnatural bank erosion by reestablishing natural flow regimes.
- **Level 4 - Levels 1, 2 and 3 plus channel-realignment**: Achieves the goals of riparian, aquatic and reestablishment of natural flow regimes by reconstructing the channel and banks.

This module additionally collects information on stream width and environment (rural vs. urban) to determine the appropriate cost curve. Output to the Costing Module is the cost of restoration per linear foot. The user input of restoration length is used as a multiplier in the Costing Module. More detailed information on the inputs and outputs is provided in **Appendix A,** while cost curve development is discussed in **Appendix B**.

2.7.3 ASSUMPTIONS

The Streams and Habitat Module assumes the following:

- Urban environments are considered those where the stream restoration takes part within an incorporated area and commercial or residential development has occurred adjacent to the riparian buffer. It is assumed that a few homes along a stream may not constitute an urban setting.
- Streams and Habitat costs compound with Level of Restoration. For example, Level 3 costs include Level 1 and Level 2 costs. The cost curves assume total cost of the project with all components of the lower levels of restoration included.
- Restoration level is categorized based on typical components of a restoration project. If a project incorporates only some levels of restoration, the user may perform multiple analysis to best represent costs. For example, if a project incorporates Level 3 and Level 1 components, but not Level 2, the user may perform multiple cost estimates and remove the calculated costs for Level 2. The new costs may be directly input into the Costing Module.

2.8 USER-SPECIFIED PROJECTS MODULE

This module is for projects that already have cost estimates for construction that may go beyond what can feasibly be calculated with the Cost Estimating Tool. Alternatively, this module could be used to capture a portion of project costs that do not fit within other modules but are included in a multi-component project. The user can input the information on construction costs, which are supplied to the Costing Module to calculate project development, annual, and other costs described in **Section 2.9**. Additional inputs beyond construction costs may be required by the user to perform these other calculations. For example, to calculate normalized cost, the average annual water supply produced by the project is needed.

The User-Specified Project Module assumes the following:

- Users with projects that do not fit into the category of the provided modules may submit their project through the User-Specified Project Module.
- The user is assumed to either have procured a professional to develop a project cost or has used a different costing mechanism to develop planning-level, or better, costs.

- In the Project Description field, the user should provide a description of the project, what needs are met by the project, total yield and any major project components that contribute to cost. It is assumed the user has a project that has been previously developed enough to provide a detailed description of project elements that affect cost.

2.9 COSTING MODULE AND COST SUMMARY

Project costs are developed separately in the Costing Module, which brings together the information supplied or calculated from the Project Modules to develop planning-level cost estimates in an overall Cost Summary sheet. The costs are broken out into construction, project development, and annual costs. The construction costs are developed using the output from the Project Modules (described in the preceding sections) and applying cost curves. These cost curves are adjusted to account for current market conditions based on the year input by the user. Project development and annual costs are developed using percent mark-ups and other inputs that can be adjusted by the user as needed.

The final Cost Summary Sheet is a summary outline of all the costs by type along with an annual cost calculation and a normalized cost that can be used for project comparison.

2.9.1 CALCULATION PROCESSES

The process for the Costing Module and Cost Summary Sheet includes calculating construction, project development, annual, and normalized costs as described in the following sections.

2.9.1.1 CONSTRUCTION COSTS

The construction costs of each component of a module are calculated using a cost curve or multiple cost curves representing different variables of the component. Each type of cost and the variables used are outlined in Table 2-3.

Table 2-3 Summary of Variables Used to Cost Infrastructure Types

Infrastructure/Project Type	Required Variable(s) for Cost Estimate	Optional Additional Information
Pipelines	Length (ft), Diameter (in), Environment	Water Delivered
Intake or Booster Pump Stations	Power (HP)	
Storage Tanks	Volume (MG)	
Wells (including the well pump)	Type, Depth (ft), Capacity (gpm)	
Reservoirs	Type, New Storage Volume (ac-ft)	Height of Falling Water (ft) and Discharge (gpm) for Hydropower Calculations
Treatment	Type, Capacity (mgd)	
Diversion Structure	None*	Type
Ditch	Project Type, Ditch Type, Capacity (cfs), Length (ft)	
Stream Restoration	Level of Restoration, Environment, Width Range (ft)	Constructability
Water Rights and User-Specified Projects	User-Supplied Cost ($)	

*Cost of a diversion structure is flat cost with no variables required

2.9.1.2 COST ADJUSTMENTS FOR CONSTRUCTION COSTS

The Cost Estimating Tool calculates costs that represent the market value for the year selected by the user. The cost curves developed and programmed into the Costing Module are based on year 2017 dollars, but the tool adjusts those costs to represent a year specified by the user based on **Equation 12**.

Equation 12. $$F = \mathrm{P}(1+i)^n$$

where F = future cost

P = present cost (specifically in 2017 dollars)

i = escalation rate

n = difference in years from 2017 to the year selected by the user

The method for adjusting costs to the current or desired year uses an escalation rate of 3.5 percent based on the rolling average of historical prices. This is different from using other cost indices that look at comparative escalation to obtain a more precise adjustment for the selected year. The method employed in this tool is smoothing out the variability in escalation rates from year to year because the level of accuracy in the cost estimate is not high enough to warrant a more precise escalation rate for the desired year costs. If the user feels that the current-market rate is significantly different, they may change the value for the escalation rate used in the tool.

Costs entered in the Water Rights or User-Specified Project Modules and any other direct cost inputs must be entered in the year dollars desired for the end project costs as these costs are not converted via **Equation 12**.

2.9.1.3 PROJECT DEVELOPMENT COSTS

The project development costs, also referred to as associated project costs or soft costs, include other types of costs related to constructing the project. These costs include the following:

- Land Acquisition
- Engineering Services
- Surveying
- Legal Services
- Financing and Bond Assistance
- Environmental and Cultural Studies
- Permitting
- Interest During Construction
- Power Connection Costs for Pump Stations

Most of these project development costs are calculated as a percentage of capital construction costs. Default percentage values are provided. Exceptions include land acquisition and permitting. Land acquisition is calculated based on the total acreage and a cost per acre, or the user may input a total cost. The user must supply such values in the global inputs. Permitting costs may vary based on the type of project. The user must consider an appropriate percentage of the capital cost to include based on the project type.

2.9.1.4 ANNUAL COSTS

The annual costs are the costs that continue beyond project completion and include the following:

- Debt service: calculated using the annual cost equation with user input on interest and duration (See **Equation 13** below)
- O&M: for some projects, calculated as a percent of the capital cost of the facility or project
- Pumping energy costs: the energy use calculated in applicable modules multiplied by the cost of energy per unit

The annual cost equation for calculating debt service is shown as **Equation 13**.

Equation 13. $$A = \frac{i(1+i)^n}{(1+i)^n - 1}$$

where A = annual cost (in current-market dollars)

i = interest rate

n = the duration of the debt service in years

The variables for calculating annual costs may vary for different types of projects; therefore, the tool provides various inputs for debt service and O&M based on the type of project.

2.9.1.5 NORMALIZED COST

Normalized cost converts the project cost to a unit cost for the purposes of comparison. For water projects, normalized cost typically divides the total cost by the amount of water produced by the project. For this Cost Estimating Tool, normalized cost may be presented using different units or project yield amounts to give the user flexibility in comparing project costs.

Normalized cost might not be applicable for certain projects included in this tool, thus it will be calculated if the appropriate inputs are supplied by the user. These inputs include the total project yield and the project peaking factor.

2.9.1.6 COST SUMMARY SHEET OUTLINE

The Cost Summary Sheet summarizes the capital costs and outlines the project development, annual and normalized costs discussed in the previous sections.

2.9.1.7 SOURCE DATA AND INFORMATION

Source data and information include unit costs and cost curves in 2017 dollars for capital costs. These inputs were developed from several sources including bid tabs available from CWCB, project experience and input from CDM Smith's construction group. The development of the unit costs or cost curves for each Project Module are documented in **Appendix B**.

Default values for percentages for project development costs and interest rates were developed from project experience but may be changed by the user in the Global Inputs tab.

2.9.2 ASSUMPTIONS

The cost data were developed from several sources of data. As these are planning-level costs, there are several assumptions associated with each Project Module as previously discussed. See **Appendix B** for any specific assumptions regarding the cost curves.

Section 3: Tool Recommendations

It is recommended that the tool be reviewed and updated on a regular basis (for example, whenever Water Plan data sets are updated). This section provides considerations for review and future iterations of the tool in the following areas; (1) cost data, (2) tool functionality, and (3) basin implementation.

3.1 COST DATA LIMITATION AND RECOMMENDATIONS

The cost datasets presented and explained in Appendix B should be reevaluated during every update of the Cost Estimating Tool. Cost curves embedded in the tool during its creation should be compared against project cost data from sources such as the forthcoming BIP updates, updated projects from CWCB or Colorado Department of Natural Resources (CO DNR), new publications, and/or other resources on cost data for water supply projects. The Cost Estimating Tool cost curves should either be adjusted to fit the updated data, or new cost curves developed. The applicability of the escalation rate should also be revisited in future iterations.

Several modules were identified as having limitations in accuracy, region-specific data, or the quantity of available cost information. Table 3-1 provides a list of each module, data limitations and additional data collection points for updating the cost curves. Specifically, several modules referenced the Texas UCM cost curves. The State of Texas maintains a database of unit costs for various project types, and Colorado does not have such a database. It is recommended that CWCB begin to track unit costs/project costs for those cost curves developed based on Texas UCM data. As stated above, updated cost data may be collected from several sources including the next round of BIPs. When providing guidance to BRTs for BIP updates, these data points should be suggested as components of project descriptions.

An aspect of cost not addressed in the Cost Estimating Tool is avoided cost. There are alternative water supply solutions and technologies that may have a higher capital cost but have other benefits or avoided costs that may outweigh the additional cost of an advanced solution compared to a traditional solution. For example, the potential avoided cost of installing a hydropower system at a reservoir to produce energy could offset some of the annual O&M costs related to energy. While the tool includes an informational calculation of the potential revenue that could be produced for installing such a feature, these costs are not included in the overall cost summary. Another example would be the avoided costs related to implementing a water conservation program.

Table 3-1 Cost Data Limitations and Recommended Cost Data Development

Module	Data Limitations for SWSI 2017 Update	Recommended Data Collection or Updates
Pipelines	- Pump Station and Storage Tank cost curves derived from Texas UCM - The ability to select source water is provided for the user; however, no cost data are available specific to pipeline projects based on raw vs. treated water	- Collect cost data for pump stations and storage tanks specific to Colorado - Compile pipeline project data for various water supply uses (potable vs. non-potable or raw vs. treated) to determine if there is a need to provide different cost curves based on source water type
Well Fields	Well Type cost curves derived from Texas UCM	- Collect cost data for well drilling and construction specific to Colorado - Collect additional ASR well field cost data
Reservoirs	- Limited data for reservoir expansion. Cost curve uses median cost per acre-foot of storage - Reservoir rehabilitation cost data does not provide enough detail on types or design details of rehabilitation activities - No consideration of credits or avoided costs included for hydropower projects	- Compile and extract reservoir expansion projects. Projects should include information on amount of added storage and land acquisition - Compline and extract additional data on reservoir rehabilitation. Projects should include reservoir size, rehabilitation activities (dam improvements, outlet works, fish ladders, etc.) as well as any design details (geometry, size, mechanical details, etc.) - Costs for constructing hydropower facilities should be researched or compiled from submitted project data - Energy or power savings provided due to use of hydropower could be developed and included as an annual credit in the Cost Summary sheet
Treatment	For treatment types where cost data were lacking, cost curves were interpolated between treatment types expected to have higher and lower construction costs	Compile further cost information for: - Conventional plus Enhanced Coagulation - Conventional plus Ozone/UV - Conventional plus GAC
Water Rights	Water Right costs are highly variable depending on the administrative/legal process. This should remain a user-input.	None

<table>
<tr><th>Module</th><th>Data Limitations for SWSI 2017 Update</th><th>Recommended Data Collection or Updates</th></tr>
<tr><td>Ditches and Diversions</td><td>- Ditch Rehabilitation cost data were limited. Cost curves currently only consider the cost of lining materials for ditch rehabilitation projects
- Diversion structure costs were limited. A cost curve based on total diversion structure cost and diversion capacity was developed, but does not account for source stream size, diversion type, and may include other activities not associated with the diversion structure
- The user is required to know the diversion capacity for new ditches</td><td>- Compile additional data for ditch rehabilitation projects. Project data should include:
· Rehabilitation activities (re-lining, length of re-lining, channel enlargements, etc.)
· Lining type, for lining rehabilitation
· Closed conduit ditches should include piping material and size
· Open channel should include details on channel geometry and capacity
· Ditch use (type of agriculture using the water supply)
- Compile additional data for only diversion structure construction. Diversion structures should be itemized on the project cost estimate and include:
· Diversion type
· Diversion capacity and/or geometry
· Size, flow, and/or geometry of source stream
· Type of agriculture using water supply in the diverted ditch
- Future iterations may consider calculating a suggested ditch capacity based on characteristics of agriculture being served. Projects submitting ditch and diversion components should include details regarding:
· Acres served
· Type of agriculture (crops, livestock, etc.)
· Months of irrigation</td></tr>
<tr><td>Streams and Habitat</td><td>- Lack of data points in each of the 16 groupings based on width class (4), level of restoration (4) and environment (2).
- Costs for the 20-50- and 50-100-foot width classes are very similar and were grouped together due to limited data.
- Riparian restoration is included in stream restoration because projects did not separate out riparian restoration activities
- Restoration projects lacked detail on project elements and design details, therefore levels of restoration were developed</td><td>- Tool preserved the option to select the 20-50- and 50-100-foot width classes for future tool iterations. Additional stream restoration data should be compiled for various stream sizes and locations, particularly basins outside of the South Platte and Metro area
- Projects including riparian/wetland restoration should include:
· Acres of restoration
· Restoration activities (regrading, seeding) and quantities
- Future tool updates may include costs for specific restoration elements. Projects should include line-item costs for:
· In-channel structures
· Quantity (cubic yards, etc.) of earthwork
· Quantity of lining or armoring materials
· Length of restoration
· Characteristics of stream prior to restoration
· Restoration objectives for stream characteristics post-restoration</td></tr>
</table>

Module	Data Limitations for SWSI 2017 Update	Recommended Data Collection or Updates
User-Specified	User-Specified Module prompts the user to submit projects not represented in the tool	Users should submit as much design detail as possible and tool updates should include additional modules or updates to existing modules based on user-specified projects

3.2 TOOL FUNCTIONALITY RECOMMENDATIONS

The following are recommendations for improving or expanding the capabilities of this tool per module. A general functionality update to consider is integrating the tool into a web-based platform where information can be directly entered through the CWCB website and documented in an online database. This would remove the need for users to download the tool and the need for manual maintenance of an off-line database for tracking project components and costs.

The following recommendations are based on review of the current projects used to develop the Project Modules. Most of these updates could not be included in the current version of the Cost Estimating Tool due to data limitations. To effectively implement these recommendations, cost data required to develop these updates should be identified and requested in the next round of BIPs. Furthermore, a method of collecting and organizing such data should be implemented. Functionality updates that require additional cost details, as listed in Table 3-1, are noted for each module.

3.2.1 PIPELINES MODULE

Updates to cost data may be made per Table 3-1, which discusses the potential to develop separate curves for raw versus treated water. Regarding functionality, this module simplifies the process for developing and costing a water supply pipeline project. A more advanced tool can be developed that gives the user flexibility in developing a profile and choosing where booster pump stations are placed.

3.2.2 WELL FIELD MODULE

ASR well fields include additional components and complexity not considered in this version of the Cost Estimating Tool. Future iterations may consider either developing a separate module for ASR wells that accounts for the other aspects of ASR, such as piping from the source water to the ASR well, additional energy requirements to introduce the water into the aquifer if under pressure, and the ability to rehabilitate existing wells for ASR. This will require further development and may require additional cost curves for the specific project components relating to ASR well fields.

3.2.3 RESERVOIRS MODULE

The Reservoirs Module simplifies the costing of reservoirs based on a given reservoir storage capacity or volume. While the tool is meant to help the BRTs develop planning-level costs where minimal design parameters are known, for some users, a more complex module may be beneficial. For those with a more detailed understanding of project location, available area, or geometry of the proposed new or expanded reservoir, a more accurate cost estimate could be developed. Reservoir costs may be developed based on a conceptual understanding of reservoir embankment height, dam type (material) slopes, and required freeboard as well as spillway and outlet works details. This would require the development of additional cost information for earthwork and specific components of reservoir design.

3.2.4 TREATMENT MODULE

The Treatment Module assumes all treatment projects are intended to have an end-use of potable water; however, there are instances where the end-use may require a lower or higher standard than potable water standards for Colorado. Additionally, the tool currently prompts the user to select a treatment type, meaning it is assumed the user knows what treatment type is appropriate for their circumstance. While a reference table is provided to help guide the user to select the appropriate treatment type, future tool iterations could include functionalities to recommend appropriate treatment types.

This process may require additional cost curves if the treatment types provided are not applicable to some source water or end-uses typical of Colorado.

Currently, there is no costing options for remediation treatment activities, such as acid-mine drainage remediation, which is included in the list of projects in the current BIPs. Future iterations of the tool may consider developing a separate module or module component to address the arduous processes for acid-mine drainage using conventional treatment or passive treatment processes. This will require identification and development of additional cost-curves specific to the processes for completing acid-mine drainage remediation.

3.2.5 DITCHES AND DIVERSION MODULE

The Cost Estimating Tool currently assumes the user will understand the required capacity of the irrigation ditch. Water needs for irrigation ditches are likely associated with a volume of water needed to meet a crop-irrigation requirement. Future development of this module may include an option to estimate a required ditch capacity based on: (1) the quantity of irrigated acres, (2) the agricultural commodity, and (3) the months of irrigation. To include this additional functionality, the module should also require the user to characterize the source water stream to ensure that it can meet the diverted capacity required by the agricultural operation to be served by the ditch. The module would then be able to estimate both the required ditch capacity to meet the water supply need and the maximum ditch capacity that can be drawn off the source stream.

The NRCS tool used to develop the cost curves in the current tool estimates costs based on channel geometry. This tool was adjusted to estimate costs based on a channel capacity; however, elements of the NRCS tool could be incorporated into future tool iterations to allow users to more accurately estimate costs based on the specific geometry of their ditch channel.

3.2.6 STREAMS AND HABITAT MODULE

The Streams and Habitat Module simplifies stream restoration activities by grouping restoration into four levels. This removes the requirement that the user have full knowledge or specific design details for their restoration project. Some users may know more about the current condition of the stream and the desired condition of the stream/habitat; therefore, more accurate costing may be achieved by identifying key characteristics that are addressed by stream restoration. The module may be updated to prompt the user to characterize the pre-project condition and the desired post-project characteristics of the stream. This update may also separate the riparian restoration component and estimate the cost of riparian/wetland restoration based on the acres of restored habitat rather than by stream-mile.

The module could also provide suggestions for the types of restoration activities that may meet the post-project parameters. The development of this functionality would require research into pre- and post-stream and habitat characteristics to identify common elements used to address particular restoration objectives. Including this update may also provide an opportunity to tie together the Cost Estimating Module and the Environmental and Recreation Flow Tool.

To fully effectuate this module update, more cost data for individual elements of a stream restoration project (e.g., in-channel structures, regrading, seeding, etc.) would have to be developed in place of grouped (i.e., levels of restoration) cost curves.

3.3 BASIN IMPLEMENTATION

The Cost Estimating Tool is available to assist the BRTs in the development of BIPs. The tool provides a baseline cost estimate for use in the planning process and serves as a mechanism to collect useful information for additional planning and tool refinement in future iterations.

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Analysis and Technical Update to the Colorado Water Plan

Technical Memorandum

Prepared for:

Colorado Water Conservation Board

Project Title:

Colorado Water Project Cost Estimating Tool
Appendix A: User Guide

Date: May 21, 2019

Prepared by: Lauren Starosta, Eli Gruber, and Devin Schultze, CDM Smith
Reviewed by: Sue Morea and Becky Dunavant, CDM Smith

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Appendix A: Colorado Water Project Cost Estimating Tool User Guide

This User Guide is intended to supplement the Colorado Water Project Cost Estimating Tool and provide users with additional guidance for use of the tool. Attached to this guide are details regarding the cost data used within the tool to develop total project costs from module inputs (Attachment 1). This information may be used by the user to assess the applicability of the data for their specific project and adjust as necessary in the Costing Module.

The Colorado Water Project Cost Estimating Tool is an Excel-based tool comprised of eight project modules intended for developing planning-level cost estimates. The outputs of each module are summarized in the Costing Module where cost curves are applied to module outputs to calculate total project costs. The total costs are then summarized and uniformly formatted in the Cost Summary Sheet, which can be exported and submitted with grant applications.

The Overview page of the tool provides general structure and easy navigation to any module within the tool **(Figure A-1**Figure A-1 Colorado Water Project Cost Estimating Tool Organization**)**.

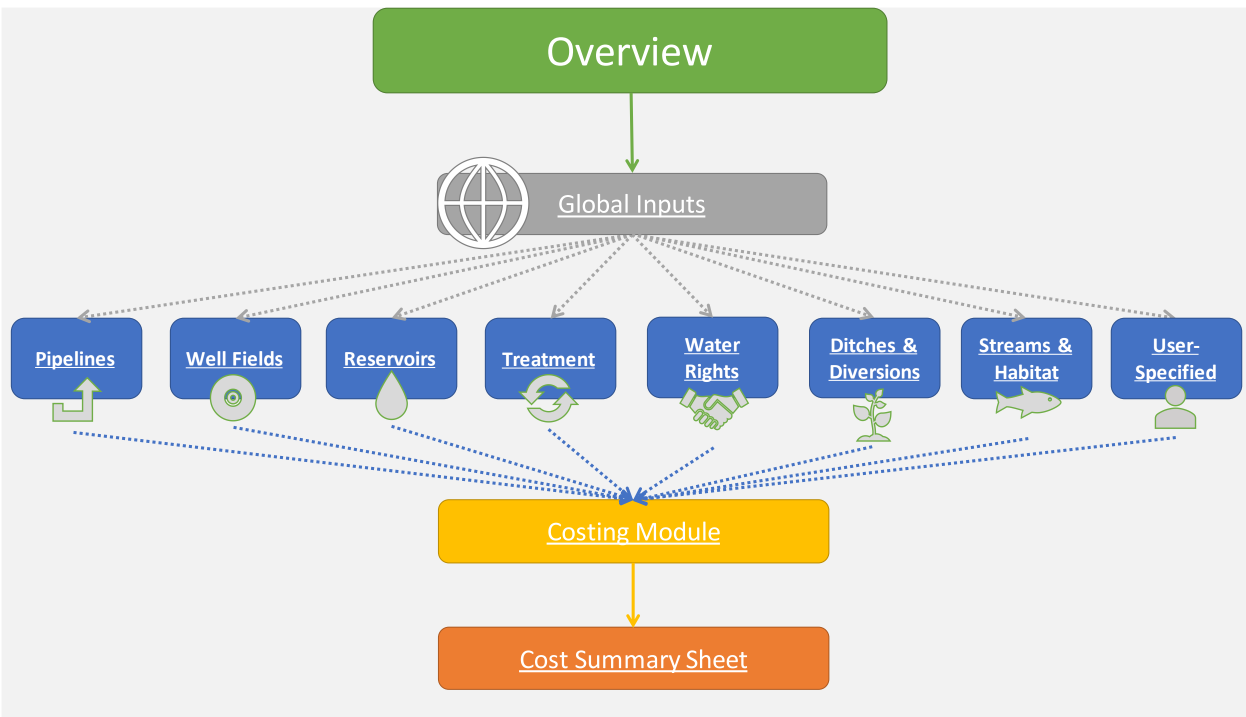

Figure A-1 Colorado Water Project Cost Estimating Tool Organization

On the Overview page, the user can navigate to any module by clicking on the module name. Because the tool is Excel-based, the user can also navigate through the tool using the Excel tabs at the bottom of the interface. When working within a module there are two buttons located in the upper corners for navigation either back to the Overview page or to the Costing Module.

The Overview page also provides brief instructions for tool use with the following introduction:

Introduction
The Colorado Water Project Cost Estimating Tool is intended to provide a common technical framework for basin roundtables (BRTs) to utilize when developing their Basin Implementation Plans. This tool builds on previous Colorado water project cost estimation methods as well as other tools developed for planning-level cost estimation to provide an accessible and user-friendly tool for basin roundtables to use in developing high-level cost estimates of projects and methods.

In addition, the use of this tool provides costs presented in a manner that enables easy comparison by the Colorado Water Conservation Board. As this tool is used, it may be adjusted over time to improve the function and costs databases as more project information and costs are collected. Each project module varies in complexity and level of detail based on the amount of data available to support development of cost curves and the required input information to define specific project-type characteristics.

User Note: For the tool to function properly, user must enable Macros in Excel. Sheets are locked to prevent user-adjustment of calculations. Password for sheet protection is SWSI 2017.

For help navigating the tool, user should refer to the Quick Reference Guide.

Instructions for Enabling Macros: Microsoft Office Support - Enable or Disable Macros in Office Files

The following disclaimer is included at the bottom of the Overview page, which users should consider while using the tool, and information included in the tool, for further development of projects:

Disclaimer
This tool was developed for the purpose of preparing regional water planning level cost estimates only. It is not intended to be used in lieu of professional engineering design or cost estimation. Results of this tool should be carefully reviewed by construction professionals, professional engineers or other knowledgeable professionals prior to implementation of a project.

Any use of the Colorado Water Project Cost Estimating Tool and results will be at the user's own risk and without liability of legal exposure to the Colorado Water Conservation Board and/or CDM Smith, Inc.

A.1: GLOBAL INPUTS MODULE

The Global Inputs Module collects general project information from the user which may be commonly referenced throughout several modules or pertains to project development, administration or annual costs.

A.1.1 INPUT KEY

The user should refer to the Input Key provided at the top of the Global Inputs Module, as shown in **Figure A-2**, when using any of the modules.

Input Key	
0	User Input
0	Informational Data*
0	Default Value, Adjustable by User
0	**Calculated Values, Not to be Adjusted**

Figure A-2 Water Cost Estimating Tool Input Key

The user should take care to only directly input values in white and green cells and review project data before adjusting default values provided in blue cells. Cells highlighted in green should be filled in as accurately as possible; however, the values do not influence project cost. The purpose of collecting informational data via the green cells is for tool improvement during future iterations. Users should not adjust grey cells as they calculate values required for project costing; grey cells are locked to prevent user-adjustment.

Throughout the tool, there are “Reset” and “Restore” buttons. The “Reset” buttons will set all user input cells (white cells) on the page back to blank. The “Restore” buttons will change back all default values (blue cells) on the page to their original values.

A.1.2 PROJECTION INFORMATION SECTION

The Project Information Section (Figure A-3) records important project identification data, water supply need(s) addressed by the project, and project costing reference information.

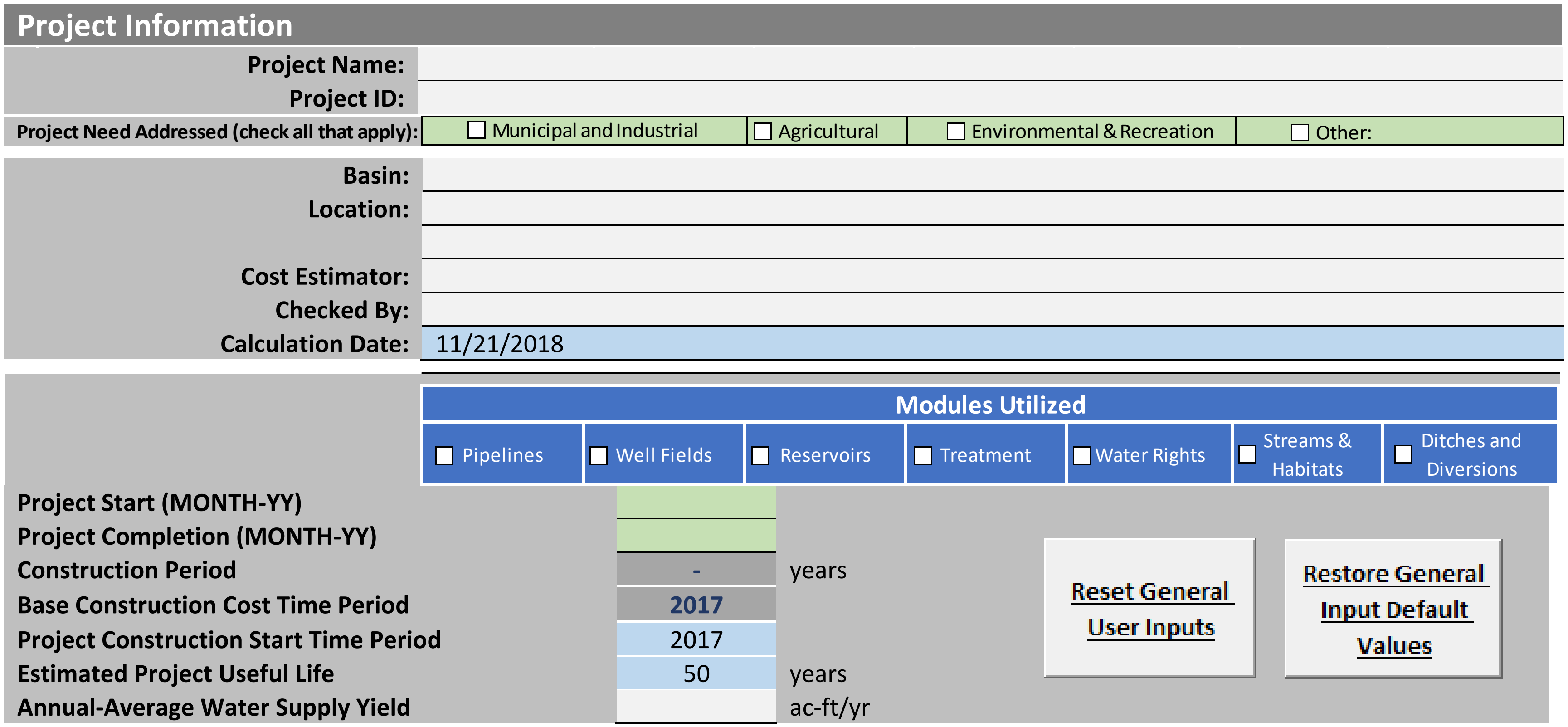

Figure A-3 Project Information Inputs

The user may provide an assumption of project construction timeframe, but the Project Construction Cost Index Time Period is the critical input for adjusting the calculated cost estimate to account for price escalation over time. The cost curves used to generate project costs are based on 2017 dollars; however, understanding that the tool may be used for costing projects that will not break ground for several years, and that costing data within the tool may not be updated until the next iteration of the Statewide Water Supply Initiative (SWSI), the tool is designed to project future costs using a fixed 3.5 percent inflation rate. This rate was based on long-term inflation rate trends provided by the Colorado Water Conservation Board (CWCB). Note that in fields where the user specifies a cost, this inflation rate will **not be applied**, and costs are assumed to be in the year construction will take place.

Project useful life represents the amount of time the user expects the project, as designed, to be operational. The user may also consider this to be the amount of time the project will be in effect before a significant retrofit, capacity increase, or update is required. For example, a treatment plant may have a peak capacity to meet the current population and, based on a 50-year population projection, it is possible that capacity will need to be increased in 50 years. Thus, the project useful life is 50-years. This may be used to estimate total maintenance costs over the life of the project.

The Annual-Average Water Supply Yield represents the additional new supply yield per year the project being costed with the Colorado Water Project Cost Estimating Tool will provide. This value is used in the Project Summary Sheet to calculate the normalized cost of the project.

A.1.3 PROJECT DEVELOPMENT COSTS

Project Development Cost inputs address the overall project administration, engineering design, and oversight costs. The default values, as shown on **Figure A-4**, are consistent with industry standards for project development but may be changed by the user. Required Land Acquisition must be input by the user if the cost of land is to be calculated based on dollars per acre. It is assumed that most project types will require the purchase of land. Note that in fields where the user specifies a cost, the inflation rate will **not be applied**, and costs are assumed to be in the year construction will take place. The Project Development Costs input allows the user to either input the total cost for acquisition of all acres or provide a cost per acre, which is multiplied by the Required Land Acquisition value provided by the user.

Project Development Costs		
Engineering Services	20.0%	% of Capital Costs
Surveying	1.0%	% of Capital Costs
Legal Service	10.0%	% of Capital Costs
Financing and Bond Assistance	1.0%	% of Capital Costs
Environmental and Cultural Studies	1.0%	% of Capital Costs
Required Land Acquisition		acres
Land Acquisition Cost		$ per acre
Permitting	1.0%	% of Capital Costs
Interest During Construction	4.0%	

Figure A-4 Project Development Inputs

A.1.4 ANNUAL COSTS AND PUMPS

The user should review the default values for calculating annual costs associated with project development, capital investment, and operations and maintenance (O&M). Each is shown on **Figure A-5**.

Annual Costs		
Debt Service	5.5%	% of Capital Costs
Debt Service (Non-Reservoirs) Period	20	Years
Debt Service (Reservoirs) Period	40	Years
Operations & Maintenance (Pipelines)	1.0%	% of Capital Costs
Operations & Maintenance (Pump Stations)	2.5%	% of Capital Costs
Operations & Maintenance (Reservoirs)	1.5%	% of Capital Costs
Rate of Return on Investments	1.0%	
Annual Interest Rate (Non-Reservoirs)	5.5%	
Annual Interest Rate (Reservoirs)	5.5%	
Power Costs	0.11	$ per kilowatt-hour
Pumps		
Power Connection Costs - Pump Stations	150	$ per horsepower

Figure A-5 Annual Costs and Pump Power Connection Costs

Debt Service refers to the quantity of money required (per year) to repay loans or external capital investment towards the proposed project. Default values assume 20 years for non-reservoir projects and 40 years for reservoir projects. Interest over the term of the loan is included with a credit for Rate of Return on Investment.

O&M costs are assumed to represent costs of monitoring, labor, equipment, and repairs of facility components. If users wish to adjust default values provided in the Global Inputs Module, they are encouraged to research similar projects completed in their basin or community. When adjusting default values within the Global Inputs Module, the user should refer to projects completed recently (within the last 5 years) throughout their basin or community. The default values are considered representative for the entire state and may vary based on region or basin.

A.2: PROJECT MODULES OVERVIEW

Most project modules are designed for developing planning-level cost estimates. As such, detailed project components are either generalized or assumed because the user is not expected to know all project details at this level. In general, modules are organized where high-level project inputs and outcomes are considered first (e.g., desired total yield). The user then works through more detailed components of the project, keeping high-level project goals in mind.

The header of each module includes the module name and intended use as well as project information, assumptions, and abbreviations.

Pipeline and Pump Station Parameters *Pipeline Module should be used for all projects with a pipeline component. The main elements of a pipeline project include the pipeline, pump stations and storage at the pump station. Three segments are available to cost out different pipe/pump parameters.*
Project Information
Enter Project Name in Global Inputs
Enter Project ID in Global Inputs
Enter Basin Name in Global Inputs
Enter Cost Estimator in Global Inputs
Assumptions
Based on typical water composition, terrain and use in Colorado, Ductile Iron Pipe is assumed for all pipeline calculations and costing.

Calculations and costs assume an average of 6ft of cover over the length of the pipeline.

Calculations and costs assume an average of 2500ft between valves in the pipeline. Bends are not considered.

Storage requirements are provided by the user, but a recommended value is 10% of the average daily flow.

Abbreviations

ac-ft/yr	-	acre-feet per year
cfs	-	cubic feet per year
ft	-	feet
ft-msl	-	feet - mean sea level
fps	-	feet per second
HP	-	horsepower
HGL	-	Hydraulic Grade Line
in	-	inches
kW-hr	-	kilowatt-hour
MG	-	million gallons
mgd	-	million gallons per day
psi	-	pounds per square inch
TDH	-	Total Dynamic Head

Figure A-6 provides an example of this header.

Pipeline and Pump Station Parameters		
Pipeline Module should be used for all projects with a pipeline component. The main elements of a pipeline project include the pipeline, pump stations and storage at the pump station. Three segments are available to cost out different pipe/pump parameters.		
Project Information		
Enter Project Name in Global Inputs		
Enter Project ID in Global Inputs		
Enter Basin Name in Global Inputs		
Enter Cost Estimator in Global Inputs		
Assumptions		
Based on typical water composition, terrain and use in Colorado, Ductile Iron Pipe is assumed for all pipeline calculations and costing.		
Calculations and costs assume an average of 6ft of cover over the length of the pipeline.		
Calculations and costs assume an average of 2500ft between valves in the pipeline. Bends are not considered.		
Storage requirements are provided by the user, but a recommended value is 10% of the average daily flow.		
Abbreviations		
ac-ft/yr	**-**	**acre-feet per year**
cfs	**-**	**cubic feet per year**
ft	**-**	**feet**
ft-msl	**-**	**feet - mean sea level**
fps	**-**	**feet per second**
HP	**-**	**horsepower**
HGL	**-**	**Hydraulic Grade Line**
in	**-**	**inches**
kW-hr	**-**	**kilowatt-hour**
MG	**-**	**million gallons**
mgd	**-**	**million gallons per day**
psi	**-**	**pounds per square inch**
TDH	**-**	**Total Dynamic Head**

Figure A-6 Example Project Module Header

The Project Information section is carried over into every module from the Global Inputs tab. The user should read and understand the assumptions for each module and refer to the main report for further guidance on the assumptions prior to completing the module inputs.

A.3: PIPELINES MODULE

The Pipelines Module may be used to cost projects that transport finished or raw water for potable or non-potable uses. The costs developed for the total project include the pipeline, pump stations, and storage at the pump stations (if required). The module assumes that the user has minimal information regarding the route; therefore, the number and size of pump stations and storage tanks needed is estimated. If the user is aware of a difference along the route that should be considered in the calculations, the module is divided up into multiple pipe segments that may be used.

A.3.5 MODULE ORGANIZATION

Each pipe segment is organized into four main components: Pipeline Information, Pipeline Diameter, Pipe Hydraulics and Pump Station Hydraulics. Each component is shown on Figure A-7 through Figure A-10.

These components are included in three separate pipe segment calculations. Use of multiple segments is not required and only necessary if there is a change in project yield, peaking factor or diameter along the pipeline length. Multiple segments may also be used if the user wants to control the number and distribution of pump stations along the project. Inputs or calculations do not transfer from one segment to another. They can, however, be used as independent calculations that combine into a single, total cost estimate. The inputs and each component are described further in the following sections.

A.3.6 MODULE INPUTS AND OUTPUTS

The inputs, calculations and source data for the Pipelines Module are described in the following sections for each of the four components. The overall module outputs that feed into the Costing Module are also described.

A.3.6.1 PIPELINE INFORMATION

This component, as shown on **Figure A-7,** requires the inputs described in **Table A-1**. Many of these inputs are used in calculations in the subsequent components. The input for Environment dictates the cost curve used for costing the pipeline project. The user specifies if the area of the pipeline project will take place in a rural or urban environment. For the purposes of this tool, urban environments are considered those within an incorporated area where commercial or residential development has occurred adjacent to the planned project site. Rural environments should be reserved for those projects planned in areas with minimal development or human influence on the natural habitat. The user should conduct site assessments either through site visits or aerial imagery analysis to determine the best characterization of the project environment. Water Delivered is for informational/data collection purposes and not included in any calculations within the tool.

Pipeline Information						
	Ground Elevation (ft-msl)	Environment		Water Delivered	Desired Head at End of Pipe (psi)	Maximum Pipeline Pressure (psi)
Pipeline Start				Raw		
Pipeline End						

Figure A-7 Pipeline Information Component

Table A-1 Pipelines Module Inputs - Pipeline Information

Input	Units	Description
Pipeline Start/End Elevation	ft-msl	Elevation in feet, relative to sea level, of upstream and downstream nodes for pipeline segment
Environment	-	Condition of area where pipeline is installed: Urban or Rural
Water Delivered	-	Characterization of raw or treated water through pipeline. Input is informational only
Residual Head at End of Pipe	psi	Required pressure at pipe end node
Maximum Pipeline Pressure	psi	Greatest allowable pressure through the pipeline. Also known as pipeline pressure class

ft-msl = feet – mean sea level; psi = pounds per square inch

A.3.6.2 PIPELINE DIAMETER

This component calculates the required pipeline diameter based on a maximum allowable velocity given project yield and peaking factor. A screenshot is shown on **Figure A-8.** Each input is described in Error! Reference source not found.. The user may change the default value provided for velocity.

Pipeline Diameter *If desired discharge and velocity are known and required diameter is unknown*		
Total Project Yield		ac-ft/yr
Peaking Factor, PF		
Peak Flow through Pipeline, q	**0.0**	**cfs**
Velocity of Flow, V	5	fps
Required Diameter	**0.00**	**in**

Figure A-8 Pipeline Diameter Calculator Component

Table A-2 Pipeline Module Inputs - Pipeline Diameter

Input	Units	Description
Total Project Yield	ac-ft/yr	Average annual water delivered through the pipeline in acre-feet/year
Peaking Factor	-	Ratio of peak flow to average flow through the pipeline
Velocity of Flow	fps	Default value of 5 feet per second (fps) represents typical maximum velocity through pressurized pipes in a transmission system

ac-ft/yr = acre feet per year; fps = feet per second

A.3.6.3 PIPE HYDRAULICS

The inputs for this component, shown on

Pipe Hydraulics		
Nominal Pipe Size, d		in
Pipeline Length, L		ft
Hazen-Williams C Factor	120	(Roughness)
Maintenance Downtime	5.0%	for Uniform Delivery

Flow

Average Flow (mgd)	**Average Flow (cfs)**	**Peak Flow (mgd)**	**Peak Flow (cfs)**	**Velocity (fps)**
0.00	**0.00**	**0.00**	**0.00**	**-**

Figure A-9, are used in the hydraulic calculations and described in

Table A-3. The user selects the nominal pipe diameter based on the required diameter calculated in the previous component. Average flow, peak flow, and velocity are calculated to be used in the subsequent component (Pump Station Hydraulics). The calculated velocity is based on peak flow.

Pipe Hydraulics				
Nominal Pipe Size, d				in
Pipeline Length, L				ft
Hazen-Williams C Factor			120	(Roughness)
Maintenance Downtime			5.0%	for Uniform Delivery
Flow				
Average Flow (mgd)	**Average Flow (cfs)**	**Peak Flow (mgd)**	**Peak Flow (cfs)**	**Velocity (fps)**
0.00	**0.00**	**0.00**	**0.00**	**-**

Figure A-9 Pipeline Hydraulics Component

Table A-3 Pipeline Module Inputs - Pipe Hydraulics

Input	Units	Description
Nominal Pipe Size	in	The Pipeline Diameter calculator provides a minimum required diameter for the pipeline. The user selects a standard pipe size diameter greater than the required diameter
Pipeline Length	ft	The length of the pipeline segment from start to end
Hazen-Williams C Factor	-	Roughness coefficient used in pipeline calculations. Default value of 140 is representative of Ductile Iron Pipe
Maintenance Downtime	%	Percent of time over the year to shut down the pipeline and pumps for maintenance. Only applied if the pipeline is providing uniform delivery (i.e., the peaking factor is equal to 1) to account for a greater maximum flow needed throughout the year to meet the project annual yield.

in = inches ft = feet % = percent

The default value for the Hazen-Williams C Factor is 140, representing Ductile Iron Pipe. However, understanding that the source water, use, and soil composition may require alternate pipe materials, Error! Reference source not found. provides a reference table of various pipe materials and respective H azen-Williams C Factors, should the user wish to adjust the default value.

Table A-4 Hazen-Williams Constants for Various Water Pipe Materials

Type of Pipe or Surface	range	clean	design
steel			
welded and seamless	150–80	140	100
interior riveted, no projecting rivets		139	100
projecting girth rivets		130	100
projecting girth and horizontal rivets		115	100
vitrified, spiral-riveted, flow with lap		110	100
vitrified, spiral-riveted, flow against lap		100	90
corrugated	80–40	80	60
mineral			
concrete	150–60	120	100
cement-asbestos	160–140	150	140
vitrified clays			110
brick sewer			100
iron			
cast, plain	150–80	130	100
cast, tar (asphalt) coated	145–50	130	100
cast, cement lined		150	140
cast, bituminous lined	160–130	148	140
ductile iron	150–100	150	140
cement lined	150–120	150	140
asphalt coated	145–50	130	160
wrought, plain	150–80	130	100

Type of Pipe or Surface	range	clean	design
miscellaneous			
aluminum, irrigation pipe	135–100	135	130
copper and brass	150–120	140	130
wood stave	145–110	120	110
transite			
lead, tin, glass	150–120	140	130
plastic (PVC, ABS, and HDPE)	150–120	155	150

[a] C values for sludge pipes are 20% to 40% less than the corresponding water pipe values

[b] The following guidelines are provided for selecting Hazen-Williams coefficients for cast-iron pipes of different ages. Values for welded steel pipe are similar to those of cast-iron pipe five years older. New pipe, all sizes: C = 130.5 yr old pipe: C = 120 (d < 24 in); C = 115 (d ≥ 24 in). 10 yr old pipe: C = 105 (d = 4 in); C = 110 (d = 12 in); C = 85 (d ≥ 30 in). 40 yr old pipe: C = 65 (d = 4 in); C = 80 (d = 16 in).

Table Referenced from PE Civil Reference Manual, Sixteenth Edition, Appendix 17.A Specific Roughness and Hazen-Williams Constants for Various Water Pipe Materials

A.3.6.4 PUMP STATION HYDRAULICS

The inputs for this component are shown on

Pump Station Hydraulics							
Pump Type			Booster				
Pump Efficiency			0.7	(Mechanical & Electrical)			
Pump Requirements							
Static Head (ft)	Total Dynamic Head (ft)	Total Power Needs (HP)	Number of Pump Stations Needed	HP per Pump Station	HP Needed for Average Flow	Total Pumping Energy (kW-hr)	Storage Volume Requirement (MG)
1115.5	1120.5	1252.1	2	626.1	633.1	3,929,021	0.22

Figure A-10 and described in **Table A-5**. Values from the previous three components are used to calculate power needs, number of pump stations, energy use, and storage volume required. The number of pump stations is a simplified calculation based on the maximum pipeline pressure. It is assumed that a pump station is needed at each point along the pipeline when the maximum pipeline pressure will be exceeded. Total horsepower is then distributed evenly over the number of pump stations needed. To estimate total pump energy needed, the average annual flow is used to calculate overall power needs. Finally, storage is assumed to be needed at 10 percent of the average annual flow.

Pump Station Hydraulics							
Pump Type			Booster				
Pump Efficiency			0.7	(Mechanical & Electrical)			
Pump Requirements							
Static Head (ft)	Total Dynamic Head (ft)	Total Power Needs (HP)	Number of Pump Stations Needed	HP per Pump Station	HP Needed for Average Flow	Total Pumping Energy (kW-hr)	Storage Volume Requirement (MG)
1115.5	1120.5	1252.1	2	626.1	633.1	3,929,021	0.22

Figure A-10 Pump Station Hydraulics

Table A-5 Pipeline Module Inputs – Pump Station Hydraulics

Input	Units	Description
Pump Type	-	Pump type used for water transmission through the pipeline; may be Intake or Booster
Pump Efficiency	HP/HP	The ratio of output power from the pump to the shaft horsepower input for the pump; default efficiency is 0.7

HP = horsepower

A.3.6.5 PIPELINE MODULE OUTPUTS

The outputs from the Pipeline Module that feed into the Costing Module are described in **Table A-6**. Some outputs are user-provided information while other outputs are calculated in one of the components described previously.

Table A-6 Pipeline Module Outputs to Costing Module

Output	Units	Description
Nominal Pipe Size	in	User selected pipeline diameter
Length	ft	Pipeline length as input by user
Environment	-	Condition of area where pipeline is installed: Urban or Rural
Pump Station Facility Size	HP	Calculated power per pump station
Number of Pump Stations	#	Ratio of pipeline pressure to maximum allowable pipeline pressure needed to convey water through the pipeline
Total Pumping Energy	kW-hr	Energy required based on average annual flow
Storage Volume Requirement	MG	Estimated onsite storage requirement for pump station

in = inches; ft = feet; HP = horsepower; # = number; kW-hr = kilowatt-hour; MG = million gallons

A.4: WELL FIELD MODULE

Well field projects that may be costed using the Well Fields Module include public supply wells, aquifer storage and recovery (ASR) wells, and irrigation wells. Additionally, the module provides the user with options regarding the number of wells, well capacity, and distribution system. The module assumes uniform capacity and depth for each well in the well field or allows the user to specify capacity per well. Similar options are available for the booster pumps stations within the well field.

The well field lay-out is simplified and assumes a main transmission line with each well connecting at a point along the line from the furthest upstream well to the delivery point as shown on **Figure A-11**. The well collector pipeline for each well is assumed to be short enough that the cost of that line in relation to the rest of the project components is negligible. The user can input additional external costs as needed at the bottom of the Costing Module if needed for the well collector pipelines.

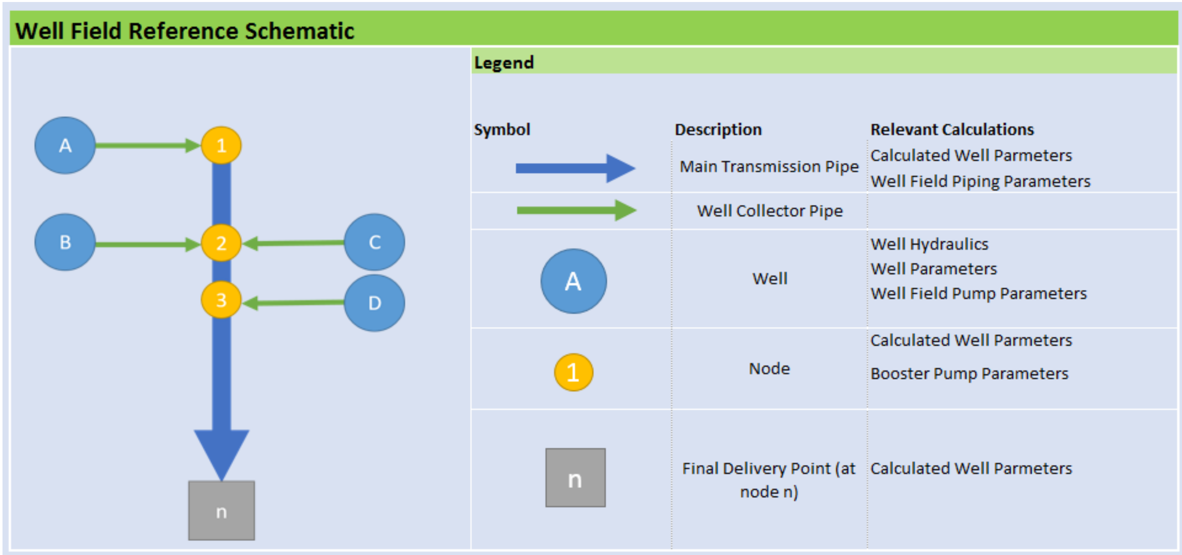

Figure A-11 Well Field Schematic

A.4.1 MODULE ORGANIZATION

The Well Fields Module is organized into three main components: Well and Pump Calculator and Cost Inputs, Pipeline Calculator and Cost Inputs, and Booster Pump Calculator and Cost Inputs. Each represents a separate component of a potential well field project. The well and pump parameters are required to generate well field project costs, but the pipeline and booster pump parameters are not necessary if the user does not need costs for those components.

A.4.2 MODULE INPUTS, OUTPUTS AND SOURCE DATA

The inputs, calculations, and source data for the Well Fields Module are described in the following sections for each of the three components. The overall module outputs that are fed into the costing module are also described.

A.4.2.1 WELL AND PUMP CALCULATOR AND COST INPUTS

The user provides well field information including: the type of well, hydraulic information, and flows. These inputs determine the required well parameters, including energy requirements to extract water to the top of the well. Additional booster pump requirements to convey water through well field transmission line piping are calculated separately in the Booster Pump Calculator and Cost Inputs component. Based on user input for average flow per well, the tool calculates the number of wells needed in the well field to meet the desired total project yield assuming the same capacity at each well. To help the user conceptualize the inputs, Figure A-12 is a schematic of a well showing the various depths and elevations. All of the inputs are shown on Figure A-13 and Figure A-14 and described in Table A-7.

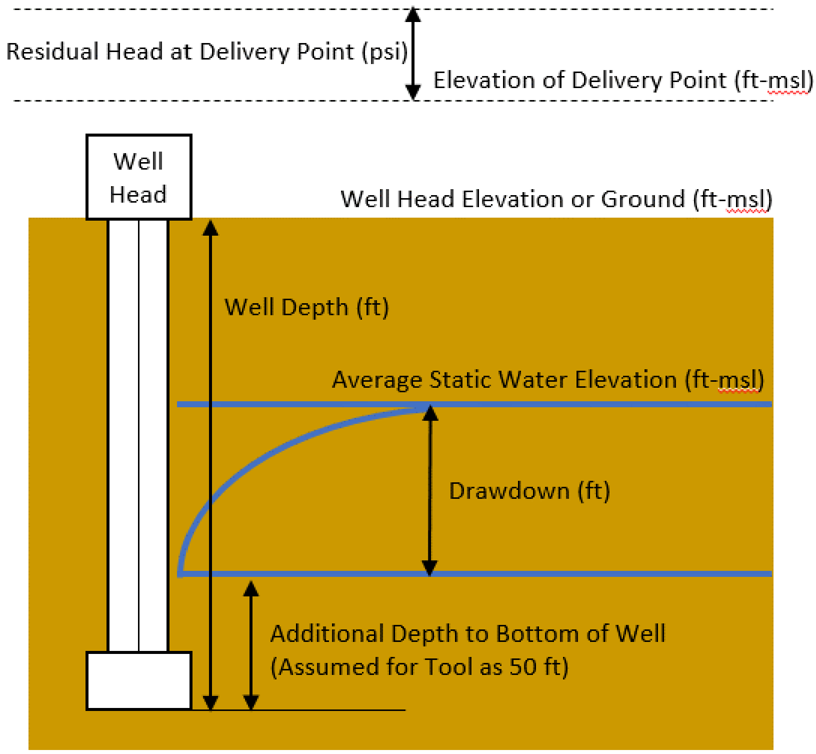

Figure A-12 Well Hydraulics Schematic

User must address all input boxes for the entire section of this module for all values to calculate. User will need to scroll to the right to see all inputs. Specific items to note when supplying inputs include the following:

- Once "Number of Required Active Wells" calculates, the user must input the "Well Head Elevation (ft-msl)" for each of the wells before additional values will calculate.
- The next inputs required to finish the calculations in "Well and Pump Hydraulics" come from "Well Parameter Cost Inputs," which are copied over using the supplied button or can be input by user.

Well Field Information	
Well Type:	
Average Static water elevation (ft-msl):	
Drawdown (ft):	
Total Project Yield (ac-ft/yr):	
Average Daily Well Field Yield (mgd):	0.00
Peaking Factor:	
Well Column Velocity (fps):	8
Elevation of Delivery Point (ft-msl):	
Residual Head at Delivery Point (psi):	
Efficiency (Mechanical & Electrical):	0.7
Hazen Williams C Factor:	140
Click Here for C Factor Roughness Reference Table	
-	

Well and Pump Hydraulics	
Average Flow Per Well (gpm):	
Peak Flow Per Well (gpm):	-
Average Flow Per Well (cfs):	-
Peak Flow Per Well (cfs):	-
Number of Required Active Wells:	0
% Operating Time:	-
Average Well Head Elevation (ft-msl):	-
Average Depth to GW (ft):	-
Well Column Losses (ft):	-
Average TDH (ft):	-
Average Well Pump Requirement (HP):	-
Total Well Pump Requirement (HP):	-
Average Energy Usage per Well (kW-hr):	-
Total Energy Usage for All Wells (kW-hr):	-

Figure A-13 Well & Pump Calculator – Well Field Information and Hydraulics

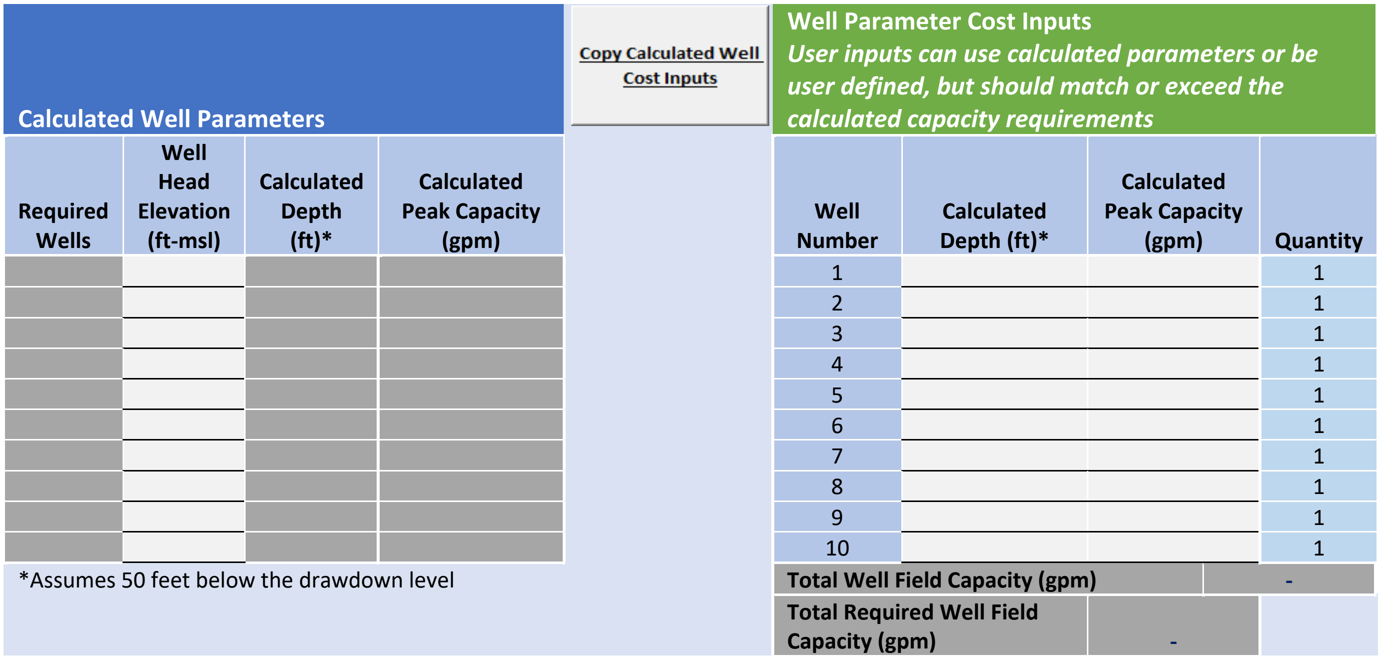

Figure A-14 Well Parameters

Table A-7 Well Field Module Inputs - Well and Pump Calculator and Cost Inputs

Input	Units	Description
Well Type	-	Public Supply, Aquifer Storage Recovery, or Irrigation Wells
Average Static Water Elevation	ft-msl	The average groundwater elevation, relative to mean sea level, across the well field without the influence of well pumping
Drawdown	ft	Difference in elevation between average static water level and water level immediately adjacent to the well during active pumping
Total Water Production	ac-ft/yr	The anticipated total annual water production of the well field
Peaking Factor	-	Ratio of maximum flow to average flow for an individual well
Well Column Velocity	fps	Typical velocity of 8 fps used to calculate losses in the well column when calculating TDH
Elevation of Delivery Point	ft-msl	Elevation, relative to sea level, at the final delivery point for well field water supply
Residual Head at Delivery Point	psi	Pressure at end of well field transmission pipe
Efficiency (Mechanical & Electrical):	HP/HP	The ratio of output power from a well or pump to the horsepower input; default efficiency is 0.7
Hazen-Williams C Factor	-	Roughness coefficient used in pipeline calculations. Default value of 120 is representative of Ductile Iron Pipe
Average Flow per Well	gpm	Average production of each individual well
Well Head Elevation	ft-msl	Elevation, relative to mean sea level, of top of well (ground elevation); enter an elevation for every well
Calculated Depth	ft	Calculated values if user chooses to utilize the calculations; alternatively, user enters more specific data for each well
Calculated Peak Capacity	gpm	Calculated values if user chooses to utilize the calculations; alternatively, user enters more specific data for each well

ft-msl = feet – mean sea level ft = feet ac-ft/yr = acre-feet per year fps = feet per second psi = pounds per square inch
gpm = gallons per minute

A.4.2.2 PIPELINE CALCULATOR AND COST INPUTS

This component is similar to the Pipelines Module but uses the calculated flow from the Well and Pump Calculator component to determine the cumulative flow through each segment of the transmission line. The module only accounts for the main transmission line (no well field collector piping) and assumes that all wells are in series, increasing in flow based on the calculated peak capacity for each well. The components are shown on Figure A-15 and Figure A-16, and the inputs are described in Table A-8. For Selected Diameter, the user selects a nominal pipe diameter for each pipe segment based on the minimum required diameter computed based on the default maximum velocity. The Selected Diameter and user-input Pipe Length are carried through to the Costing Module. The input for Environment dictates the cost curve used for costing the well field project. For the purposes of this tool, Urban environments are considered those where the planned project takes place within an incorporated area where commercial or residential development has occurred adjacent to the project site. Rural environments should be reserved for projects planned in areas with minimal development or human influence on the natural habitat. The user should conduct site assessments either through site visits or aerial imagery analysis to determine the best characterization of the project site.

Well Field Piping Parameters

Calculates required pipe diameter and booster pump capacity for conveying water along main well field transmission line to delivery point

US Node/ Pipe Number	Flow (gpm)	Peak Flow (cfs)	Computed Diameter for 5 fps (in)	Selected Diameter (in)	Velocity (fps)	Length (ft)
1	400	0.9	5.7	6	4.5	200
2	800	1.8	8.1	10	3.3	300
3	1200	2.7	9.9	10	4.9	50
4	1600	3.6	11.4	12	4.5	400
Totals						950

Figure A-15 Well Field Pipeline Calculator

Well Field Piping Parameter Cost Inputs

Pull from user inputs in Well Field Piping Parameters table

Pipe Size (in)	Environment	Pipe Length (ft)
6	Urban	200
10	Urban	300
10	Urban	50
12	Urban	400

Figure A-16 Well Field Pipeline Cost Inputs

Table A-8 Well Field Module Inputs - Pipeline Calculator and Cost Inputs

Input	Units	Description
Selected Diameter	in	Diameter of each transmission pipe segment for delivery from well field to final delivery point
Length	ft	Length of transmission pipe segment
Environment	-	Condition of area where pipeline is installed: Urban or Rural

in = inches ft = feet

A.4.2.3 BOOSTER PUMP CALCULATOR AND COST INPUTS

Booster pump stations are added along the well field transmission line in this component using the values from the previous components to calculate the number, capacity, and power for each pump station. The component is shown on Figure A-17 and Figure A-18. The inputs for this component are described in Table A-9. The calculations assume a booster pump station for each segment (between each well) with head and power needs calculated for each individual booster pump. If the system uses gravity, the head and power requirements will be zero.

The user is required to enter the Well Head Elevation of each well and select the booster pumps. Well Head Elevation should either be the same as previously entered in the “Calculated Well Parameters” component or specific elevations related to the user’s selected wells in the “Well Parameter Cost Inputs”. For the booster pumps, the user may choose to use the calculated pump capacity and total dynamic head by using the “Copy Calculated Booster Pump Cost Inputs” button. Alternatively, there is the option to manually input a selected number of booster pumps with varying capacities and head requirements. These inputs generate the required pump power and energy, which are carried through to the Costing Module.

Well Field Pipeline Booster Pump Requirements *Calculates required booster pump capacity for conveying water along main well field transmission line to delivery point*										
US Node/ Pipe Number	Capacity (gpm)	Well Head Elevation (ft-msl)	DS Well/ Pipe Node	DS Elevation Well/Pipe (ft)	Elevation Delta (ft)	HGL Slope (ft/100ft)	Segment Pipe Head Loss	TDH (ft)	Power (HP)	Energy (kW-hr)
1	400	100	2	200	100	15.9	3.17	103.2	14.9	37,683
2	800	200	3	300	100	4.8	1.43	101.4	29.3	74,089
3	1200	300	4	400	100	10.1	0.50	100.5	43.5	110,124
4	1600	400	5	500	100	7.1	2.82	102.8	59.3	150,218
Totals					100			407.9	147.0	372,114

Maximum Pipeline Pressure (psi)	226.6
Calculated Number of Booster Pumps	1

Figure A-17 Well Field Pipeline Booster Pump Calculator

Booster Pump Parameters ***User inputs can use Calculated Booster Pump Inputs or be User-defined, but should match or exceed the Total Required Capacity and TDH requirements***				
Pump Number	**Pump Capacity (gpm)**	**Pump TDH (ft)**	**Power (HP)**	**Energy (kW-hr)**
1				-
2				-
3				-
4				-
5				-
6				-
7				-
8				-
9				-
10				-
Total	-	-	-	-
Total Required	-	-		

Figure A-18 Well Field Booster Pump Parameters

Table A-9 Well Field Module Inputs - Booster Pump Calculator and Cost Inputs

Input	Units	Description
Well Head Elevation	ft-msl	Elevation, relative to mean sea level, of top of well (ground elevation); enter an elevation for every well. Values should be the same as entered in “Calculated Well Parameters” unless user chose to enter specific well information in “Well Parameter Cost Inputs”.
Capacity (optional)	gpm	Cumulative flow rate through transmission line booster pump for each transmission line segment
Total Dynamic Head (TDH) (optional)	ft	Required pressure resistance pump needs to overcome to convey water through the pipeline

gpm = gallons per minute ft = feet

A.4.2.4 WELL FIELDS MODULE OUTPUTS

The outputs from the Well Fields Module that feed into the Costing Module are described in Table A-10. Some outputs are user-provided information while other outputs are calculated in one of the components described previously.

Table A-10 Well Field Module Outputs to Costing Module

Output	Units	Description
Well Type	-	Public Supply, Aquifer Storage Recovery, or Irrigation Wells
Calculated Depth	ft	Tool-generated depth of individual wells
Calculated Peak Capacity	gpm	Tool-generated capacity for each well based on total well field yield, peaking factor, and average flow per well
Energy	kW-hr	Total energy required for well and booster pumps to extract water and convey to the delivery point
Selected Diameter	in	Diameter of each transmission pipe segment for delivery from well field to final delivery point
Length	ft	Length of transmission pipe segment
Environment	-	Condition of area where pipeline is installed: Urban or Rural
Pump Station Power	HP	Power calculated for a pump station at each transmission line segment

ft = feet gpm = gallons per minute kW-hour = kilowatt-hour in = inch HP = horsepower

A.5: RESERVOIRS MODULE

The Reservoirs Module includes new reservoirs or reservoir expansions. This module simply uses cost curves for developing construction costs of a new reservoir or expansion based on the new or added storage volume. A calculation of energy provided from hydropower is provided for information purposes and is not accounted for in the cost summary.

A.5.1 MODULE ORGANIZATION

The Reservoir Module is organized into two main components: Reservoir Parameters and Hydropower. These are shown on **Figure A-19**.

Reservoir Project Parameters			
Project Type			
New Storage Volume		ac-ft	
Existing Storage (enter 0 if New Reservoir project)		ac-ft	
Total Storage (informational)	**0**	ac-ft	
Reservoir Rehabilitation Project Parameters			
Reservoir Rehabilitation Project Description			
User-Defined Reservoir Rehabilitation Cost		**Click Here for Reservoir Rehab Cost Data Table**	
Hydropower Option *Not factored into cost estimation*			
Height of Falling Water		ft	
Discharge		gpm	
Turbine Efficiency	0.9		*Encompasses mechanical and electrical efficiency used in calculating power and energy production*
Power	**0**	**HP**	
Annual Turbine Use Percentage	60%		*Percent of time over the year that a hydropower generation station will be utilized*
Estimated Annual Energy Production	**0**	**kW-hrs**	

Figure A-19 Reservoir Module Organization

A.5.2 MODULE INPUTS, OUTPUTS AND SOURCE DATA

The inputs, calculations and source data are described in the following sections for each of the components. The overall module outputs that are fed into the Costing Module are also described.

A.5.2.1 RESERVOIR PROJECT PARAMETERS

The inputs required for Reservoir Project Parameters are described in Table A-11. New storage volume applies to a new reservoir or a reservoir expansion in that it is the additional storage added by the project. Existing storage can be added by the user for informational purposes and the module will calculate the total storage of the reservoir.

Table A-11 Reservoir Module Inputs - Reservoir Project Parameters

Input	Units	Description
Project Type	-	New reservoir construction or expansion of existing reservoir
New Storage Volume	ac-ft	Volume of water to be stored in the reservoir in excess of existing storage

ac-ft = acre-feet

A.5.2.2 RESERVOIR REHABILITATION PROJECT PARAMETERS

The reservoir rehabilitation component of the Reservoir Module provides users who intend to complete significant maintenance or repair projects. Reservoir rehabilitation encompasses a variety of activities that may affect the reservoir outfall, outlet works, dredging, water quality, or embankment. Because rehabilitation does not have any defined characteristics, the user is encouraged to provide a detailed description of the rehabilitation activities taking place, as detailed in Table A-12.

Table A-12 Reservoir Module Inputs - Reservoir Rehabilitation Project Parameters

User-Specified Reservoir Rehabilitation Project Description	-	Provide project characteristics to define type of rehabilitation activities taking place. (e.g., spillway expansion/improvement, outlet-works improvements, embankment stabilization, dredging, among others)
User-defined Cost	-	User-provided cost of reservoir rehabilitation activities

To help the user estimate a reasonable cost for reservoir rehabilitation activities, a PDF reference table (Table B-1 Estimated Reservoir Rehabilitation Costs from 2015 Basin Implementation Plan) is provided with actual or estimated reservoir rehabilitation project costs from the April 2015 Basin Implementation Plans. This table is further discussed in Appendix B.

A.5.2.3 HYDROPOWER OPTIONS

This component is provided for informational purposes with the inputs described in Table A-13. Estimated annual energy production is calculated using the inputs and the default values for efficiency and percent annual use.

Table A-13 Reservoir Module Inputs - Hydropower

Input	Units	Description
Height of falling water	ft	Height difference between water surface elevation and outlet into hydropower station
Discharge	gpm	Flow rate over hydropower dam

Ft = feet gpm = gallons per minute

A.5.2.4 RESERVOIR MODULE OUTPUTS

The outputs from this module that feed into the Costing Module are direct inputs from the user and are those previously described in Table A-11.

A.6: TREATMENT MODULE

Water treatment projects may be operated to provide water for potable or non-potable uses. The principal guidelines for determining the appropriate water treatment technology is the source water quality and required effluent water quality, which is dictated by the intended effluent use. The Treatment Module was designed to address these two factors through a qualitative self-assessment of source water characteristics by the user for determining the best-suited treatment type.

The module allows the user to select a treatment type, the planned treatment average day demand, and peaking factor. A wide variety of source water quality may be considered by using the provided table of indicator parameters identified as drivers/thresholds for treatment and discussed in more detail in Section A.6.3.

A.6.1 MODULE ORGANIZATION

The Treatment Module includes two module components for the user to complete: Treatment Type and Treatment Capacity as shown on Figure A-20.

Treatment Type		
Treatment Capacity		
Average Day Demand		mgd
Peaking Factor		
Required Capacity	**0**	**mgd**

Figure A-20 Treatment Module Organization

There is no specified order in which the user should complete the module components. The “Clear Treatment Parameters” button removes all user inputs from the module, should the user wish to start over.

A.6.2 MODULE INPUTS, OUTPUTS AND SOURCE DATA

The inputs required for estimating treatment costs include water treatment type and plant design capacity. The inputs required for the Treatment Module are provided in Table A-14.

Table A-14 Treatment Module Inputs

Input	Units	Description
Water Treatment Type	-	Treatment technology selected based on source water quality and user-identified treatment needs
Average Day Water Demand	mgd	The average annual demand ultimately planned for the treatment plant
Peaking Factor	-	Used to determine a maximum day capacity

mgd = million gallons per day

A.6.2.1 TREATMENT TYPE

Treatment type should consider source water quality and the desired treated water quality.

If the user does not have a treatment type predetermined, the tool provides a reference table to aid in determining an appropriate treatment type. The reference table, shown on Figure A-21, requires that the user have, at a minimum, a qualitative understanding of the source water influent to the proposed facility. Typical water quality parameter ranges are provided for different source water types such as snow melt, reservoirs, or brackish groundwater, et al. may be used to characterize source water through a qualitative assessment (Driver/Thresholds for Treatment) or a basic quantitative assessment (Drivers/Approximate Numeric Thresholds for Treatment).

Treatment Type	Drivers/Thresholds for Treatment							Drivers/Approximate Numeric Thresholds for Treatment							Source Water Characteristics
	Pathogens	TOC	Suspended Solids & Turbidity	Salinity	Hardness	Nutrients/Taste & Odor	Emerging Contaminants	Cryptosporidium (oocysts/L)	TOC (mg/L)	Turbidity (NTU)	Chloride (mg/L)	Hardness as $CaCO_3$ (mg/L)	Threshold Odor Number	Emerging Contaminants	
Direct Filtration[1]	LOW	LOW	LOW	LOW	LOW	LOW	LOW	< 0.075 (Bin 1)	≤ 3	≤ 10	< 250	≤ 150	≤ 3	Not Detected or < Action Levels/MCLs	Pristine water quality, consistent with few excursions.
Conventional[1]	MED	MED	MED	LOW	LOW	LOW	LOW	< 0.075 to < 1.0 (Bins 1 or 2)	> 3	> 10	< 250	≤ 150	≤ 3	Not Detected or < Action Levels/MCLs	Moderate-high quality water, moderate to high frequency of excursions.
Conventional + Enhanced Coagulation	MED	MED-HIGH	MED-HIGH	LOW	LOW	LOW	LOW	<0.075 to < 1.0 (Bins 1 or 2)	> 3	> 10	< 250	≤ 150	≤ 3	Not Detected or < Action Levels/MCLs	High natural organic matter (NOM is precursor material to disinfection by-products, aka DBPs).
Conventional + Lime Softening	MED	MED-HIGH	MED-HIGH	LOW	HIGH	LOW	LOW	<0.075 to < 1.0 (Bins 1 or 2)	> 3	> 10	≥ 250	> 150	≤ 3	Not Detected or < Action Levels/MCLs	High hardness in source water, often accompanied by high NOM, turbidity, and other treatment challenges.
Conventional + Ozone/UV	MED-HIGH	MED-HIGH	MED-HIGH	LOW	LOW	MED-HIGH	MED-HIGH	< 0.075 to ≥ 3.0 (Bins 1 thru 4)	> 3	> 10	< 250	≤ 150	> 3	Detected ≥ MCLs or Action Levels	High natural organic matter (precursors to DBPs), high NOM and/or increased levels of pathogens, increased levels of bromide, moderate to severe taste and odor, potential for contaminants of emerging concern (CECs).
Conventional + GAC	MED	MED-HIGH	MED-HIGH	LOW	LOW	MED-HIGH	MED-HIGH	< 0.075 to < 1.0 (Bins 1 or 2)	> 3	> 10	< 250	≤ 150	≤ 3	Detected ≥ MCLs or Action Levels	Similar to Conventional + Ozone, but with lower risk of pathogens in source water.
Conventional + Membranes	MED-HIGH	MED-HIGH	MED-HIGH	LOW	LOW	LOW	LOW	< 0.075 to ≥ 3.0 (Bins 1 thru 4)	> 3	> 10	< 250	≤ 150	≤ 3	Not Detected or < Action Levels/MCLs	High pathogens and/or NOM.
Conventional + Nanofiltration/Reverse Osmosis	MED-HIGH	MED-HIGH	MED-HIGH	MED-HIGH	MED-HIGH	MED-HIGH	MED-HIGH	< 0.075 to ≥ 3.0 (Bins 1 thru 4)	> 3	> 10	≥ 250	> 150	> 3	Detected ≥ MCLs or Action Levels	Treats all of the challenging characteristics listed above for NOM removal, disinfection, softening, CECs, and salinity removal. Not always effective for taste and odor issues.

Figure A-21 Treatment Type Reference Table based on Source Water Characteristics

The applicable water quality parameters for treatment are:

- Pathogen concentration
- Total Organic Compounds (TOC)
- Total Suspended Solids (TSS) and Turbidity
- Salinity
- Hardness
- Nutrients/Taste and Odor, and
- Emerging Contaminants

The approximate numeric thresholds provide the user the option for a more detailed source water characterization by providing reasonable ranges for parameter indicators. The user should consult water quality data from sources such as USGS Water-Quality Data website, the National Water Quality Monitoring Council (NWQMC) Water Quality Portal, EPA STOrage and RETreival (STORET) data warehouse, or similar sources, or conduct a baseline water quality assessment of their source water to most accurately use the numeric thresholds.

Once the user has characterized the source water, the most appropriate treatment technology should be selected in the tool. However, it is understood that the basins understand their specific needs and available resources for developing water treatment projects. The most appropriate treatment type for a community may differ from the treatment type suggested by the reference table; therefore, the user should select the treatment type that best suits the needs of their community. The end use of the treated water is also a factor in determining the appropriate treatment technology. While the tool may be used to calculate non-potable use projects, for the purposes of tool simplicity, it was assumed that all end use is potable drinking water.

A.6.2.2 TREATMENT CAPACITY

The user must input the capacity for the treatment facility. Treatment facilities for potable drinking water are designed for anticipated peak day demands. The user inputs the average annual demand and a peaking factor to account for seasonal peaking.

If the user has not yet determined the capacity of the proposed water treatment facility, resources that may be useful for estimating the required capacity of a water treatment facility include American Society of Civil Engineers (ASCE) publications and EPA resources.

The outputs of the Treatment Module, which are summarized in the Costing Module of the tool, are listed in Table A-15. These parameters are used to calculate the appropriate point on the cost curve to represent a planning-level cost for constructing a treatment facility.

Table A-15 Treatment Module Outputs to Costing Module

Input	Units	Description
Water Treatment Type	-	Treatment technology selected based on source water quality and user-identified treatment needs.
Total Required (Peak) Design Capacity	mgd	The required capacity (peak day demand) of the water treatment facility

mgd = million gallons per day

A.7: WATER RIGHTS

Water rights in Colorado are administered by the Colorado Division of Water Resources. Water rights pertain to both surface and groundwater sources and are typically defined in Colorado by a process known as prior appropriations (first in time, first in right). For more information regarding water rights and water right administration in Colorado, the user should refer to the resources provided by the Colorado Department of Natural Resources (CO DNR) - Colorado Division of Water Resources.

Water Rights may be required for some projects costed using the Water Cost Estimating Tool. Water rights may be purchased for permanent or leased uses. Projects which may require the purchase of a water right or leasing include groundwater wells, in-stream channel work, and agricultural diversions. The process of converting a water right from one user to another typically requires both a lawyer and water resource engineer. Before beginning project design, users should investigate the need and feasibility of obtaining the necessary water rights.

A.7.1 MODULE ORGANIZATION

The Water Rights Module is organized for direct user input of the project description and cost information. Figure A-22 shows the Water Rights Module organization. The user should note that in fields where the user specifies a cost, such as in this module, it must be entered in the year dollars desired and selected in the Global Inputs for the project construction start time period. These costs are not converted from 2017 dollars to the selected year.

Water Rights Inputs		
User Cost Input		*Total cost of water right*

Figure A-22 Water Rights Module Organization

A.7.2 MODULE INPUTS, OUTPUTS AND SOURCE DATA

The only input required for the Water Rights Module is provided in Table A-16. Before beginning the process of designing a project relating to water supply, the user should check that the proper water rights have been procured. The module prompts the user to input the total cost of the water right (including all capital, legal and administrative costs).

Table A-16 Water Rights Module Inputs

Input	Units	Description
User Cost Input	$	Total cost of water right (in year dollars selected by user)

$ = dollars

A.8: DITCHES AND DIVERSIONS

The Ditches and Diversions Module uses high-level design considerations for the construction of a new irrigation ditch or rehabilitation of an existing one. Research into modern irrigation ditches and canals showed that ditch lining is the most variable factor in designing a ditch. In addition, it is a common rehabilitation practice to install or upgrade lining material for existing ditches. To complete the module, the user must have an estimate of the total flow the ditch should deliver to meet their water supply needs and the length of the ditch from the diversion structure to the delivery point.

A.8.1 MODULE ORGANIZATION

The Ditches and Diversions Module contains three components: Project Options, Diversion and Headgate Structure, and Diversion Structure, which focuses on characterization of ditch components and quantification of ditch capacity and length. Figure A-23 shows these components.

Project Options		
Project Components		
Maximum Diversion Capacity		cfs
Diversion and Headgate Structure		
Type of Diversion Structure (informational)		
Diversion Headgate Capacity		cfs
Default Cost of Diversion Structure		
User Diversion Structure Cost Override		
Ditch Structure (Conveyance)		
Type of Project		
Type of Ditch		
Required Ditch Capacity		cfs
Length		lf

Figure A-23 Ditches and Diversions Module Organization

There is no specified order in which the user should complete the module components. The Reset Ditches and Diversions Inputs button removes all user inputs from the module, should the user wish to start over.

A.8.2 MODULE INPUTS, OUTPUTS AND SOURCE DATA

The inputs required by the Ditches and Diversions Module are provided in Table A-17. The inputs are focused on simplifying ditch characterization by only requiring basic design requirements from the user. It is assumed that the user will have quantified the amount of water required by the project and be able to convert the required yield into a ditch capacity. In addition, the user should know the type of ditch for their needs. If cost is a factor in determining ditch lining material, the user may utilize this module as a tool for determining the best suitable lining type.

Table A-17 Ditches and Diversions Module Inputs

Input	Units	Description
Project Components	-	Project may include a diversion structure, ditch, or both
Maximum Diversion Capacity	cfs	Maximum capacity diverted by the structure and/or conveyed through the ditch
Type of Diversion Structure	-	Characterization of diversion structure; captured for informational purposes only
Selected Cost of Diversion Structure	-	User-supplied cost for diversion structure construction
Type of Project	-	Construction of new ditch or ditch rehabilitation
Type of Ditch	-	Type of ditch lining or construction method
Length	lf	Length of the ditch from intake point at river to delivery point

cfs = cubic feet per second lf = linear feet

It is assumed that the user knows the basic design components of the proposed ditch project. These inputs are used directly in the Costing Module and therefore the module inputs and outputs are the same.

A.8.2.1 PROJECT OPTIONS

Project options provides general information for the project to be constructed. As some projects will only require the construction of a diversion structure or a ditch, the user may elect to cost only those components. However, for either component a capacity is required. The ditch capacity directly relates to both the amount of water diverted by the structure and the total flow conveyed through the ditch. This value will carry over to the Diversion and Headgate Structure and Ditch Structure components, as applicable.

A.8.2.2 DIVERSION AND HEADGATE STRUCTURE

The cost of a diversion structure depends on several variables relating to diversion use, type, capacity, and construction methods. This component collects the type of diversion structure and diversion structure cost installed by the user for informational purposes. This is intended to capture data to improve cost data in future iterations of the tool. The Recommended Diversion Structure Cost estimates a cost for the diversion structure, however, this curve is based on limited data points and several assumptions, discussed in the Ditches and Diversions Section of Appendix B. For these reasons, the cost is only recommended, and the user is encouraged to review the data points provided in the Ditches and Diversions Project Cost Reference (Table B-2 Estimated Ditch and Diversion Costs from Various CO DNR Projects) to determine a reasonable cost for their diversion structure. The user will input their diversion structure cost into Selected Diversion Structure Cost. The user should note that in fields where the user specifies a cost this inflation rate will not be applied and costs are assumed to be in the year construction will take place.

A.8.2.3 DITCH STRUCTURE (CONVEYANCE)

Project components relevant to designing and costing an irrigation ditch begin with understanding the type of project. Costs vary significantly for projects requiring construction of a new ditch, versus installing or re-lining an existing ditch. If the user has a ditch already constructed but knows that significant earthwork or ditch realignment will occur as part of the rehabilitation efforts, the New Ditch option may be selected, as the Rehabilitation option only accounts for lining material costs. In addition, if the project is ditch rehabilitation, it is assumed that a diversion structure is already constructed, and the user may elect not to include a diversion structure. For new ditch projects, the user should select the type of diversion structure included in the project to divert flow into the new ditch.

Type of Ditch pertains to lining material installed during ditch construction. Common lining materials for irrigation ditches included in the tool are:

- Non-Reinforced Concreted Lined
- Reinforced Concreted Lined
- Synthetic Lining
- Closed Conduit (PVC)
- Closed Conduit (DIP)

If the user is unsure of the ditch lining type to be used in the proposed project, they may consult publications by local universities, or contact the local ditch authority for guidance. The user should keep in mind that lining types may affect not only cost but may also have environmental or flow effects. Users should consult with professionals in the field of irrigation ditch construction before making a final selection of ditch lining.

The process of designing and constructing an irrigation ditch or canal can be complex, particularity in Colorado where topography and subsurface soil conditions can vary within short distances. To simplify design for the user, only the necessary ditch capacity, which can be interpreted as an estimate of water required for their irrigation needs, is input into the tool. In order to allow for ditch capacity to represent ditch geometry, several assumptions were made and are discussed in Section A.8.3. These assumptions should be reviewed carefully and considered by the user before engaging in ditch design.

A.8.2.4 DITCH LENGTH

The final component of the Ditches and Diversions Module is Ditch Length. For new ditches this is interpreted as the length of the ditch to be constructed, usually from the diversion structure within the supply stream to the final delivery or storage point. This length will be used as a multiplier in the Costing Module and therefore should only reflect the length of the ditch being lined for ditch rehabilitation projects.

A.9: STREAMS AND HABITAT MODULE

The Streams and Habitat Module generates planning-level restoration costs based on the restoration activities employed, while keeping in mind that Colorado is home to both headwaters and major rivers that serve a myriad of communities and interests.

A.9.1 MODULE ORGANIZATION

The Streams and Habitat Module contains one section which focuses on characterization of the stream and the complexity of restoration activities, which are organized into four levels. Figure A-24 shows the inputs for this component.

Stream and Habitat Inputs		
Stream Width Range	20 to 50	ft
Stream Environment	Rural	
Length of Restoration	1,000	lf
Level of Restoration	Level 3	

Figure A-24 Streams and Habitat Module Organization

There is no specified order in which the user should complete the module components. The Reset Restoration Inputs button removes all user inputs from the module, should the user wish to start over.

A.9.2 MODULE INPUTS, OUTPUTS AND SOURCE DATA

The inputs required by the Streams and Habitat Module are focused first on an understanding of the stream to be restored. While the level of restoration is also important, cost for restoration activities can vary greatly depending on the stream environment. A summary of module inputs is provided in Table A-18.

Table A-18 Stream and Habitat Inputs

Input	Units	Description
Stream Width Range	ft	Approximate width of stream segment where project takes place
Stream Environment	-	Location of project: urban or rural
Length of Restoration	lf	Linear feet of stream being improved due to project
Level of Restoration	-	Qualification of project based on tiered grouping of typical stream and habitat project components

ft = feet lf = linear feet

It is assumed that the user can quantify the basic design components of the proposed stream and habitat project. These inputs are directly referenced in the Costing Module and therefore the module inputs and outputs are the same.

A.9.2.1 STREAM AND HABITAT INPUTS

Colorado hydrology is characterized by not only the headwaters and mainstems of large rivers such as the Colorado, Arkansas and Rio Grande, but by small mountain streams and meandering channels through the plains. An understanding of the stream environment can have significant effects on the type and extent of restoration, and therefore cost. The characterization of streams is a complex process, however for the purposes of this tool, streams are defined by three variables: width, environment and length of restoration.

Stream size is represented by stream width range. Streams are categorized into four width ranges described in Table A-19. Ranges were selected as opposed to direct input of a stream width because the width of a stream may vary significantly over the length of restoration activities. It is understood that multiple stream width ranges may represent a stream over the length of restoration; the user should select the width range that is most representative of the stream over the restoration area. It should also be noted that the stream width range accounts for width of the stream from top of bank to top of bank. If riparian activities outside of the banks are to be included in restoration, they should not be accounted for in stream width.

Table A-19 Stream Width Ranges

Typical Stream Type	Stream Width Range (ft)
Headwaters or Local Stream	5 to 20
Headwaters or Small Tributary	20 to 50
Large Tributary	50 to 100
Large River Trunk	>100

Stream length is used as a multiplier in the Costing Module and therefore should only reflect the length of the stream affected by the restoration activities. For example, if the project involves two sites that are 100 feet in length along one mile of a stream, the length input into the tool should be 200 feet, not one mile. To determine the approximate length and width range of restoration, the user should conduct site surveys or use aerial imagery tools such as Google Earth or Geographic Information Systems (GIS).

Stream restoration activities and costs also vary based on stream environment. The user specifies if the area of stream restoration will take place in a rural or urban environment. For the purposes of this tool, Urban environments are considered those where the stream restoration takes part within an incorporated area and commercial or residential development has occurred adjacent to the riparian buffer. Rural environments should be reserved for those restoration activities in areas with minimal development or human influence on the natural habitat. For instance, a few homes along an isolated river may not constitute an Urban area. The user should conduct site assessments either through site visits or aerial imagery analysis to determine the best characterization of the stream environment.

To create a simplified means of costing, restoration activities were binned into compounding levels. The tool provides a reference table, shown on **Figure A-25**, to help the user determine the appropriate level of restoration for their project.

Reference Table		
Level of Restoration	**General Description**	**Typical Components**
Level 1	*Riparian restoration*	*Grading; revegetation*
Level 2	*Level 1 + bank stabilization*	*Riprap; root wads; log jams*
Level 3	*Level 2 + in-channel structures*	*Riffles; rock vanes; boulder weirs*
Level 4	*Level 3 + channel realignment*	*Channel realignment*

Figure A-25 Stream and Habitat Level of Restoration Reference Table

The levels of restoration are compounding, meaning that if Level 4 is chosen, it is assumed that all Level 3, 2, and 1 activities are also included in restoration. Level 1 restoration is intended to only address riparian habitat improvements and assumes no in-channel work or work within the stream banks. Activities associated with riparian habitat improvements may involve regrading or contour reconnection in riparian buffer, soil compaction, vegetation restoration, landscaping and adaptive management practices.

Level 2 restoration includes work along stream banks, which may include regrading of eroded banks and erosion prevention activities such as hard armoring (rip rap or structural bank protection) or bioengineered bank stabilization which incorporates natural components such as root wads, log jams, soil wraps or geo-grid fabrics, brush mattresses and timber pilings.

Level 3 restoration includes in-channel structures typically utilized to facilitate mixing, improve water quality, improve in-stream habitats, and control erosion. In-channel structures may include pool-and-riffle habitat construction, gabion baskets, rock vanes (cross vanes, single vanes and J-hooks) and boulder or log weirs.

Level 4 restoration involves channel realignment and significant earthwork and is most typically employed during the construction of stream crossings for roadways. In stream and habitat restoration, channel realignment may be used to reverse the effects of channelization and reestablish natural flow regimes to a stream.

If the user has not determined the appropriate level of restoration for the proposed project, resources are provided on the CWCB website on watershed protection and restoration, stream management plans, and species protection.

A.10: USER-SPECIFIED PROJECTS

The purpose of the User-Specified Project Module is two-fold. First, the module provides users with projects that do not align with the pre-installed modules to submit costs for their projects; and, second, the module allows users with pre-defined cost estimates that may be more detailed than the intent of this tool to submit project costs. While the tool will not aid these users with cost-estimating, project costs may still be presented in a uniform manner with the Cost Summary Sheet.

A.10.1 MODULE ORGANIZATION

The User-Specified Projects Module is organized for direct user input of the project description and cost information. **Figure A-26** shows the User-Specified Projects Module organization.

User-Specified Project Input		
Project Description		
Total Project Yield		*ac-ft/yr*
User Cost Input		*Total Capital Cost of Project Construction*
User Cost Input		*Annual Project Operations & Maintenance Costs*

Figure A-26 User-Specified Projects Module Organization

A.10.2 MODULE INPUTS, OUTPUTS AND SOURCE DATA

In the User-Specified Project Input component, the user must provide significant elements of the project as no specific inputs are defined by the tool. Therefore, these inputs are used directly in the Costing Module and therefore the module inputs and outputs are the same. The inputs required by the tool are provided in **Table A-20**. The user should note that in fields where the user specifies a cost, such as in this module, it must be entered in the year dollars desired and selected in the Global Inputs for the project construction start time period. These costs are not converted from 2017 dollars to the selected year.

Table A-20 User-Specified Module Inputs

Input	Units	Description
Project Description	-	Project description should include any significant project parameters (size, capacity) and required infatuation (pipes, pumps, dams, among others) and activities (earthwork, special construction methods, among others)
User Cost Input	$	Total cost for only construction of project (in year dollars selected by user)
User Cost Input	$	Anticipated annual operations and maintenance costs (in year dollars selected by user)

$ = dollars

If the user is submitting a project that aligns with one of the provided modules, but has more detailed cost estimates, the user should include the same information in the project description. For example, users with a detailed cost estimate for a treatment plant should include the treatment type, average daily flow, peaking factor and design capacity of the plant, just as they would if using the Treatment Module. Data collected through the User-Specified Module will be analyzed for updates and improvements to costing data for future iterations of this tool.

Similarly, if a user is submitting a project through the User-Specified Project Module because the project does not align with a pre-defined module, the user should outline the significant project elements that most affect costs. This information will be analyzed and used to include additional modules, as needed, in future tool iterations.

A.11: COSTING MODULE AND COST SUMMARY SHEET

A.11.1 COSTING MODULE

As mentioned throughout this guide, outputs from the eight project modules are summarized and applied to project-specific cost curves in the Costing Module. An example of project information displayed in the Costing Module is provided on **Figure A-27**. The user should note that in fields where the user specifies a cost, such as in this module, it must be entered in the year dollars desired and selected in the Global Inputs for the project construction start time period. These costs are not converted from 2017 dollars to the selected year.

Treatment Project

Treatment Project Capital Costs				
Treatment Type	*Capacity (MGD)*	*Capital Cost*	*External Cost Est.*	*Cost*
-	-	-		-

Treatment Project Annual O&M Costs				
Treatment Type	*Capacity (MGD)*	*Annual Cost*	*External Cost Est.*	*Cost*
-	-	-		-
Total Treatment Capital Project Cost				**$0**

Reservoir Project

Reservoir Project Costs			
Reservoir Project Type	*New Capacity (ac-ft)*	*External Cost Est.*	*Cost*
-	-		-

Reservoir Rehabilitation Project Costs			
Reservoir Rehab Project	*User-specified Cost*	*External Cost Est.*	*Cost*
-	-		-
Total Reservoir Project Cost			**$0**

Water Rights Project

Water Rights Project Costs	
External Cost Estimate	-
Total Water Rights Project Cost	**$0**

Ditches and Diversions Project

Ditch Project Costs					
Type of Ditch Project	*Type of Ditch*	*Maximum Discharge (cfs)*	*Length (lf)*	*External Cost Est.*	*Cost*
-	-		-		-

Diversion Project Costs			
Type of Diversion	*Maximum Discharge (cfs)*		
-			
Total Ditches & Diversions Project Cost			**$0**

Streams and Habitat Project

Streams and Habitat Project Costs						
Stream Width (ft)	*Environment*	*Level of Restoration*	*Unit Cost*	*Quantity (lf)*	*External Cost Est.*	*Cost*
-	-	*Level 1*	-	-		-
-	-	*Level 2*	-	-		-
-	-	*Level 3*	-	-		-
-	-	*Level 4*	-	-		-
Total Streams and Habitat Project Cost						**$0**

Figure A-27 Example of Costing Module Project Outputs and Costs

The user should review the project information within the relevant module sections for accuracy of data and an initial check of unit costs and direct capital costs. In general, the Costing Module does not require any inputs by the user. However, should the user have an external cost estimate for some project modules, an alternate cost estimate may be entered in the External Cost Estimate Cell, shown on **Figure A-28**. The user should note that in fields where the user specifies a cost this inflation rate will **not be applied** and costs are assumed to be in the year construction will take place.

Treatment Project Capital Costs			
Capacity (MGD)	*Capital Cost*	*External Cost Est.*	*Cost*
2.2	*$14,928,678*		*$14,928,678*
Treatment Project Annual O&M Costs			
Capacity (MGD)	*Annual Cost*	*External Cost Est.*	*Cost*
2.2	*$702,742*	*800,000*	*$800,000*
Total Treatment Capital Project Cost			**$15,728,678**

Figure A-28 External Cost Entry Example

The user should note that when an external cost estimate is entered in the Costing Module, that value supersedes the unit cost estimate generated by the tool. If the user wishes to compare costs, the tool-generated costs are preserved in the cells to the left, which report the unit costs for that module. Should the user decide to revert to the tool-generated costs, the external cost estimate value must be deleted; entering a value of zero will result in a cost of zero dollars for that module.

The final section of the Costing Module also encourages user-input where applicable. If line item costs are not included in the existing tool modules, the user may add these costs in the Additional External Costs section (**Figure A-29**). These costs are added to capital costs and reported as Additional Project Costs in the Cost Summary Sheet.

Additional External Costs			
Additional Line Item	***Related Module***	***Line Item Description***	*Item Cost*
Fencing	*Pipelines*		*$50*
Seeding	*Streams & Habitats*		*$50*
Total Additional Project Costs			**$100**

Figure A-29 Additional External Costs Example

A.11.2 COST SUMMARY SHEET

The Cost Summary Sheet summarizes all project capital, development and annual costs for the proposed project. After reviewing data on the Cost Summary Sheet to verify accuracy, the user should select Create Cost Summary. This alters the Cost Summary Sheet to display only relevant data with associated costs. For example, if only the Pipelines and Well Fields Modules were utilized, only line items associated with their construction will be displayed on the sheet. The sheet can then be exported to a PDF for submission with a CWCB grant application. An example of a completed Cost Summary Sheet is shown in **Figure A-30**.

Pipeline and Treatment Project
ARK-2018-001
Arkansas Basin
Cost Analysis Computed by John Doe
11/27/2018

Capital Construction Costs

Total Pipelines Project Cost	*$21,672,000*
Total Treatment Capital Project Cost	*$41,438,000*
Construction Project Costs Subtotal (Non-Reservoir)	***$63,110,000***

Project Development Costs

Land Acquisition	*$50,000*

Non-Reservoir Project Development Costs

Engineering Services	*$12,622,000*
Surveying	*$631,000*
Legal Service	*$6,311,000*
Financing and Bond Assistance	*$631,000*
Environmental and Cultural Studies	*$631,000*
Permitting	*$631,000*
Interest During Construction	*$2,524,000*
Power Connection Costs - Pump Stations	*$136,000*
Project Development Costs Subtotal (Non-Reservoir)	***$24,117,000***
Total Project Cost (Non-Reservoir)	***$87,227,000***

Reservoir Project Development Costs

Total Project Cost	***$87,227,000***
Normalized Project Cost (per ac-ft per year)	*$8,723*

Annual Costs

Debt Service (Non-Reservoirs) Period	*$7,299,000*
Operations & Maintenance (Pipelines Project)	*$474,000*
Operations & Mainteance (Treatment)	*$1,285,000*
Power Costs	*$1,646,000*
Total Annual Costs	***$10,704,000***

Figure A-30 Water Cost Estimating Tool Cost Summary Sheet Export Example

Analysis and Technical Update to the Colorado Water Plan

Technical Memorandum

Prepared for:

Colorado Water Conservation Board

Project Title:

Colorado Water Project Cost Estimating Tool

Appendix B: Cost Curves Development

Date: May 21, 2019

Prepared by: Lauren Starosta, Eli Gruber, and Devin Schultze, CDM Smith

Reviewed by: Sue Morea and Becky Dunavant, 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-1**Error! 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.

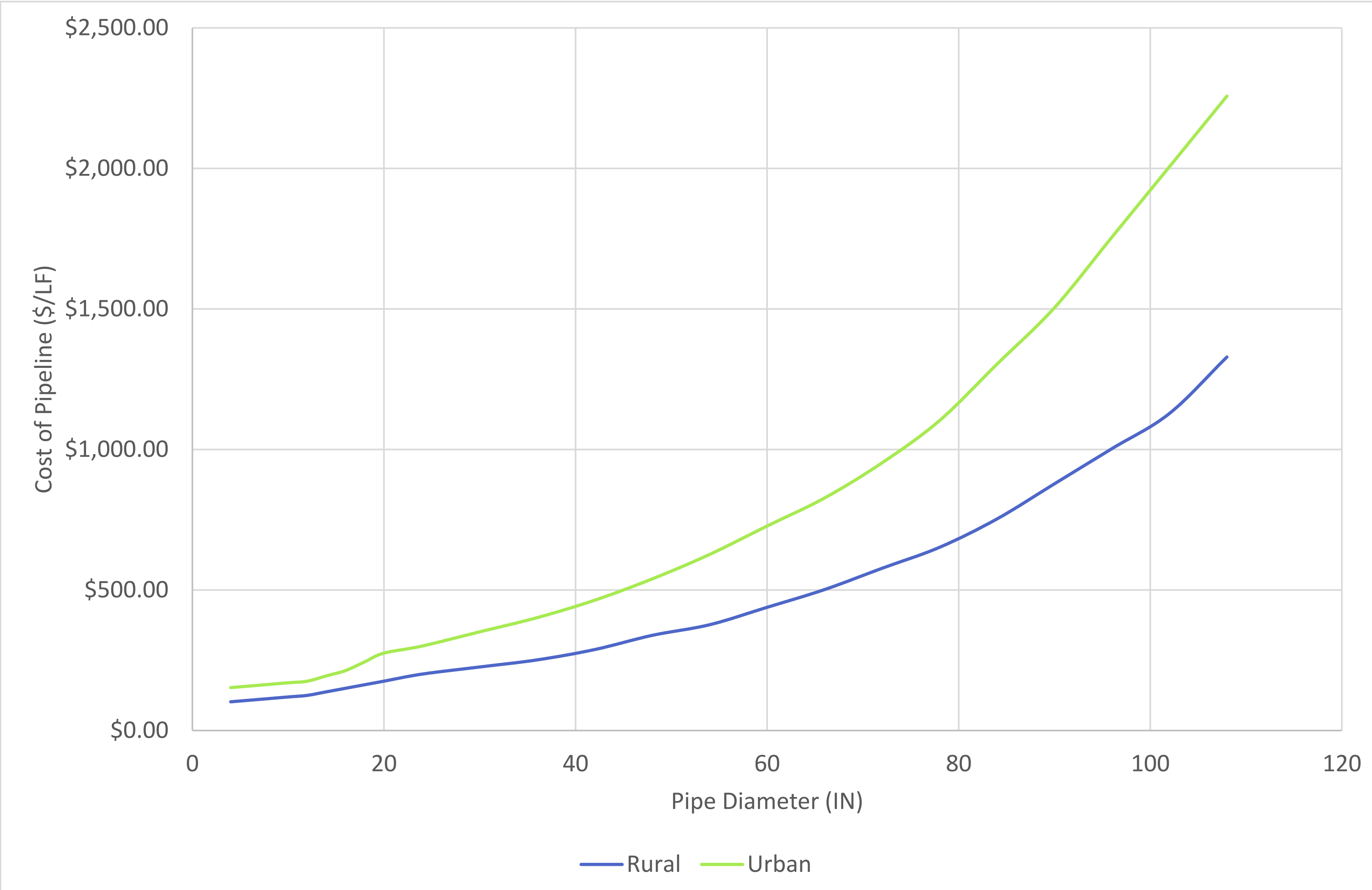

Figure B-1 Pipelines Cost Curve

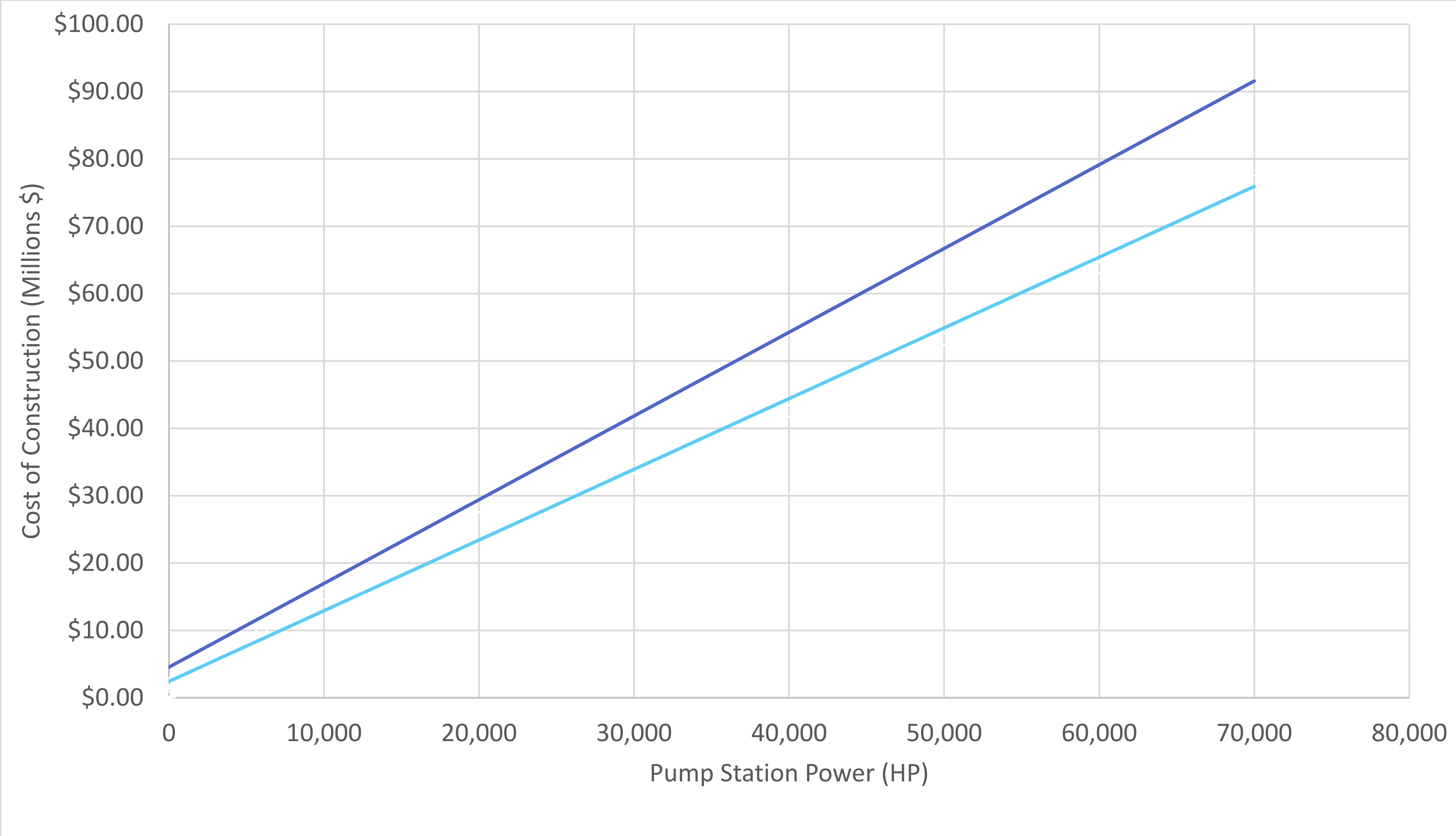

Figure B-2 Pump Station Cost Curves

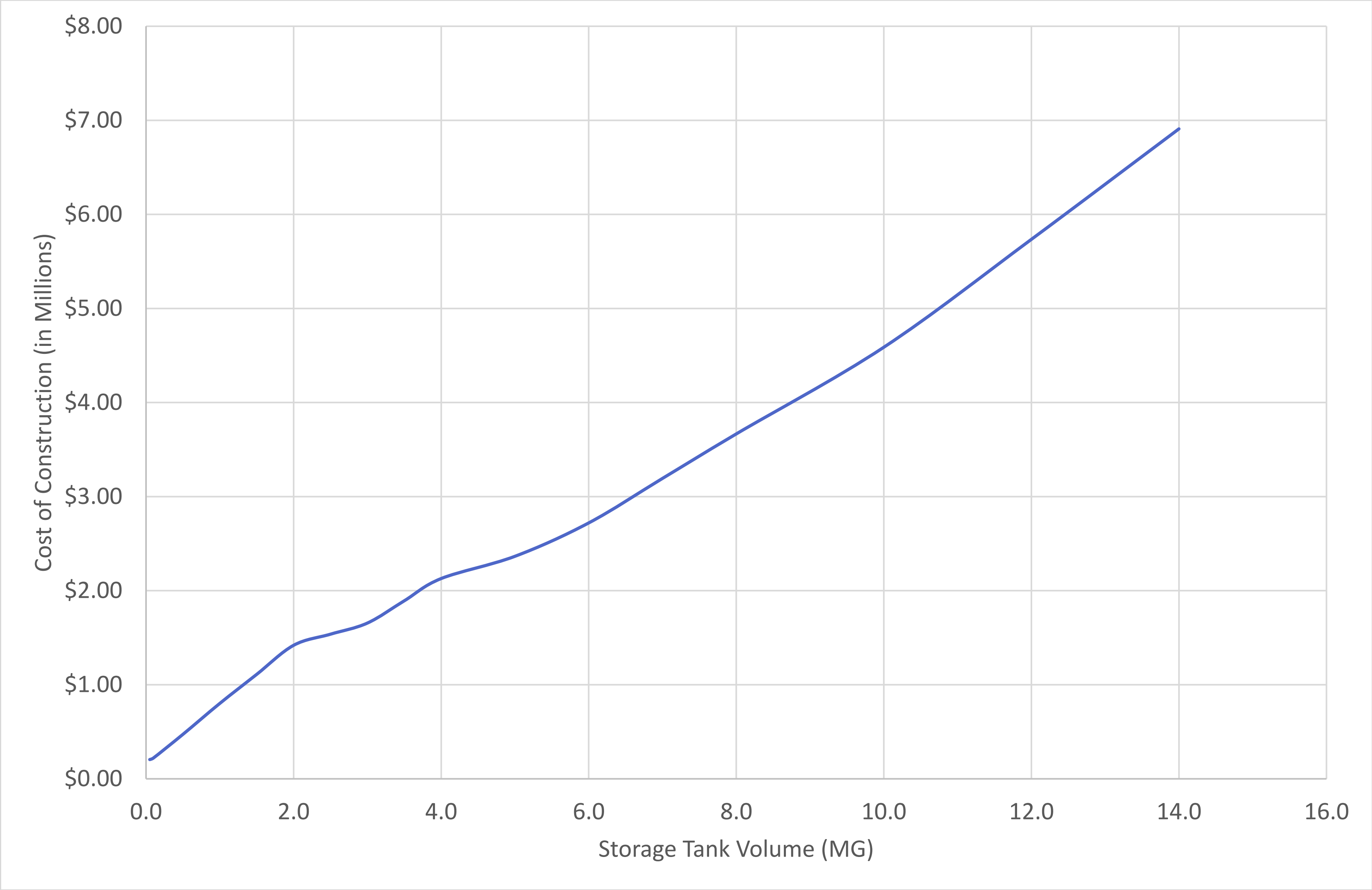

Figure B-3 Booster Pump Station Storage Tank Cost Curve

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.

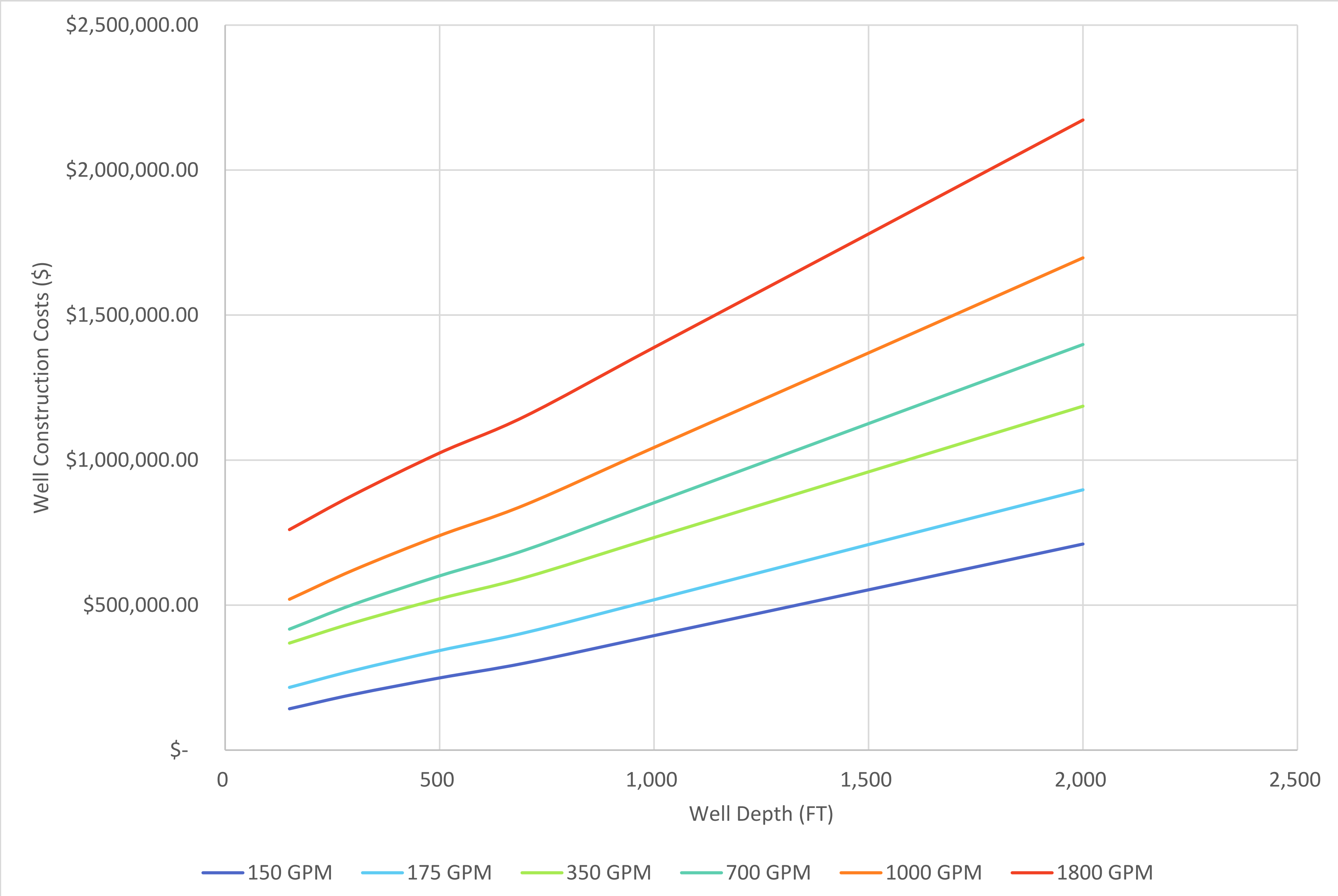

Figure B-4 Public Supply Well Cost Curves

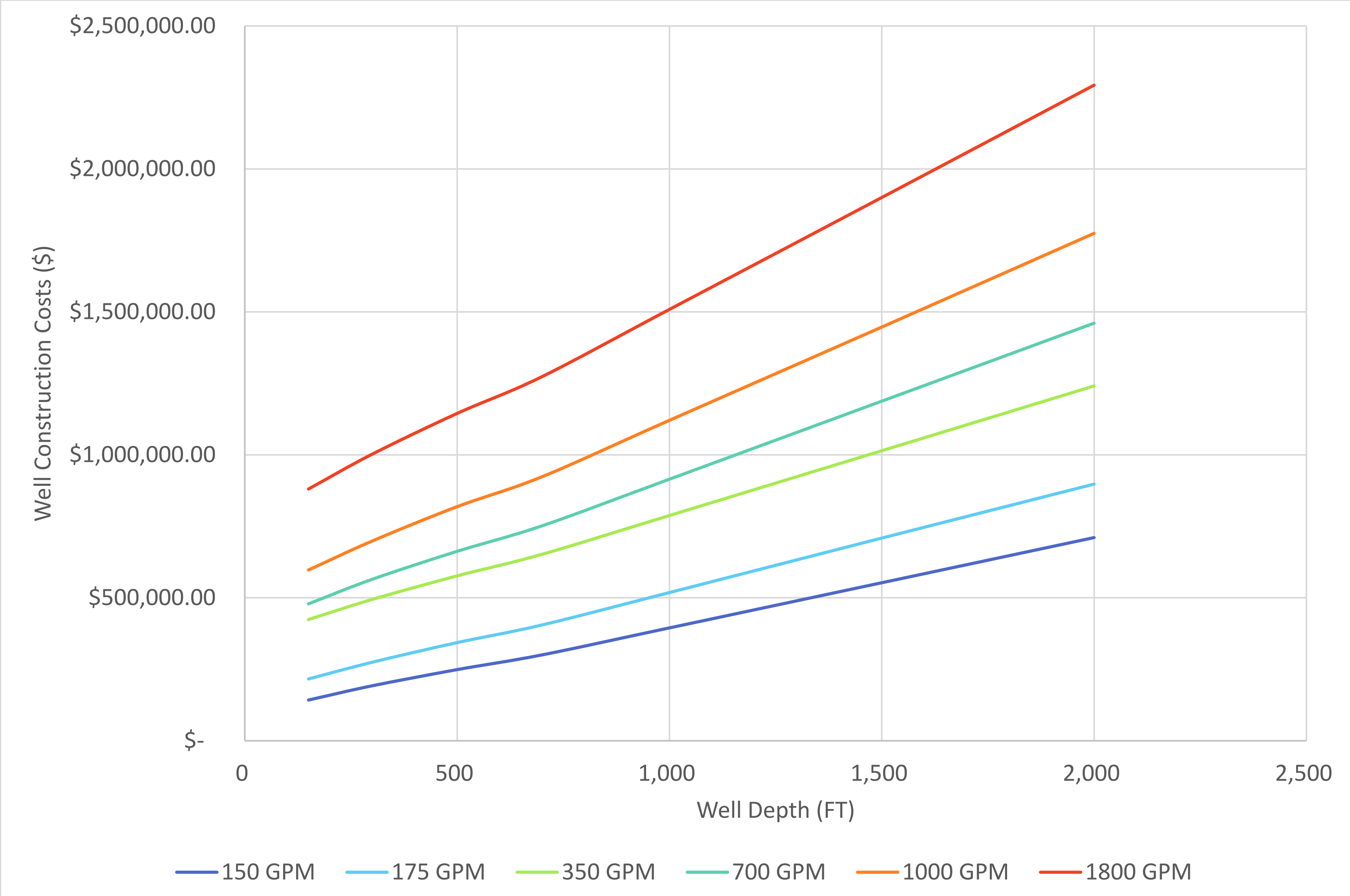

Figure B-5 Aquifer Storage and Recovery Well Cost Curves

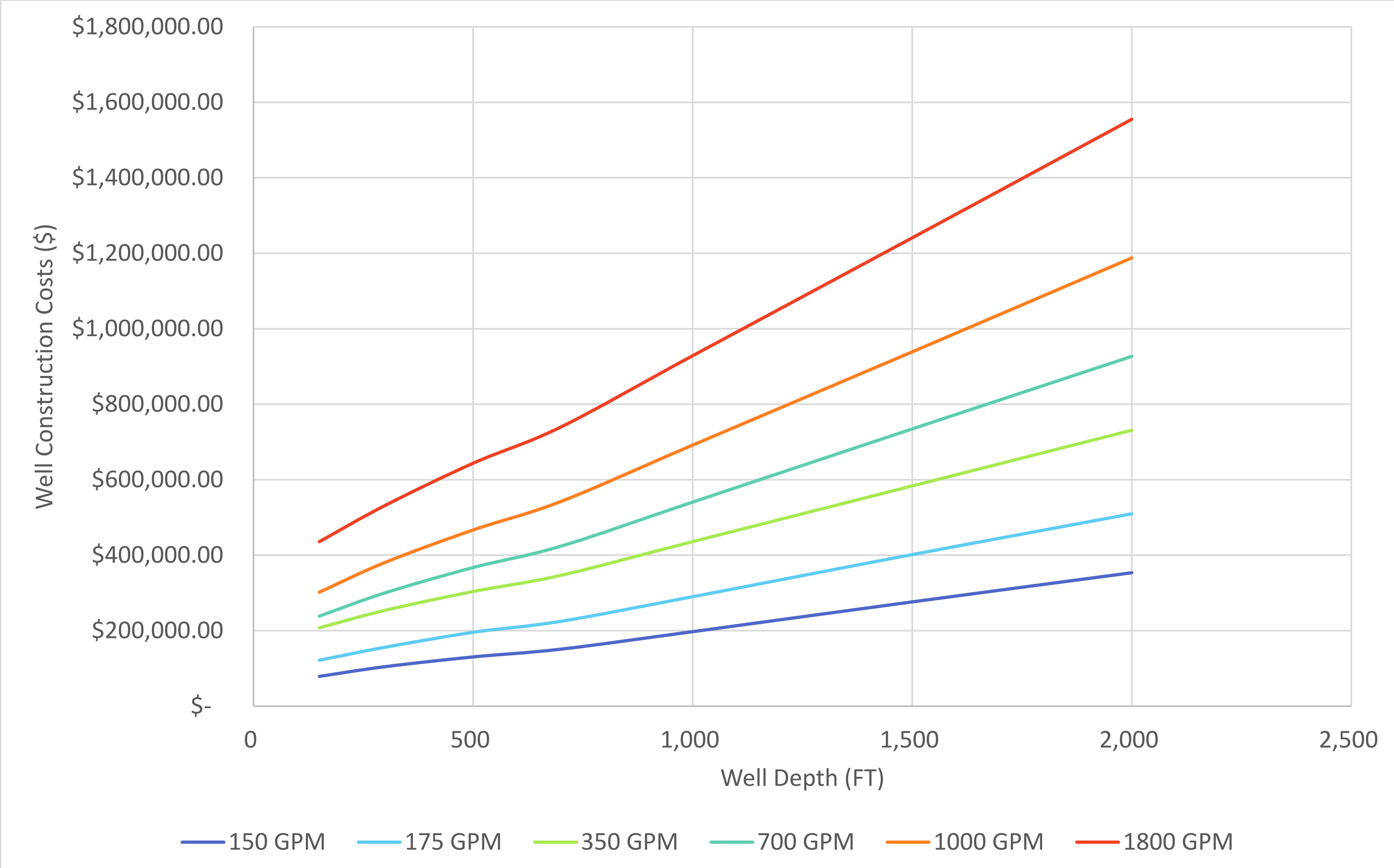

Figure B-6 Irrigation Well Cost Curves

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 the South Platte Storage Study Final Report (Stantec & Leonard Rice, 2015) was 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

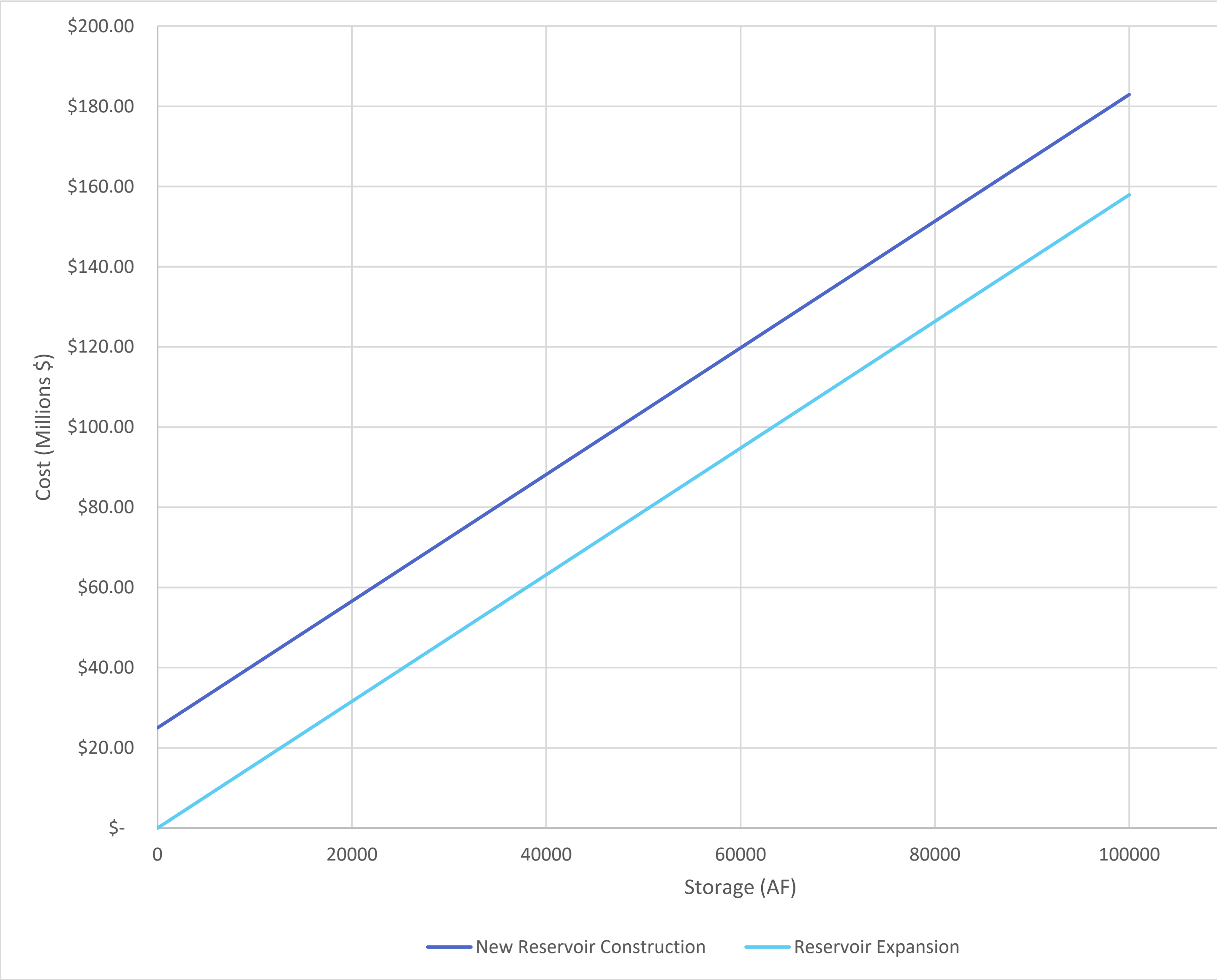

Figure B-7Error! Reference source not found.. Costs of reservoirs greater than 100,000 acre-feet is highly variable; therefore, the Cost Estimating Tool scope was limited to reservoirs up to 100,000 acre-feet. The cost curve developed assumes a minimum cost of $25 million for any new reservoir construction. Due to the limited data available for reservoir expansions, the average cost per acre-foot of storage for new reservoirs was used to develop the cost curve shown but with no minimum cost.

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) c ategorized 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.

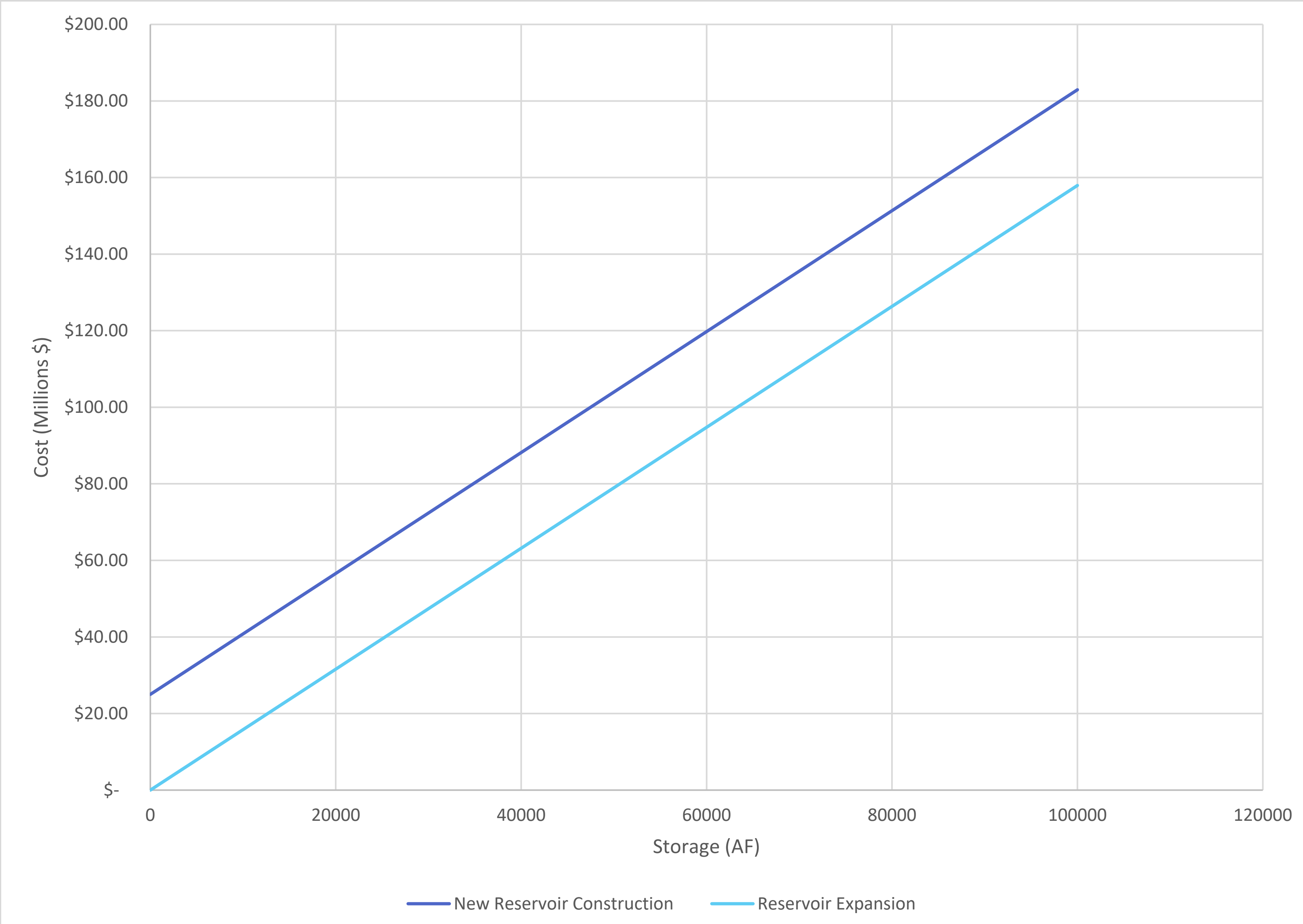

Figure B-7 New Reservoir Construction and Reservoir Expansion Cost Curves

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 *	
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 *	

Basin	Project Name	BIP Project Description	Estimated BIP Cost	Notes
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.

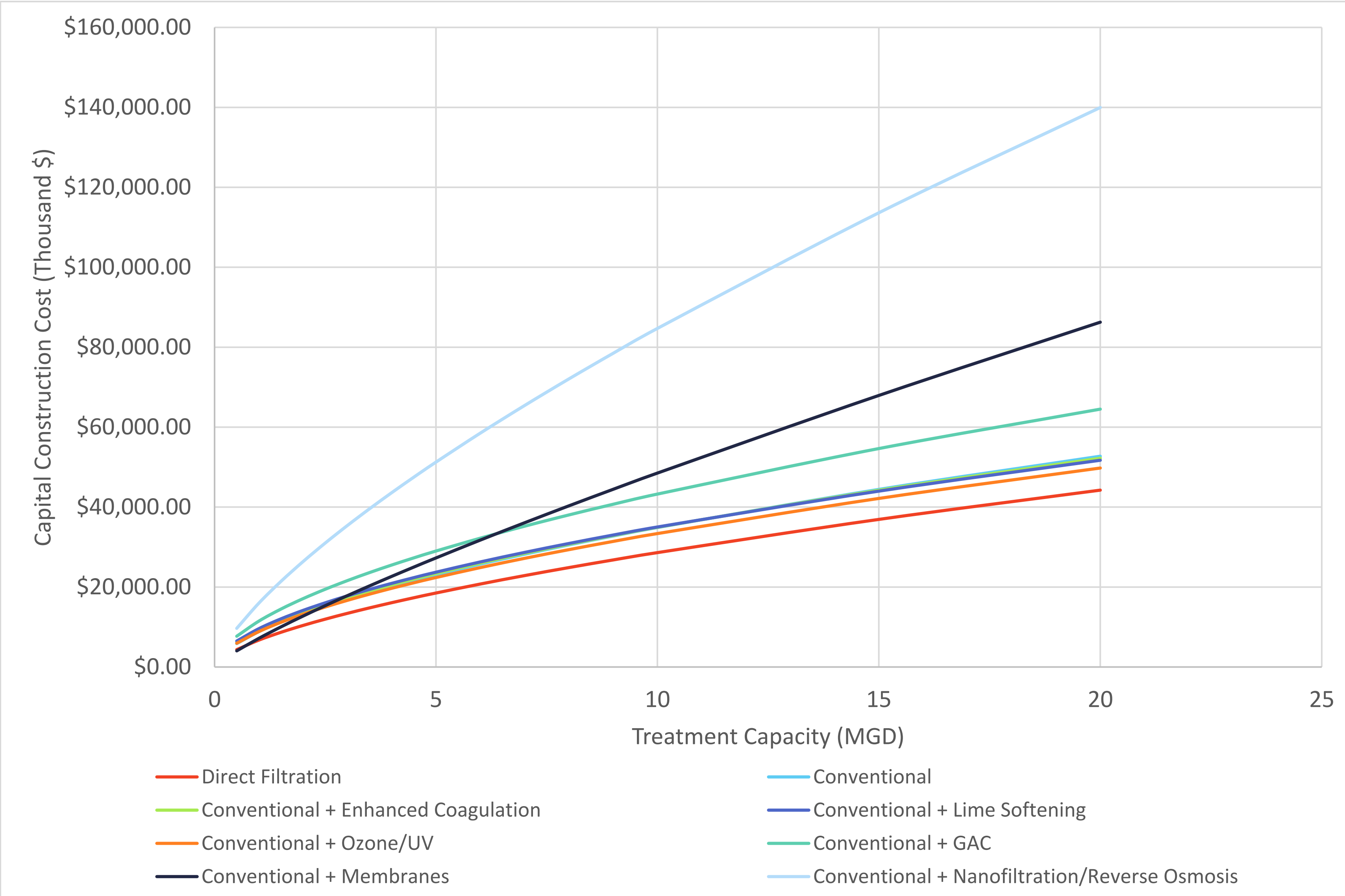

Figure B-8 Water Treatment Technology Capital Construction Cost Curves

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.

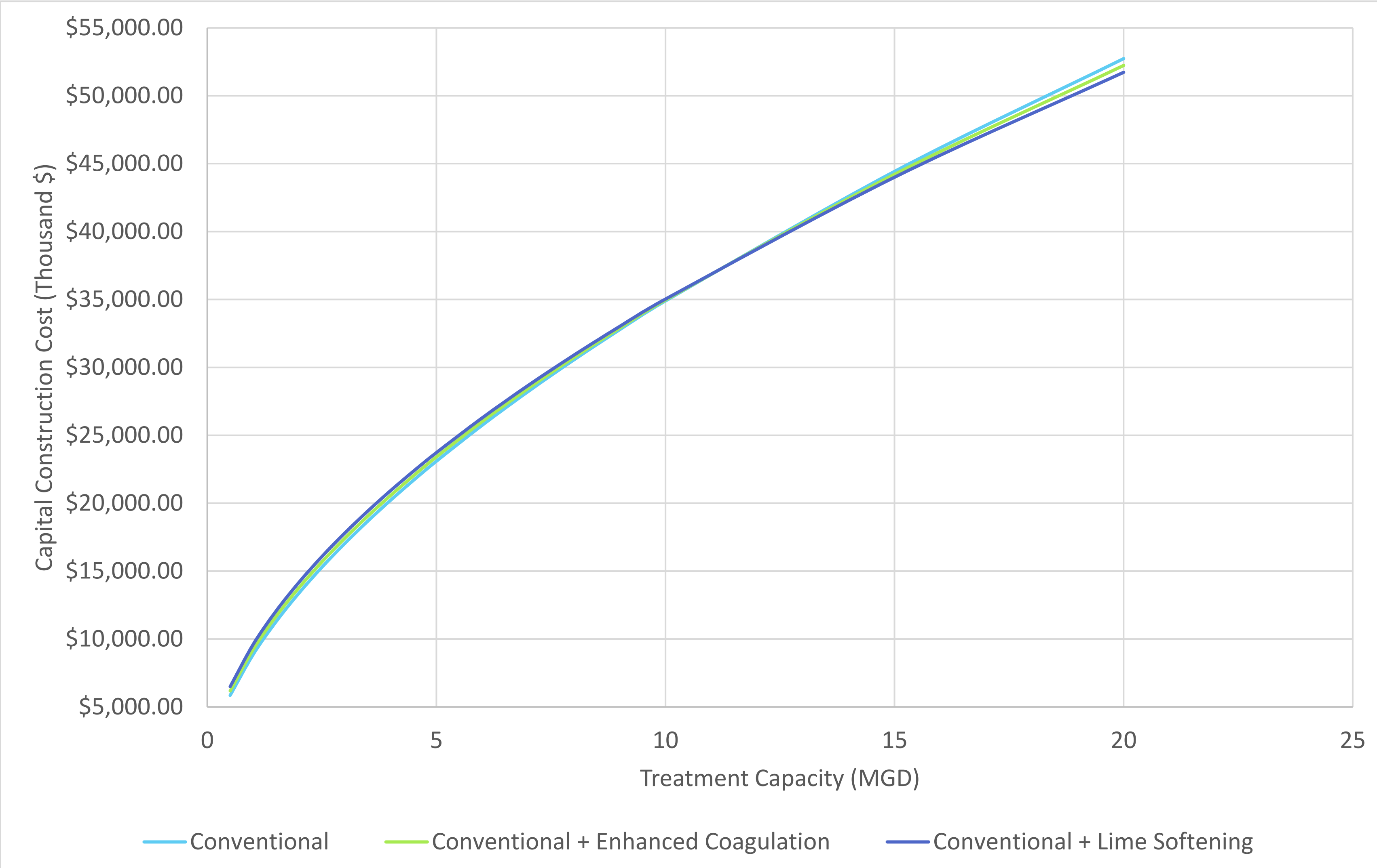

Figure B-9 Interpolated Cost Curves for Conventional plus Enhanced Coagulation Treatment

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.

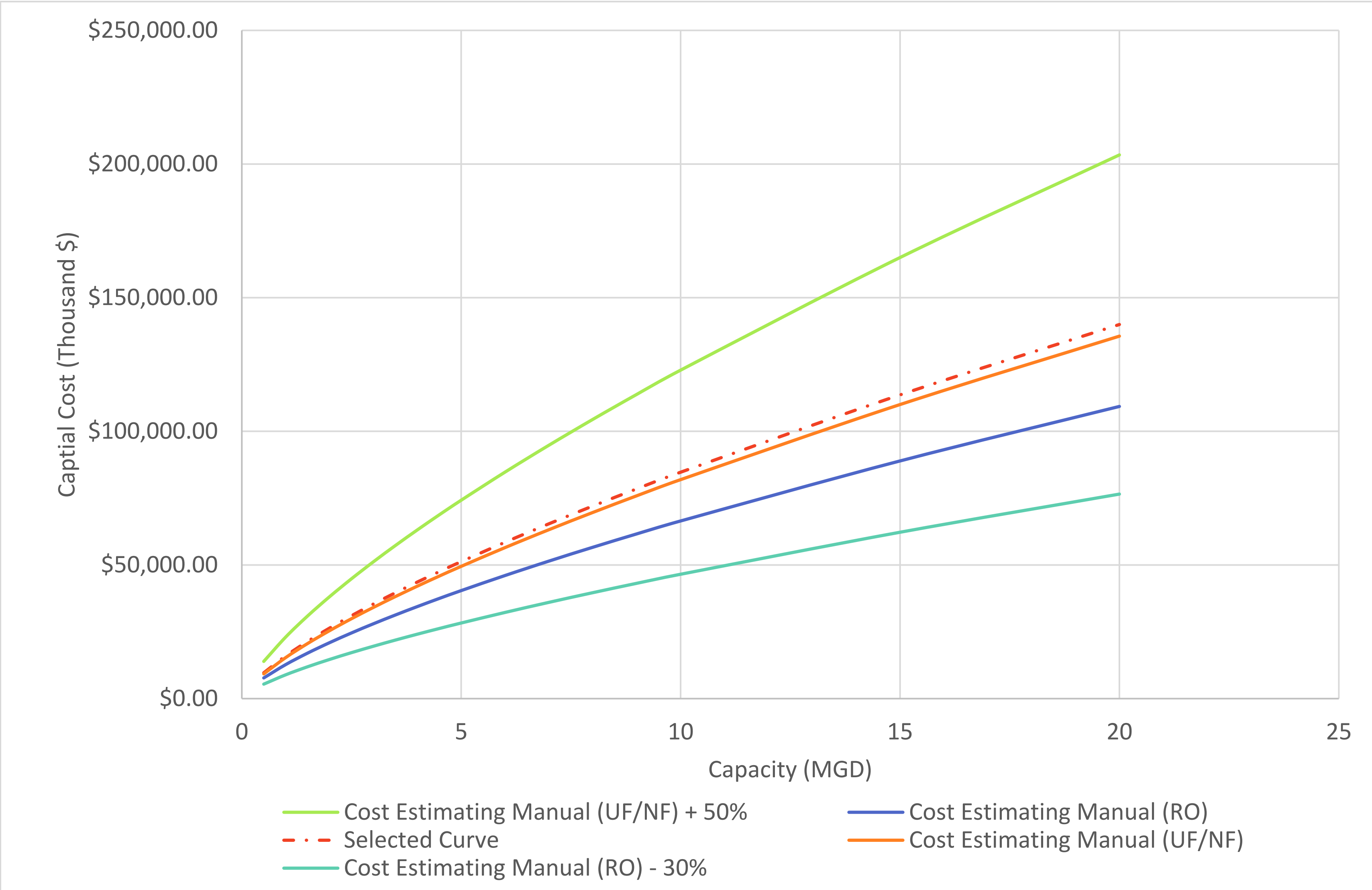

Figure B-10 Analysis of Ultra/Nano Filtration and Reverse Osmosis Capital Construction Cost Curves

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.

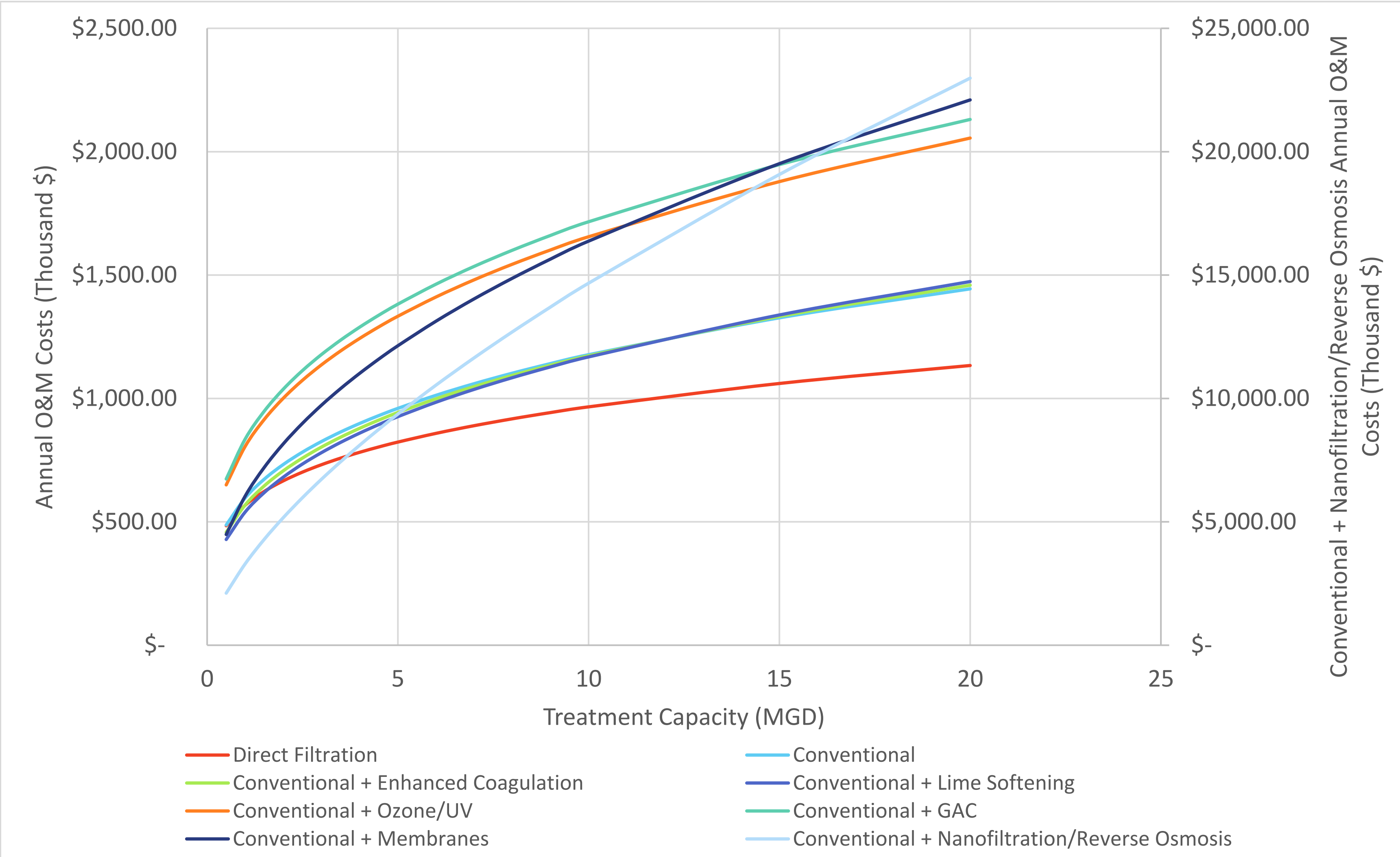

Figure B-11 Water Treatment Technology Annual O&M Cost Curves
*Note: Conventional + Nanofiltration/Reverse Osmosis Annual O&M Costs are plotted on a secondary axis

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-12**Error! Reference source not found. and **Figure B-13**Error! Reference source not found., respectively.

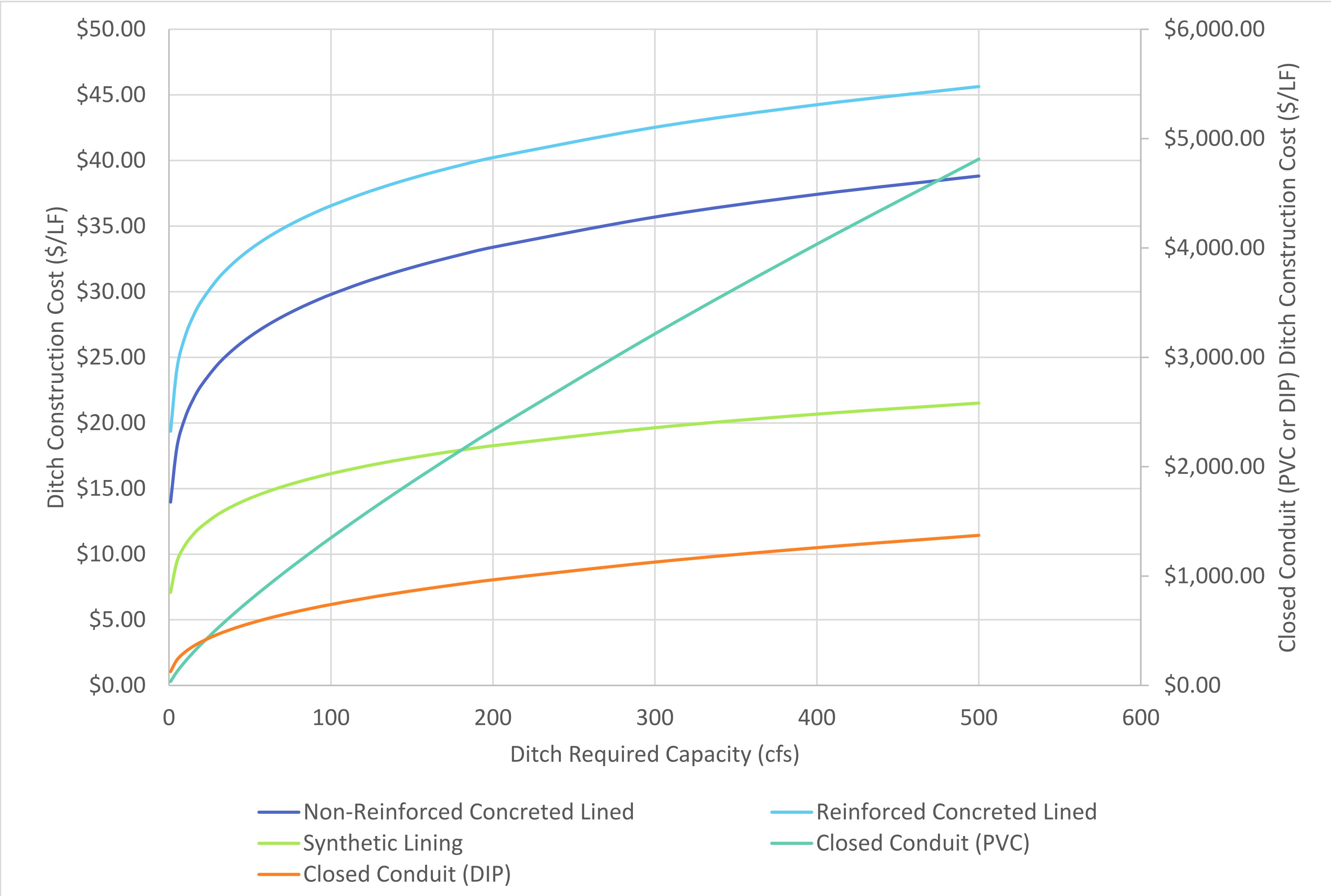

Figure B-12 New Ditch Construction Cost Curves

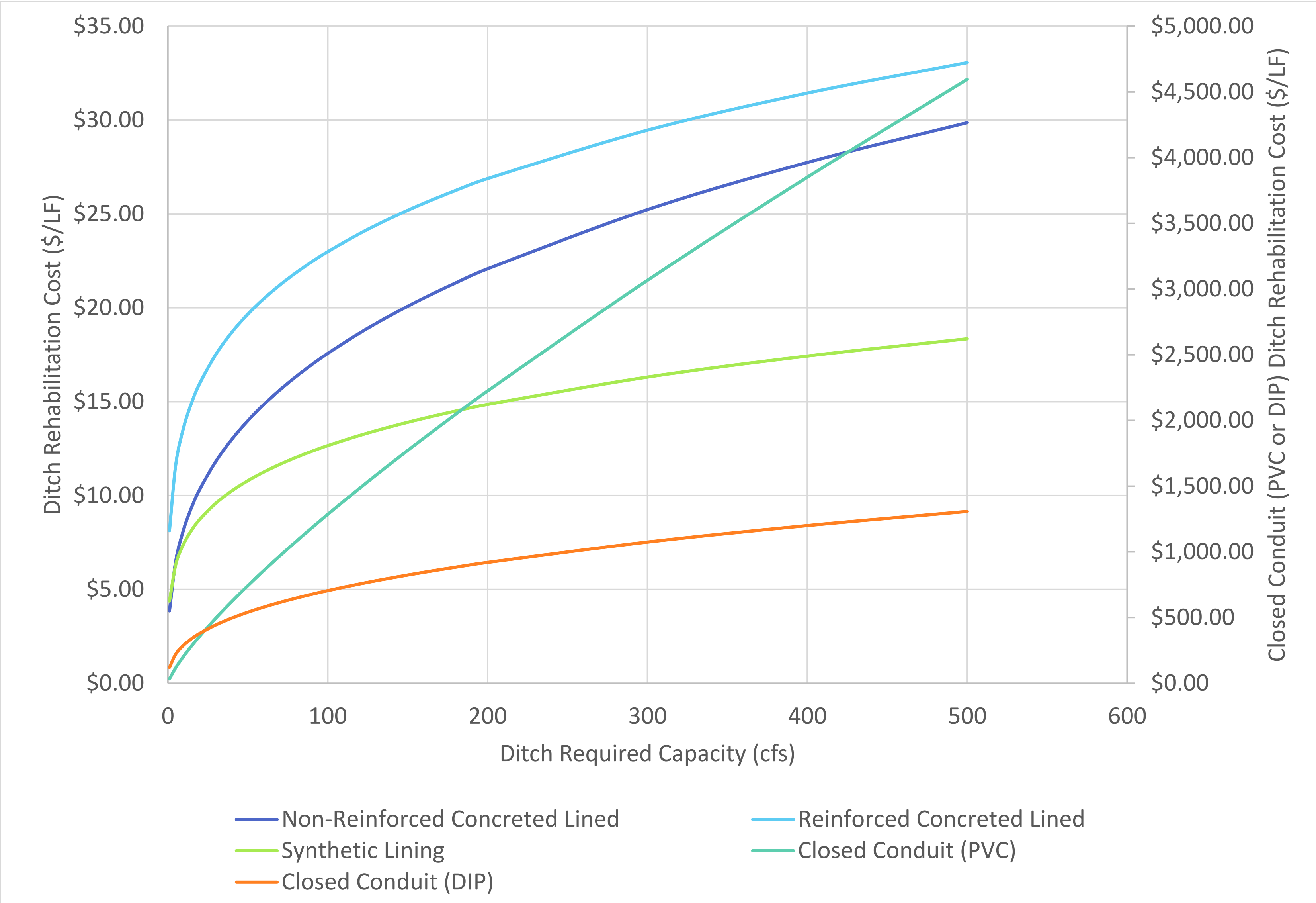

Figure B-13 Ditch Rehabilitation *Cost* Curves

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 a pplied 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.

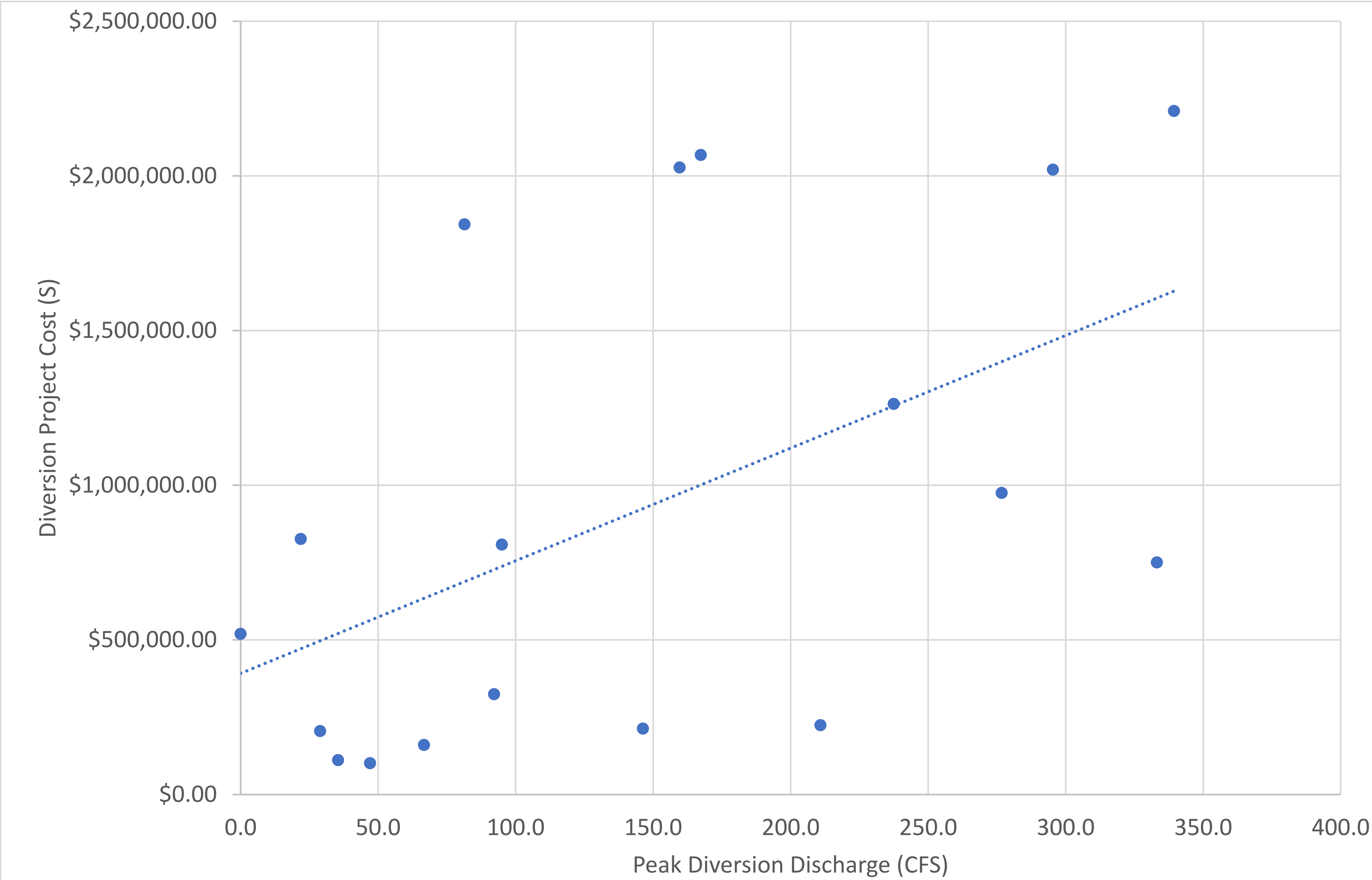

Figure B-14 Recommended Cost of Diversion Structure Cost Curve

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
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

Project ID	Project Stream	Project County	Diversion Structure Type	Maximum Diversion Capacity (CFS)	Approximate Diversion Structure Cost	Description of Project Costs
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.

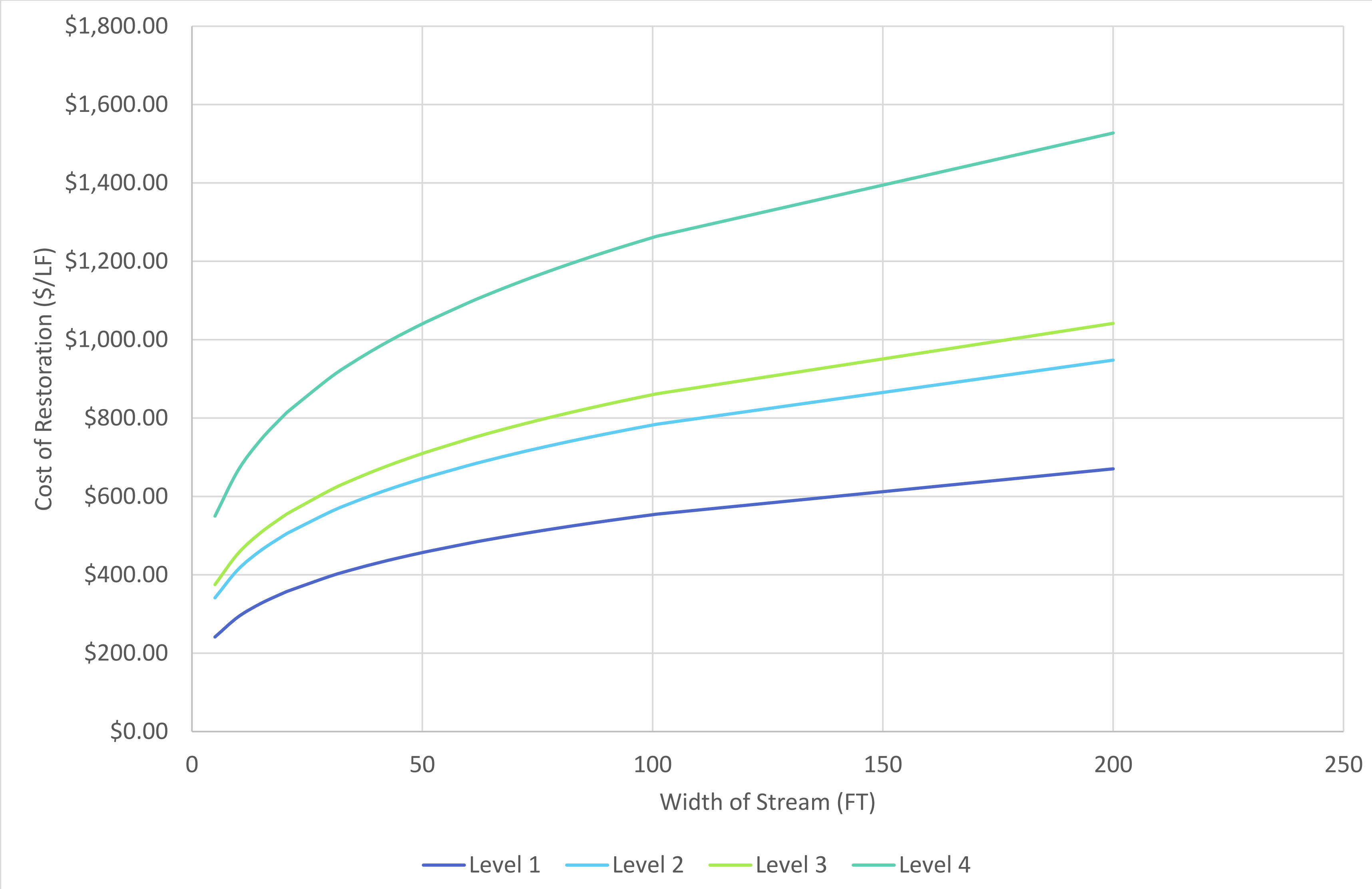

Figure B-15 Rural Streams and Habitat Project Cost Curves

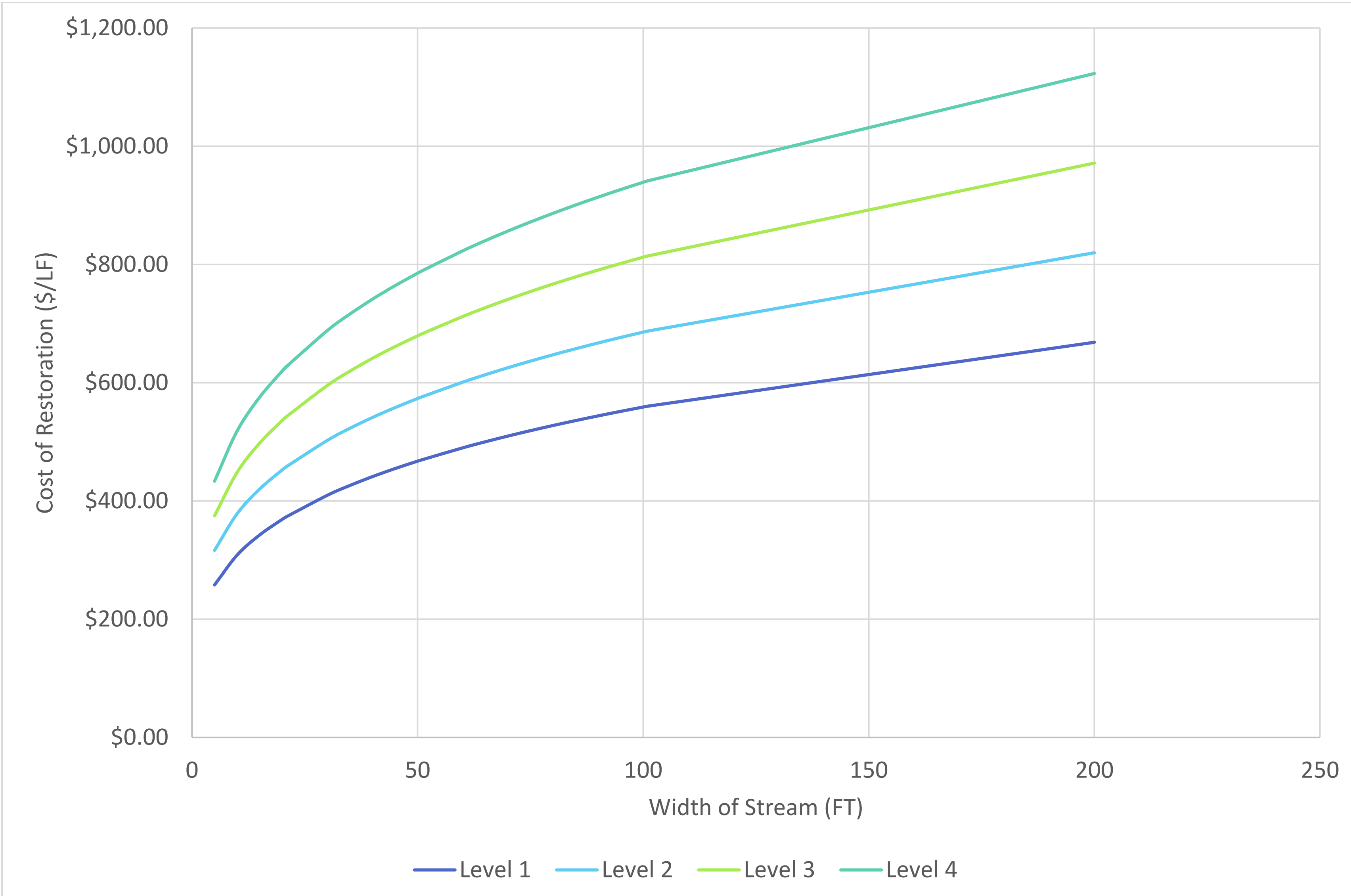

Figure B-16 Urban Stream and Habitat Project Cost Curves

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-3**Error! 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 Projects**Table B-3Error! Reference source not found.** and

Table B-4**Error! 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.