

# Automated Network Sizing

*add-on module for AFT Fathom™ 13*

*Quick Start Guide | English Units*

Dynamic solutions for a fluid world™

**AFT**  
Applied Flow Technology

# ***AFT Fathom™ ANS Module***

## **Quick Start Guide**

English Units

**AFT Fathom Version 13**  
**Automated Network Sizing Module**

Published: November 09, 2023



*Dynamic solutions for a fluid world™*

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**CAUTION!**

AFT Fathom is a sophisticated pipe flow analysis program designed for qualified engineers with experience in pipe flow analysis and should not be used by untrained individuals. AFT Fathom is intended solely as an aide for pipe flow analysis engineers and not as a replacement for other design and analysis methods, including hand calculations and sound engineering judgment. All data generated by AFT Fathom should be independently verified with other engineering methods.

AFT Fathom is designed to be used only by persons who possess a level of knowledge consistent with that obtained in an undergraduate engineering course in the analysis of pipe system fluid mechanics and is familiar with standard industry practice in pipe flow analysis.

AFT Fathom is intended to be used only within the boundaries of its engineering assumptions. The user should consult the AFT Fathom internal help files for a discussion of all engineering assumptions made by AFT Fathom.

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# Introducing AFT Fathom ANS Module

Welcome to the AFT Fathom™ ANS module, Applied Flow Technology's powerful pipe and duct system automated sizing tool. With the ANS module you can automatically size all pipes or ducts in a system to minimize monetary cost, weight, volume, or surface area. In addition, you can concurrently size the pumps and pipes to obtain the absolute lowest cost system that satisfies your design requirements. Finally, by including non-recurring and recurring costs, you can size pipe and duct systems to minimize life cycle costs over some specified duration.

## How the AFT Fathom ANS module works

The AFT Fathom ANS module consists of three basic elements: the Graphical Interface, the Hydraulic Solver, and the Automated Sizing Engine. Figure 1.1 shows the relationship between the three.

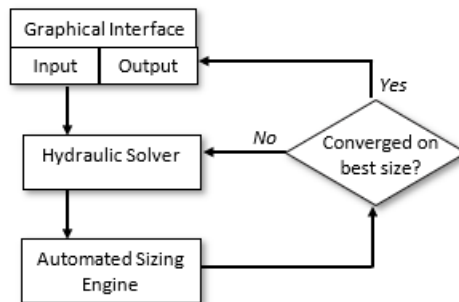


Figure 1.1 ANS module main component flow chart



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The Hydraulic Solver obtains a balanced hydraulic solution for a specific pipe or duct system. The Automated Sizing Engine then modifies the design, and the Hydraulic Solver evaluates the modified design. The Automated Sizing Engine continues this process until it is satisfied that no further design improvements are possible. At this point, the Automated Sizing Engine has converged on a design, and the resulting sized design is then sent back to the Graphical Interface where it is displayed to the user.

The Hydraulic Solver, which functions as the prime mover in performing an engineering analysis (e.g., AFT Fathom™), becomes a subroutine called by the Automated Sizing Engine. The Automated Sizing Engine is the prime mover in the ANS module.

The Automated Sizing Engine employed by the ANS module uses state-of-the-art numerical searching technology licensed from a leading developer in this field. This technology has been used for many years in engineering design, with extensive use in structural finite element analysis.

## Analysis vs. design

### Analysis

Traditional piping system engineering has employed pipe flow *analysis*. Engineering analysis is the process of using accepted calculation methods to predict the behavior of a given system. These calculation methods may be manual, or automated in a computer program.

The weakness of analytical methods for design is that they require the specification of the system before the methods are applied. Specifically, the pipe or duct sizes, pumps, valves, and other equipment must be specified in order to perform the calculation.

However, when a new pipe system is being designed, these parameters are not known. To use the analytical methods, the engineer must guess at the pipe sizes and required equipment, perform the analysis, then modify their original selections as necessary.

The analytical methods are used iteratively to arrive at a final design.

## **Design**

A design-oriented approach to piping system engineering allows the selection parameters to be variables. Rather than specifying pipe diameters, the engineer solves for pipe diameters by specifying the flows and pressures (and other design requirements) and using these to select the appropriate pipes which minimize the overall system weight, volume, or monetary cost.

Within certain limits, engineers do this with traditional analytical methods; however, the number of design tradeoffs that can be considered is limited and the tradeoffs considered are indirectly tied to weight, volume, or monetary cost.

The ANS module offers a true design-oriented approach to piping system engineering by using advanced automated sizing methods to evaluate competing designs vs. weight, volume, or cost, and select the best design. The analysis method (i.e., the Hydraulic Solver) is called repeatedly by the ANS module in an effort to identify said design improvements.

## **Weight, volume, and monetary cost are all costs**

In the English language we usually associate the word “cost” with money. However, in engineering that does not have to always be the case. If an engineer is designing an aircraft, for example, minimizing weight is essential. In that respect extra weight is a “cost”.

To simplify discussion in this guide, and to avoid needless repetition, the word “cost” will be used to represent any of the parameters an engineer may wish to minimize. In the ANS module, this can be weight, volume, surface area, or monetary cost. When discussing issues specifically related to monetary cost, the words “monetary cost” will be used unless the context is otherwise clear that the discussion refers to “monetary cost”.

## **Cost-based automated sizing vs. cost estimating**

The ANS module is *not* a cost estimating tool. Rather, it offers a rational and automated approach for comparing potential pipe or duct system

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designs using the common denominator of cost. It is the pipe or duct system design that the ANS module obtains that is of immense value, not the process of cost estimating.

### **AFT Fathom ANS module design capabilities**

The AFT Fathom ANS module can be used to size a wide variety of engineering systems.

#### **Types of systems that can be sized**

- Piping, ducting, and tubing systems
- Open and closed (recirculating) systems
- Network systems that branch or loop, with no limit on the number of loops
- Pressure fed systems and gravity fed systems
- Pumped systems, including multiple pumps in parallel or in series
- Pumps with variable speed, controlled pressure, controlled flow, and viscosity corrections
- Systems with pressure and/or flow control valves
- Systems with valves closed and pumps turned off
- Systems with heat transfer and energy balance
- Systems with variable density and viscosity
- Systems with non-Newtonian fluid behavior

#### **Types of automated sizing parameters available**

- Pipe/duct size
- Pipe velocity, pressure gradient, pressure, flow, and temperature
- Pump head rise, NPSH margin, proximity to BEP (Best Efficiency Point), power, and others
- Control valve pressure drop and open percentage

## **ANS Module primary window**

When the ANS module is activated in AFT Fathom several changes are made to the interface, though the main impact is the addition of a new Primary Window called the Sizing window. The Sizing window allows for the sizing and (optionally) cost settings to be configured for the model. When the model is set to perform sizing, input information in the Workspace and Model Data windows for the components being sized is used for initial guesses. Components which are not being sized are treated as constants for the automated network sizing.

## **Automated sizing terminology**

General automated sizing terminology applied to pipe systems is as follows:

### **Design requirements**

There are numerous design requirements in the ANS module. Common requirements are pipe velocity, control valve pressure drop, pump Net Positive Suction Head (NPSH) margin, and proximity to Best Efficiency Point (BEP).

### **Active and inactive design requirements**

An active Design Requirement is a requirement which has a direct impact on the solution, whereas an inactive Design Requirement is a passive requirement which does not impact the solution. If an active requirement is removed, the ANS module will find a different solution, whereas removing an inactive requirement will not affect the solution.

Consider a case where several Design Requirements are set for the velocity in a pipe. One may set the maximum to 10 feet/sec, and the minimum to 2 feet/sec. If the final pipe velocity were 9.9 feet/sec, the maximum velocity Design Requirement would be active because the final value of the velocity is at or near the maximum velocity. On the other hand, the 9.9 feet/sec pipe velocity is far away from the 2 feet/sec minimum. If we remove the minimum velocity Design Requirement, the result will still be an actual pipe velocity of 9.9 feet/sec. Thus, the minimum velocity Design Requirement is inactive and does not

influence the selected pipe size. On the other hand, if one removed the 10 feet/sec maximum velocity Design Requirement, the actual velocity would probably increase above 10 feet/sec, thus resulting in a different pipe size.

### **Objective**

This is the goal of the analysis in the system. Typically, the Objective is to minimize monetary cost either directly using monetary cost data, or indirectly by minimizing parameters such as pipe weight. As the ANS module varies the pipe sizes, the objective value (cost, weight, etc.) varies. The Automated Sizing Engine searches for combinations of pipe sizes that achieve the objective by comparing these variations.

### **Continuous vs. discrete sizing**

Discrete data is a set of data which lists explicit values that can be used, such as a set of pipe sizes within a given schedule. Continuous data is a set of data that includes all values between the given minimum and maximum, such as percent open values for a valve.

Generally, the desired sizing within the ANS module is discrete, since commercial pipe sizes must be chosen from a set of specific sizes. However, since it is much easier to minimize values using a continuous solution, many methods in the ANS module will first implement continuous sizing, then use this solution to find a nearby discrete solution for the system. Note that this is not as simple as just choosing the closest discrete value around the continuous minimum. Good searching algorithms like those used in the ANS module will consider values that are more than one discrete size from the continuous value.

### **Common size groups**

The automated sizing process takes longer as the number of pipes being independently sized increases. Frequently there are groups of pipes in a system which would ideally be the same size for design purposes, or must be the same size by virtue of their location in the system. To link the sizes of pipes together one can create *Common Size Groups*. When one places pipes into a Common Size Group, one is saying that the group of pipes must all have the same pipe size, and be the same material and schedule, class, or type. A Common Size Group thus

consolidates the individual pipes that are part of that group to a single pipe size for that group.

### **Feasible and infeasible designs**

A feasible design is one which satisfies all Design Requirements, while an infeasible design does not satisfy one or more Design Requirements. There are many ways you can create a model that has no feasible solution. For example, connect a pipe to an Assigned Pressure junction set to 200 psig. Then place a Design Requirement on the pipe that it cannot have a pressure greater than 100 psig. Since the pipe is connected to an Assigned Pressure junction at 200 psig, there is no way for it to satisfy the 100 psig Design Requirement. Thus, no feasible solution exists.

### **Candidate sets**

A Candidate Set is a collection of potential sizes that will be considered for the sizing calculations. Each pipe being sized in the system must have one Candidate Set assigned to it. If continuous sizing is being performed, only the minimum and maximum pipe sizes in the Candidate Set will be used to bound the continuous sizing.



# Weight Sizing Example

This example shows how to use the ANS module to perform a non-monetary automated sizing on a system. Parameters such as pipe weight or volume frequently relate closely to the actual pipe cost and are easier to set up than monetary cost based automated sizing. This makes them useful for approximating an initial design. Further, on some systems such as aircraft, marine vessels, or automobiles, minimizing weight may be the primary goal.

This example demonstrates minimizing the pipe weight in a system.

## Topics covered

- Sizing using pipe weight
- Creating Common Size Groups
- Defining Candidate Sets
- Defining Control Valve Design Requirements

## Required knowledge

No prior knowledge is required for this example. However, users who are completely new to AFT Fathom are advised to first complete the AFT Fathom Quick Start Guide examples. There, one will see how to use basic features for conventional pipe flow modeling. This example focuses on the automatic sizing features in the ANS module.



### Model file

This example is intended to be built from scratch to help familiarize yourself with the steps to define a complete model in AFT Fathom. For reference purposes only, the completed example model file can be found in the Examples folder as part of the AFT Fathom installation:

C:\AFT Products\AFT Fathom 13\Examples

- *US - Control Valve - ANS - Final.fth*

### Problem statement

The example is for a fluid transfer system that feeds water from an elevated reservoir at 40 feet to a lower reservoir at 10 feet. A control valve is used to control the flow rate at 250 gal/min and can be placed anywhere within the line, though it must have a minimum pressure drop of 12.5 psid. For simplicity, we will locate the flow control valve at the midpoint of the 200 foot pipeline.

The pipeline uses STD Steel - ANSI pipe in the size range from 1 inch to 12 inch.

### Step 1. Start AFT Fathom

From the Start Menu, choose AFT Fathom 13 from the AFT Fathom 13 folder.

Activate the ANS module from the Startup Window by checking the box next to the ANS module. Alternatively, it can be activated from the Modules panel in Analysis Setup.

Once the ANS module has been activated, check that it is enabled for use by selecting Network in the ANS section of the Modules panel. This should be done automatically by AFT Fathom when the module is activated.

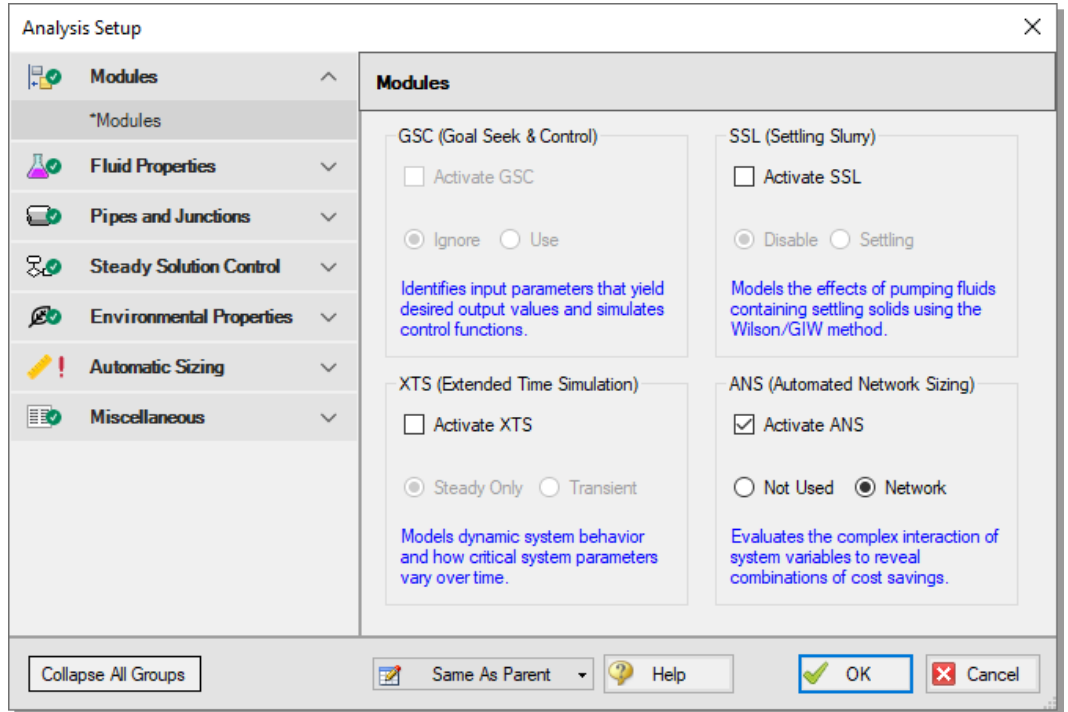


Figure 2.1 Activating and enabling the ANS module for use.

## Step 2. Specify Analysis Setup

Open Analysis Setup by selecting Analysis Setup from the toolbar.

1. On the Fluid panel under the Fluid Properties group, select the AFT Standard option and then select Water (liquid) in the Fluids Available in Library list.
2. Click Add to Model to select water for use in this model.
3. Enter 70 deg. F in the fluid temperature box. This automatically calculates the fluid properties to use in the model.
4. Click OK to save and close Analysis Setup.

## Step 3. Build the model

### A. Place the pipes and junctions

In the Workspace window, assemble the model as shown in Figure 2.2.

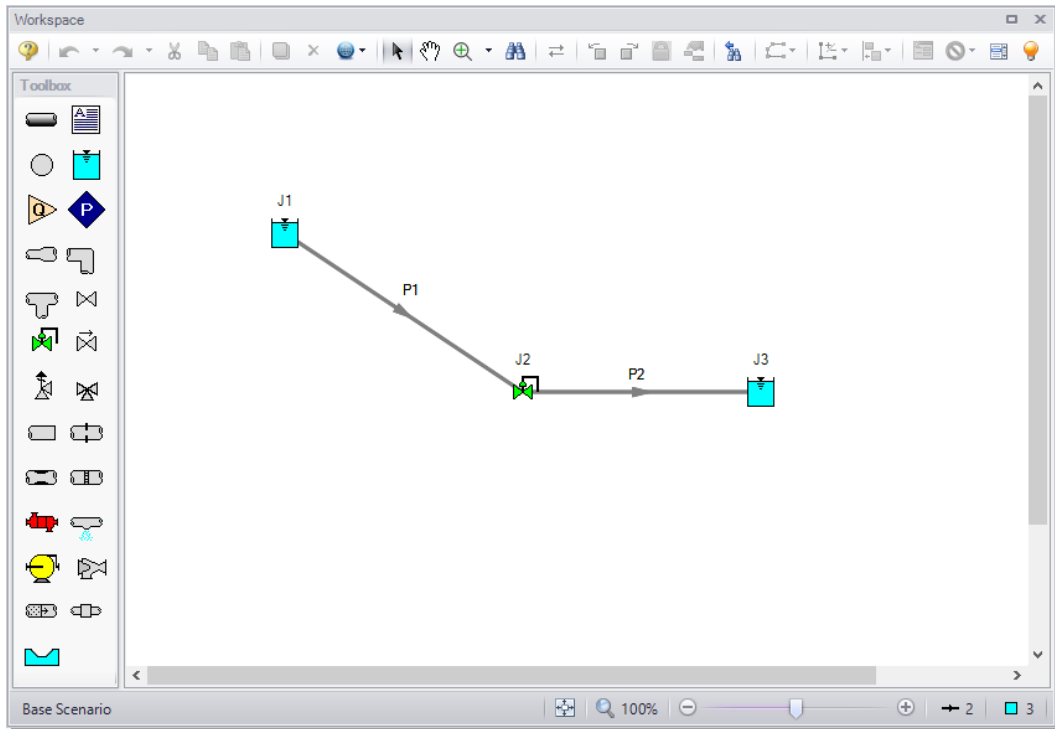


Figure 2.2 Control Valve system layout

### B. Enter the pipe data

For this example, we need to find the best pipe size, but we are limited to STD pipe sizes. Now we need to use engineering judgment to take an initial guess at the pipe size for a flow rate of 250 gal/min. Let's try a 3 inch pipe. Specify both the pipes as follows:

1. Pipe Material = Steel - ANSI
2. Size = 3 inches
3. Type = STD (schedule 40)

4. Length = 100 feet
5. Friction Model = Standard

### **C. Enter the junction data**

#### ***J1 - Reservoir***

1. Liquid Surface Elevation = 40 feet
2. Liquid Surface Pressure = 0 psig
3. Pipe Depth = 0 feet

#### ***J2 - Control Valve***

1. Inlet Elevation = 10 feet
2. Valve Type = Flow Control (FCV)
3. Volumetric Flow Rate = 250 gal/min

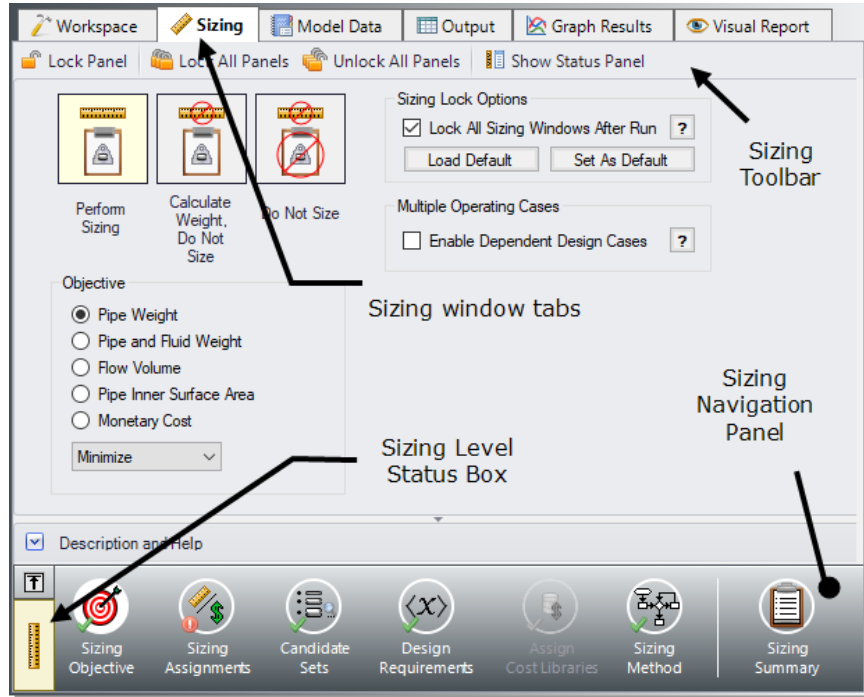
#### ***J3 - Reservoir***

1. Liquid Surface Elevation = 10 feet
2. Liquid Surface Pressure = 0 psig
3. Pipe Depth = 0 feet

## **Step 4. Define sizing input**

In this model we are going to perform sizing to minimize the pipe weight, while maintaining a minimum pressure drop of 12.5 psid across the control valve. To do this, first go to the Sizing window by clicking on the Sizing tab, or from the Window menu.

The Sizing window is comprised of multiple panels which can be accessed using the buttons on the Sizing Navigation Panel along the bottom of the window, as shown in Figure 2.3. The sizing panels can be accessed in any order, though it is easiest to enter the information by navigating the panels from left to right, since the input on panels such as the Sizing Objective and the Size/Cost Assignments panels will affect the options available on later panels. Depending on the type of sizing being done, some panels may be disabled or unused.



**Figure 2.3 Sizing window layout identifying common features**

Each panel button contains either a green checkmark or red circle which denotes the completion status of that panel. If the minimum required information to run the model is present, the symbol will be green, whereas the red symbol represents incomplete input. The amount of information required will vary based on whether the sizing is set to Perform Sizing, Calculate Weight/Do Not Size, or Do Not Size. A detailed summary of the items which have been completed and the items which are still incomplete can be seen in the Status Panel.

The type of sizing calculation being performed, also called the Sizing Level, can always be seen on the Sizing Level Status Box on the left of the Sizing Navigation Panel as shown in Figure 2.3. Clicking this box will bring you to the Sizing Objective panel, where the calculation type can be changed. The choice of continuous or discrete sizing is selected on the Sizing Method panel, which is discussed later.

Note that some panels will always be shown as complete since the model can be run without any additional information entered on them, such as the Design Requirements panel. However, in order to find the best system design, it will often be necessary to enter more than the minimum information required by the Solver.

The Lock Panel toggle located on the Sizing Toolbar prevents changes to the current panel when it is enabled. This is primarily useful to prevent editing once a scenario has been run, since any changes that are made to a scenario which has output will cause all output to be erased. By default, all panels will lock after a sizing run is completed, requiring panels to be unlocked before any changes can be made. This setting can be changed on the Sizing Objective panel. All panels can be locked or unlocked simultaneously by using the Lock/Unlock All Panels buttons on the Sizing Toolbar.

### **A. Sizing Objective**

The Sizing Objective panel will be displayed by default when the Sizing window is first opened, as shown in Figure 2.3. This panel is used to select the option for calculation and to set the desired Objective.

The first option is Perform Sizing, which sets up the model to perform the automated sizing calculation. While it is typically desired to run the sizing calculations, the other two selections can be useful in certain cases.

The second option is Calculate Weight, Do Not Size. This option is useful to find the cost of the initial design, or for troubleshooting. If the objective is set to use monetary cost, this option is similar to running AFT Fathom with the Cost Calculation option turned on.

The last option is Do Not Size. This is equivalent to performing a regular AFT Fathom analysis without needing to disable the ANS module and potentially lose the entered Sizing settings. This can also be useful to check the feasibility of the initial design before sizing.

- **Select Perform Sizing** to begin configuring the sizing run.

The next step is to set a Sizing Objective, which can be monetary cost or a non-monetary cost such as pipe weight or flow volume. It is easier to perform a non-monetary sizing, since all of the geometry and material information necessary to calculate the pipe weight/volume is already

contained in the pipe material libraries. A monetary cost objective would require cost information to be obtained and entered into cost libraries. For many systems, sizing the system using one of the simpler non-monetary objective options provides a sufficient approximation for minimized cost. In this case, we will be performing a minimization of pipe weight.

- **For the Objective choose Pipe Weight** and select the Minimize option from the drop-down list.

### **B. Sizing Assignments**

On the Sizing Navigation Panel select the Sizing Assignments button. The Sizing Assignments panel allows the user to define what will be sized in the model, and what will be included in the cost calculation without being sized (in this case, what will be included in the weight, but will not have its weight minimized). Common Size Groups for pipes can be created on this panel as well.

In the Sizing Assignments panel the table can be used to select various options to either Automatically Size, or Do Not Size each pipe.

If an Automatically Size option is selected, the ANS module will treat the pipe diameter as a variable and vary it according to certain criteria that will be discussed shortly.

In a new system, typically all pipes will be desired to be sized and included in the cost calculation (in this case, the cost is being calculated in terms of weight). If you are instead analyzing the possible replacement of existing pipes, it may be better to choose Include in Weight if Size Changes. This will allow the weight to only be calculated for pipes if they change size, since using the existing pipes will incur no new costs.

If Do Not Size is selected, the pipe will retain the settings currently set in the Workspace. Why would one choose to not size a pipe? There could be a number of reasons, but one good reason is that the pipe represents a pipe in an existing system and the design does not allow the replacement of that pipe with a new one. Therefore, its diameter is fixed, and sizing the pipe would be incorrect.

Another reason may be if a certain size is necessary for the design due to certain requirements, in which case the pipe cost can be included without sizing the pipe by choosing Include in Weight.

This model is a new system, so all pipes will be sized and included in the cost (weight).

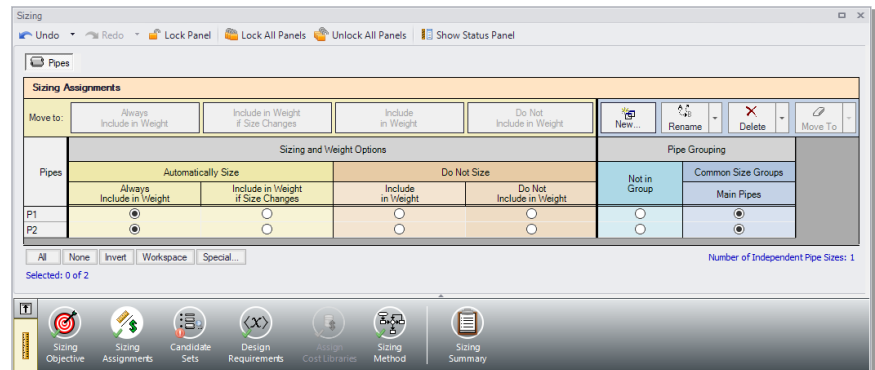
- **Select Always Include in Weight** next to each of the pipes.

For this system it is required that both pipes be the same size. We will need to add both pipes to a Common Size Group to specify this as follows:

1. Click New above Pipe Grouping, and specify the name Main Pipes.
2. A new section will now appear with the Main Pipes group listed under Common Size Groups. Add both pipes to this group by clicking the corresponding radio buttons (Figure 2.4).

Now that the pipes are both in a Common Size Group, the ANS module will force them to have the same diameter, rather than allowing them to be varied separately.

For larger models, multiple Common Size Groups can be created as desired. Selection tools are available at the bottom of the window to help assign multiple pipes to a Common Size Group at once. Pipes can only be assigned to a group once they are set to use one of the Automatically Size options.



**Figure 2.4** Pipes P1 and P2 settings in the Sizing Assignments panel



### C. Candidate Sets

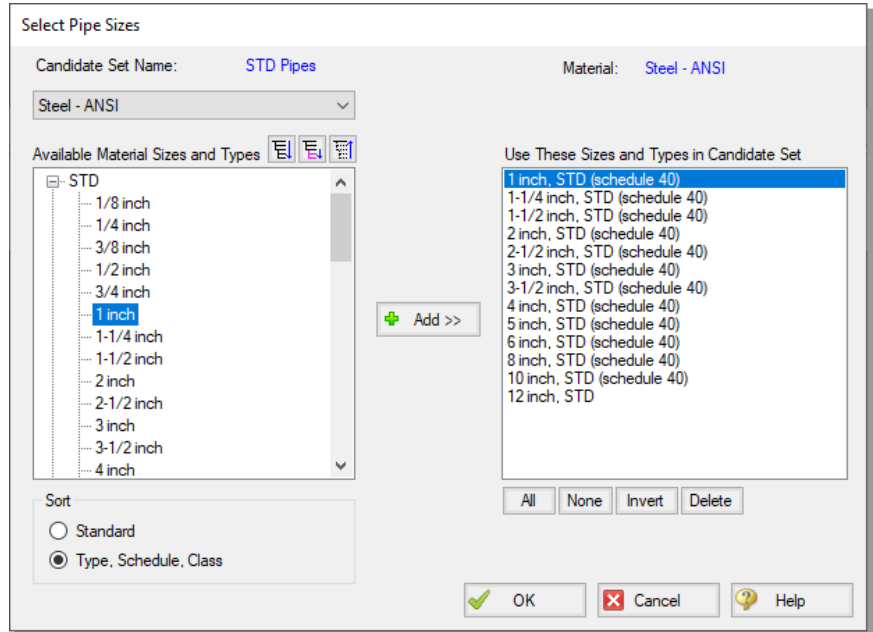
Click on the Candidate Sets button to open the Candidate Sets panel.

To select a specific pipe size, the ANS module needs a list of potential sizes from which to choose. This list is called a *Candidate Set*. A specific pipe can only access one Candidate Set, but a specific Candidate Set can be accessed by any number of pipes.

So as not to limit the sizing unnecessarily, the Candidate Sets should include both smaller and larger pipes than your anticipated final size. If you make the Candidate Set too small, you may limit the ability of the ANS module to find the best sizing. It is better to make the Candidate Set too large than too small. Experience in applying the ANS module to actual systems will help you choose appropriate Candidate Sets. If after obtaining a solution you find that one or more of the sized pipes is at the extreme of the Candidate Set, a warning will appear and recommend that the defined Candidate Set be expanded.

To create a Candidate Set, do the following:

1. Under Define Candidate Sets, click the New button.
2. Give the set the name STD Pipes and click OK.
3. From the drop-down list choose Steel - ANSI.
4. In the bottom of the Select Pipe Sizes window, check that the Sort option Type, Schedule, Class is selected.
5. In the Available Material Sizes and Types on the left, expand the STD pipe sizes list.
6. Double-click each of the sizes from 1 to 12 inches to add them to the list on the right or use the Add button (Figure 2.5).
7. Click OK to save and close the Select Pipe Sizes window.



**Figure 2.5** Select Pipe Sizes window with STD Steel-ANSI pipe sizes added for 1 inch to 12 inch

The STD Pipes set will now appear. However, we still need to define which pipes will use this Candidate Set during the automated sizing. By necessity, a Common Size Group will use one Candidate Set for all pipes within the group, since all pipes in the group must be the same size, so there is only one item to assign the set to.

- **Under Assign Candidate Sets to Pipes, set the Main Pipes Common Size Group** to use the STD Pipes Candidate Set. The Candidate Sets are now fully defined and assigned to the appropriate pipes, as can be seen in Figure 2.6.

Once a Candidate Set is assigned, the list of available pipe sizes on the Pipe Properties window in the Workspace is restricted to pipe sizes in that Candidate Set. In Figure 2.7 you can see the area normally described as Size is now described as Size (From Common Size Group). If the initial pipe sizes defined in the pipes were not included in the assigned Candidate Set, the ANS module will provide the option to

change the pipes in the Workspace to a pipe size from the defined Candidate Set when the model is run.

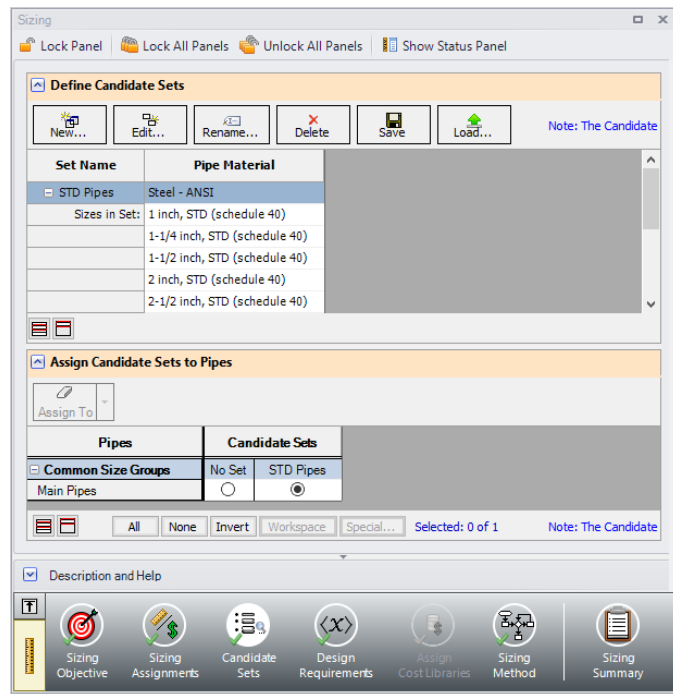
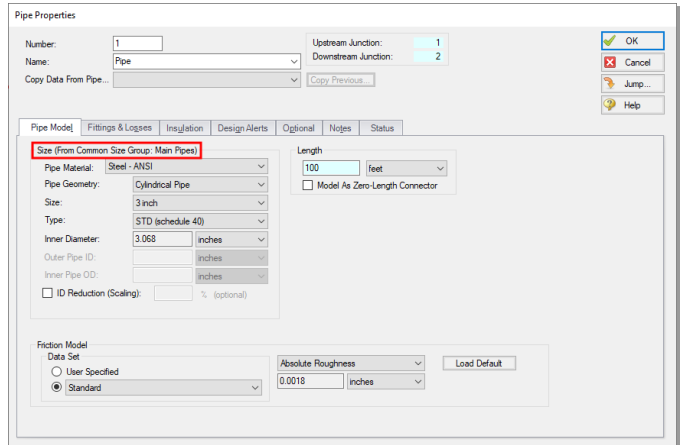


Figure 2.6 Candidate Sets panel fully defined for the model



**Figure 2.7 Pipe Properties window showing pipe size selections limited to those in the Common Size Group**

## D. Design Requirements

- **Select the Design Requirements button.**

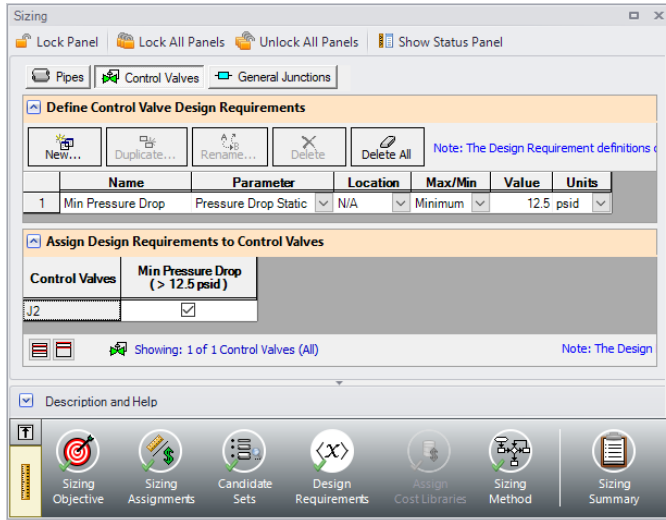
This panel is used to define restrictions on the final solution by applying Design Requirements to the system.

For this model we only have one Design Requirement, which is for the minimum pressure drop across the Control Valve. To define this requirement:

1. Select the Control Valves button at the top of the window.
2. Click New under Define Control Valve Design Requirements.
3. Enter the name Min Pressure Drop.
4. Select Pressure Drop Static as the Parameter.
5. Choose Minimum for Max/Min, and enter 12.5 psid

Now assign the defined Design Requirement to the appropriate junction.

- **Check the box next to the Control Valve Junction J2** in the Assign Design Requirements to Control Valves section. The Design Requirements panel should now appear as shown in Figure 2.8.



**Figure 2.8 Minimum pressure drop defined for the control valve**

**Note:** It is strongly recommended that all control valves have a Design Requirement specified for the minimum pressure drop/head, or the maximum Cv/percent open at the valve. If no Design Requirements are applied, the ANS module will allow the control valve to control to any pressure required to meet the control setpoint, even if this requires the control valve to add pressure to the system for design purposes. To avoid this behavior in the final solution, a Design Requirement should be applied.

## E. Assign Cost Libraries

This panel is only used to assign the necessary monetary cost information when Monetary Cost is chosen as part of the Sizing Objective. In this case this panel is disabled since we are minimizing pipe weight.

## F. Sizing Method

- Select the **Sizing Method** button from the Sizing Navigation Panel.

The Sizing Method panel defines the calculation methods to be used for sizing the system. The user has the option to select whether discrete or continuous sizing will be used, and which method will be applied.

If Continuous Sizing is selected, the ANS module will use the minimum and maximum Candidate Set sizes as boundaries. It will then calculate the ideal hydraulic diameter for the pipes being sized, which will likely not match any of the possible chosen commercial sizes. While this is not useful as a final solution, this may be helpful as a baseline to check the final solution using the provided discrete methods. For this model, make sure Discrete Sizing is selected.

For the Search Method, the ideal method will often change based on the number of independent pipe sizes (number of pipes not in groups and Common Size Groups in sizing), number of Design Requirements, and feasibility of the initial system design. The Help File provides more information on the strengths and weaknesses of each method. It is generally recommended to run the sizing with more than one method, as it is often not obvious which method will be most effective for each system.

For a simple model such as this one, the Modified Method of Feasible Directions (MMFD) or Sequential Quadratic Programming (SQP) method should be appropriate since there is only one Design Requirement, and only one pipe size is being varied. Choose the default Modified Method of Feasible Directions (MMFD).

## **Step 5. Run the automated sizing**

We are now in a position to run the automated sizing. Before doing so, take a moment to consider what this model is trying to accomplish. The Pipe P1 and P2 sizes will be selected together from the STD Pipes candidate set such that their weight is minimized while still obtaining a minimum 12.5 psid pressure drop across the control valve.

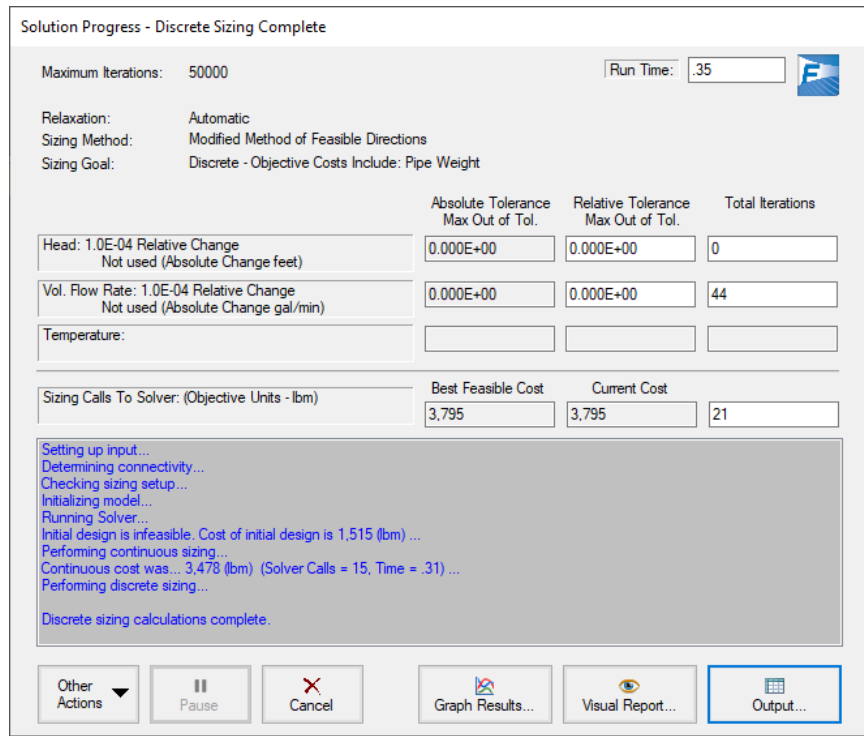
To begin sizing the system select Run Model from the Common Toolbar. While the model is running, the Solution Progress window shows the Sizing Calls to Solver. This is how many times a complete hydraulic analysis was run.

The Solver also displays the Current Cost and Best Feasible Cost, which will display the last calculated value for the cost, as well as the Best

Feasible Cost which has been found so far (Figure 2.9). The Solver will continue to iterate using the defined method to find a global minimum. For most methods, the Solver will first perform a continuous sizing, then perform discrete sizing based on the continuous solution, though this is not always the case.

**Note:** For complex systems using the Genetic Algorithm Sizing Method, the solution can be paused and accepted at any time by using the Pause button, then selecting Accept Sizing under Other Actions. This allows the user to accept the best current solution, rather than continuing to search for the global minimum.

When the sizing has completed, click the Output button to display the results.



**Figure 2.9** The Solution Progress window shows the progress of the AFT Fathom Solver and the ANS module

## Step 6. Review automated sizing results

The Cost Report tab in the General Output section shows a total weight of 3,795 lbm, while each pipe has a weight of 1,897 lbm (Figure 2.10). This makes sense since the pipes have equivalent length and a common diameter due to the fact that they are in a Common Size Group.

The Sizing tab in the Pipe Output section shows the ideal pipe size was found to be 6 inch for the pipes when sized together.

The CV Design Requirements tab shows that the 12.5 psid minimum pressure drop is satisfied - the pressure drop for 6 inch pipe was 12.61 psid. Note that the Design Requirement result is highlighted in blue, indicating that the Design Requirement was active during the continuous solution, but the discrete solution was outside of a certain tolerance from the continuous solution. Yellow highlighting will be used if the Design Requirement is active in the final solution, and the discrete solution is within a close tolerance to the continuous solution.



The screenshot shows the 'Output' window with several tabs: General, Warnings, Design Alerts, Cost Report, Valve Summary, and Res. The 'Cost Report' tab is active, displaying a table of costs. Below it, the 'Pipes Sizing' tab is active, showing a table of pipe sizing results. At the bottom, the 'CV Design Requirements' tab is active, showing a table of pressure drop results.

Table Units:	Type	Name	Pipe Weight
lbm			
<b>Total of All Shown Costs</b>			<b>3.795</b>
<b>Items In Sizing</b>			<b>3.795</b>
<b>Items Not In Sizing</b>			<b>0</b>
<b>Pipe Subtotal</b>			<b>3.795</b>
o	P1	Pipe	Pipe 1,897
o	P2	Pipe	Pipe 1,897

Pipe	Name	Sized - Material	Sized - Nominal Size	Sized - Type/Schedule	Sized - Hyd. Diameter (inches)
1	Pipe	Steel - ANSI	6 inch	STD (schedule 40)	6.065
2	Pipe	Steel - ANSI	6 inch	STD (schedule 40)	6.065

Jct	Pressure Drop Static Minimum > 12.5 psid [Min Pressure Drop]
2	12.61

**Figure 2.10** The Output window shows the hydraulic results of the sized system, plus the sizing results

## Conclusions

This example demonstrates the automated sizing capabilities of the ANS module for a simple system with a single Design Requirement. Sizing for non-monetary objectives such as pipe weight is fast and easy to implement.

# Initial and Life Cycle Cost Sizing

This example demonstrates some key features by using the ANS module to size a cooling water system for monetary cost.

## Topics covered

- Connecting and using existing engineering and cost libraries
- Sizing for Initial or Life Cycle Cost
- Using Initial Cost Limits
- Sizing a pump, and sizing piping for the chosen pump
- Interpreting Cost Reports

## Required knowledge

This example assumes that the user has some familiarity with AFT Fathom and the ANS module such as placing junctions, connecting pipes, entering pipe and junction properties, and creating and using Candidate Sets and Design Requirements. Refer to the Weight Sizing Example in Chapter 2 for more information on these topics.

### Model files

A partially completed model file will be utilized as the starting point for this example. A completed version of the model file can be referenced if desired. Both the initial and final model files can be found in the Examples folder as part of the AFT Fathom installation:

C:\AFT Products\AFT Fathom 13\Examples

- *US - Cooling System.fth* - initial model file
- *US - Cooling System - ANS.fth* - completed model file
- *Cooling System.dat* - engineering library
- *Cooling System Costs.cst* - cost library for Cooling System.dat
- *Steel - ANSI Pipe Costs.cst* - cost library for Steel - ANSI pipes

### Problem statement

This example uses an existing model to investigate three automated sizing cases:

1. Size system for *initial cost* with a 10-year system life
2. Size system for *life cycle cost* with a 10-year system life
3. Size system for *life cycle cost with an initial cost limit* for a 10-year system life

### Step 1. Start AFT Fathom

From the Start Menu, choose AFT Products and AFT Fathom.

Enable the ANS module from the Startup Window by checking the box next to the ANS module. Alternatively, it can be activated from the Modules panel in Analysis Setup.

## Step 2. Open model file

For this example, we will be starting from a pre-built model file that is fully defined for a normal AFT Fathom run. We will add automated sizing settings to find a more cost-effective design. From either the Startup Window or the File menu, open the model file *US - Cooling System.fth*. Right-click the scenario named Initial Model for ANS Quick Start Chapter 3 and select Save Scenario to File Without Children. After it is saved, open it. The Workspace should appear as shown in Figure 3.1.

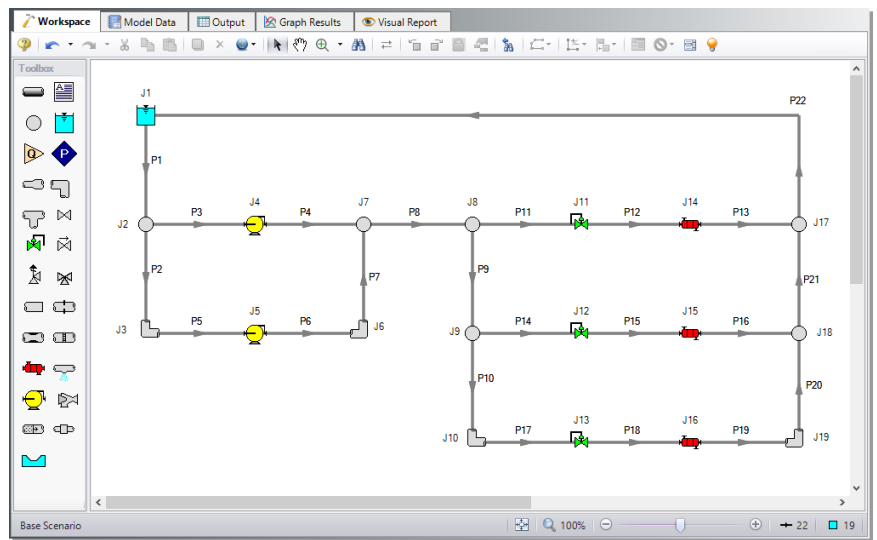


Figure 3.1 Cooling System example model

### ***Sizing systems with pumps***

A centrifugal pump can be modeled with either the Pump Curve or as a fixed flow rate or pressure/head as the Sizing option. Generally, if a specific pump has been identified, the Pump Curve type would be chosen, whereas the Sizing option is useful during the selection stage in order to identify the pumping requirements for the system. In some cases, even though the specific pump has not been chosen, several candidate pumps are available. For this third case it would be best to model each candidate pump with a pump curve using separate scenarios for each pump.

### ***Pump model in this system***

The pumps in our cooling water case are both set as Sizing at fixed flows of 3000 gal/min. In order to allow the pumps to be defined as fixed flows, the flow control valve J13 has been defined as a Constant Pressure Drop (PDCV) of 5 psid. This model thus represents a first cut model where, based on the first cut results, the two pumps will become actual pumps with pump curves, and control valve J13 will become a flow control valve controlling to 2000 gal/min, similar to control valves J11 and J12.

As already stated, when a pump is modeled as a fixed flow, it is not a specific pump from a specific manufacturer. Thus, the costs for the pump can only be approximated. To a first approximation, it should be possible to estimate the non-recurring cost (i.e., material and installation cost) for the pump as a function of power requirements. For instance, a typical one horsepower pump (of specific configuration and materials of construction for a given flowrate) may cost \$2000, and a ten horsepower may cost \$4000. Other typical costs for different power requirements can be approximated. The actual cost for the pump will, of course, highly depend on the application. As AFT Fathom evaluates different combinations of pipe sizes, each combination will require a certain power from the pump. With a cost assigned to this power, the ANS module can account for this over the life of the system. Later in this chapter, we will look at the costs for the pumps in our example cooling water network.

In addition to non-recurring costs, recurring costs can also be estimated. Specifically, the cost of the power used by the pump over a period of time (which the ANS module calls the system life) can be determined.

All AFT Fathom needs is an overall pump efficiency to determine the actual power from the ideal power. Again, since we do not have a specific pump selected yet, the efficiency can only be approximated. The ANS module calls this the Nominal Efficiency. In addition, users can provide a Nominal NPSHR.

A step-by-step method of pump selection proceeds in two phases. The steps are outlined in the Help System.

## **Step 3. Review model settings**

The pipes and junctions are already defined, but we need to review and complete the sizing settings before running the analysis. In the Modules panel in Analysis Setup, click the box next to Activate ANS and make sure Network is selected. Next, go to the Sizing window by clicking the tab.

### **A. Sizing Objective**

The Sizing Objective panel should be displayed by default.

To begin we will first need to choose the calculation option, so select Perform Sizing.

As explained previously, a non-monetary parameter such as weight could be chosen to simplify the sizing. However, there are a few downsides to this method, as this does not allow one to include pump and other junction initial costs for the sizing. Additionally, recurring costs cannot be calculated using non-monetary cost. To more thoroughly size the pumps in this system we will need to minimize monetary cost directly.

- **Select Monetary Cost as the Objective** and select **Minimize** from the drop-down list.

With the Monetary Cost selected, the options to minimize monetary cost will appear displayed in a table, along with several options to the side that will activate depending on the cost types being analyzed. Several common analysis types can be selected in the list box above the table to automatically configure the table.

- **From the list box choose Size for Initial Cost, Show Energy Costs.**  
This will set the table to include material and installation costs in the Sizing Objective and will calculate the energy costs without including them in the Objective, as can be seen in Figure 3.2. This will allow us to size for the initial costs and include the energy costs for comparison when we later size the system for life cycle cost (initial costs and recurring costs combined).

Since the energy costs are included in the cost calculation, users must provide a System Life and, optionally, interest and inflation rates to calculate the present value of the recurring costs.

- **Enter 10 years for the System Life**, with 0% for the interest and inflation rates.

The source of the energy costs must also be defined. Simple energy costs can be entered here, or it can be specified that energy costs come from Energy Cost Libraries, which would need to be added on the Assign Cost Libraries panel. An Energy Cost Library allows variable energy costs to be used to account for varying prices during different times of day, different seasons, etc.

- **Choose Use this Energy Cost Information**, with a cost of 0.11 U.S. Dollars per kW-hr. Note this assumes the pump will run all day, every day, for the entire 10 years.

The Sizing Objective panel should now appear as shown in Figure 3.2.

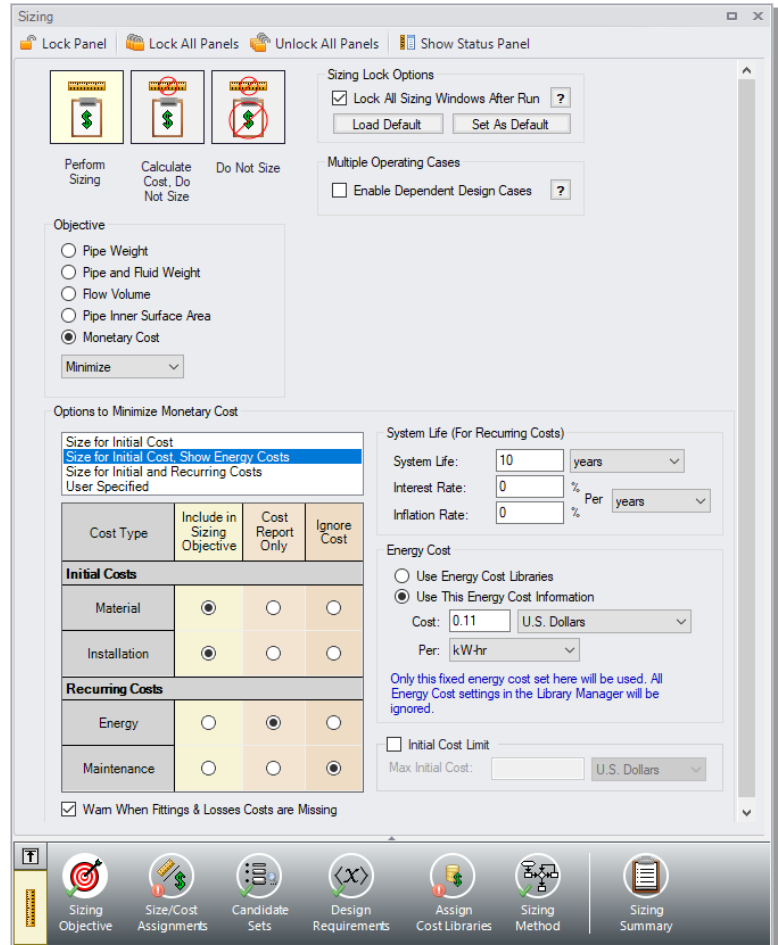


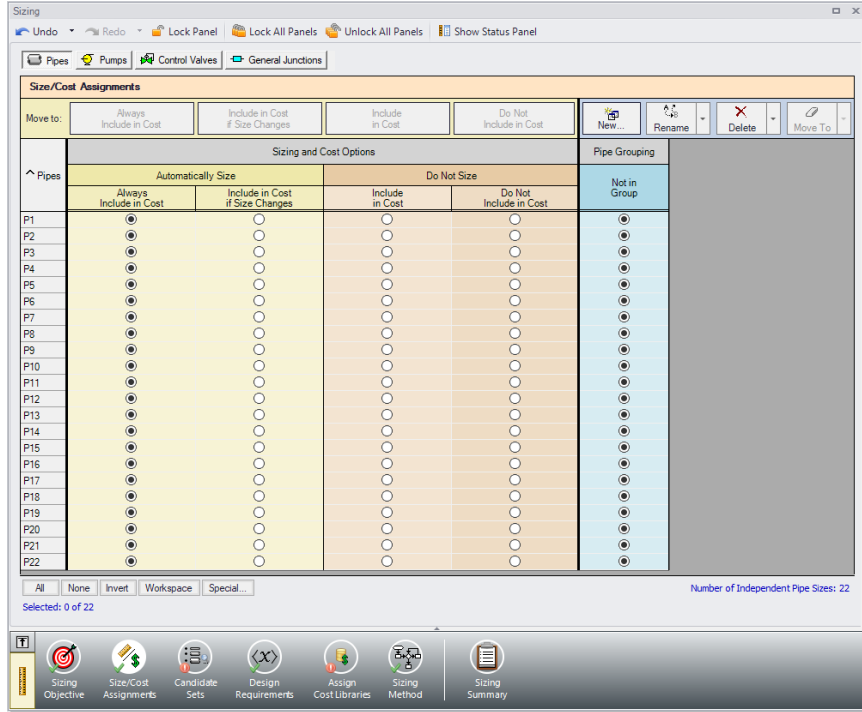
Figure 3.2 Sizing Objective panel setup for an Initial Cost sizing

## B. Size/Cost Assignments

On the Sizing Navigation Panel select the Size/Cost Assignments button. For this example we are sizing both the pipes and pumps for a new system, so we will need to calculate and minimize cost for all related components in the model.

- **Select the Pipes button** and set all pipes to Always Include in Cost. See Figure 3.3.





**Figure 3.3** Size/Cost Assignments panel with all pipes included in sizing

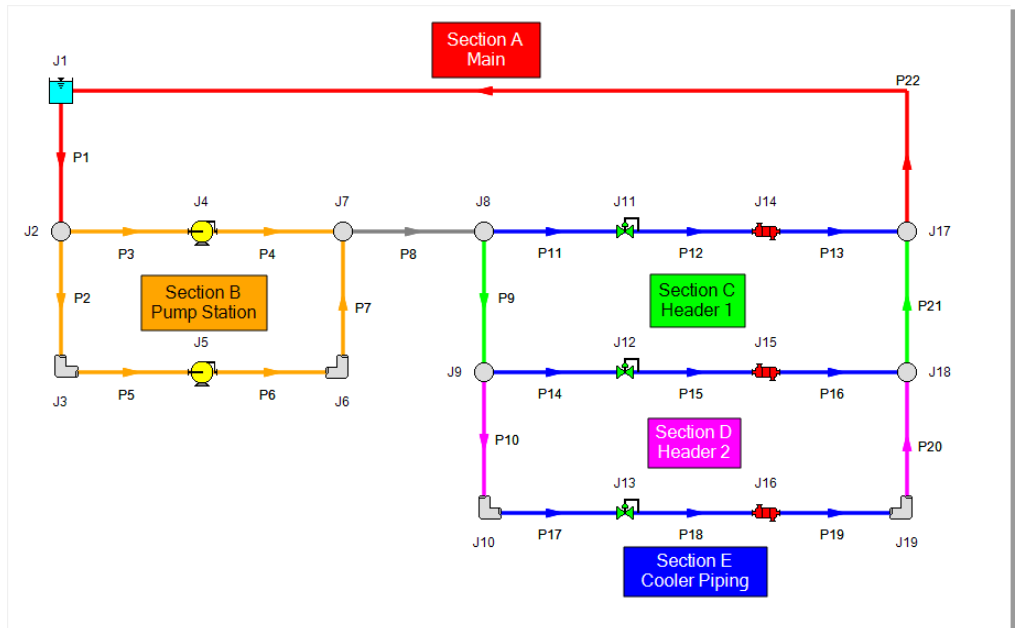
**Note:** The selection tools below the Size and Cost Options table and the Move To buttons above the table can be used to quickly select and assign large groups of pipes simultaneously.

To decrease the run time and reduce complexity, as well as to enforce some design uniformity, it is useful to create Common Size Groups to link the pipes in different sections of the model.

For example, if all 22 pipes are set as Not In Group, then 22 independent pipe sizes will be selected by the automatic sizing engine. That could potentially mean, for example, different suction pipe diameters in Pipes P3 and P5. A similar thing would happen for discharge pipe diameters. If one wanted the suction Pipes P3 and P5 to be sized to the same diameter, one would group them into a Common Size Group. To see how this works, in this model all suction and

discharge piping for both pumps will be put into a Common Size Group. What this means is that there will be a single diameter chosen for this group of pipes, rather than potentially six different diameters.

For this system we will define five groups to be sized in this model. To set the groups, it is normal to select pipes which must have the same size due to their placement relative to other pipes and junctions, such as pipes at the entrance and exit of valves. In Figure 3.4 we have identified three main sections of the model to begin grouping the pipes.



**Figure 3.4 Cooling System model with sections identified to make groups**

First we will create a Main size group for pipes P1 and P22, which are red in Section A. The inlet and outlet lines to the cooling reservoir would logically be identical, though they will not necessarily share a size with other piping in the model.

- **Click the New button** above the Pipe Grouping section to create the group, and name it Main. Select the radio buttons under the Main heading next to P1 and P22 to add them to the group. Alternatively, the

pipes can be selected in the Workspace, then moved to a group by right-clicking the Workspace and selecting the corresponding option from the menu.

Now we will repeat this process for the piping in Section B in orange around the pumps. Since these units are operating in parallel with identical flow rates, we would again expect the pipes in this section to have a common size. Similar to above, create a new group called Pump Station, and add Pipes P2 through P7 outlined in Figure 3.4 to the new group.

Lastly, consider Sections C through E (green, magenta, and blue), the piping near the coolers. In this case we have three coolers in parallel, with several header pipes connecting the cooler piping segments. We would expect the piping at the coolers and control valves to have a common size, but the header piping (P9, P10, P20, P21) would likely be larger, which is why they are grouped separately. Create three common size groups as follows:

1. Header 1 with Pipes P9 and P21
2. Header 2 with Pipes P10 and P20
3. Cooler Piping with Pipes P11 through P19

The completed Size/Cost Assignments can be seen in Figure 3.5, with only Pipe P8 left not in a group.

---

**Note:** The number of Independent Pipe Sizes in the model can be seen in the bottom right of the Size/Cost Assignments panel, and denotes the number of pipe sizes being independently varied (i.e. the number of Common Size Groups, plus the sized pipes not in a group). This information is useful for choosing Sizing Methods and troubleshooting purposes.

---

- **Click the Pumps button** to switch to the Pump Size/Cost Assignments. Select the option to Include in Cost Report and Sizing for both pumps so that the ANS module will size the pumps along with the pipes as shown in Figure 3.6.

Similar to the Common Size Groups for pipes, Pumps can be placed into Maximum Cost Groups based on monetary cost. If pump costs are added to a Maximum Cost Group, the ANS module will determine the pump in

the group with the maximum costs and set all pumps in the group to the same costs as that pump. In this case we do not want to group the pumps, so nothing else needs to be added for the pumps.

We also want to include the Bend junctions in the sizing for this model.

- **Click the General Junctions button** and change each of the Bends (J3, J6, J10, J19) to Include in Cost Report and Sizing (Figure 3.7). We are now finished with the Size/Cost Assignments.

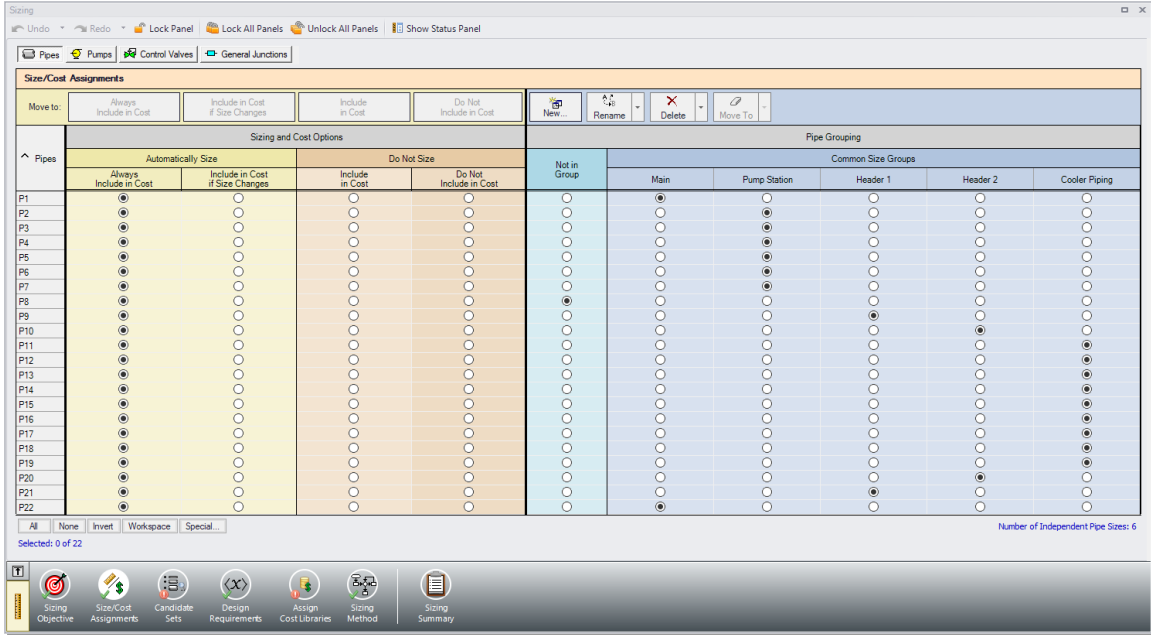
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**Note:** Pipes in the Size/Cost Assignments table can be sorted by Common Size Group instead of sorting by number by clicking on the Pipe Grouping header. Clicking on the header for a particular group will sort the pipes in that specific group to the top of the window.

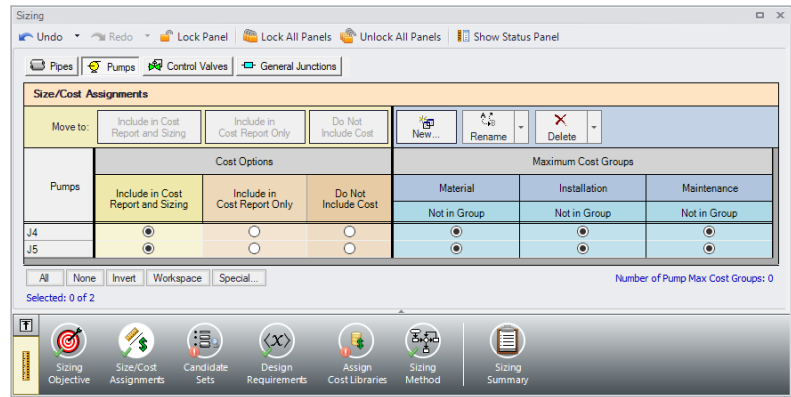
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Now go to the Workspace window. It is possible to inspect the Common Size Groups in the model by coloring the pipes. From the View menu, select All under Color Common Size Groups. The model should appear as shown in Figure 3.8. It is also possible to color a specific Common Size Group from the Size/Cost Assignments panel by right-clicking on the header of the desired group.

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**Figure 3.5 Pipe settings in the Size/Cost Assignments panel**



**Figure 3.6 Pump settings in the Size/Cost Assignments panel**

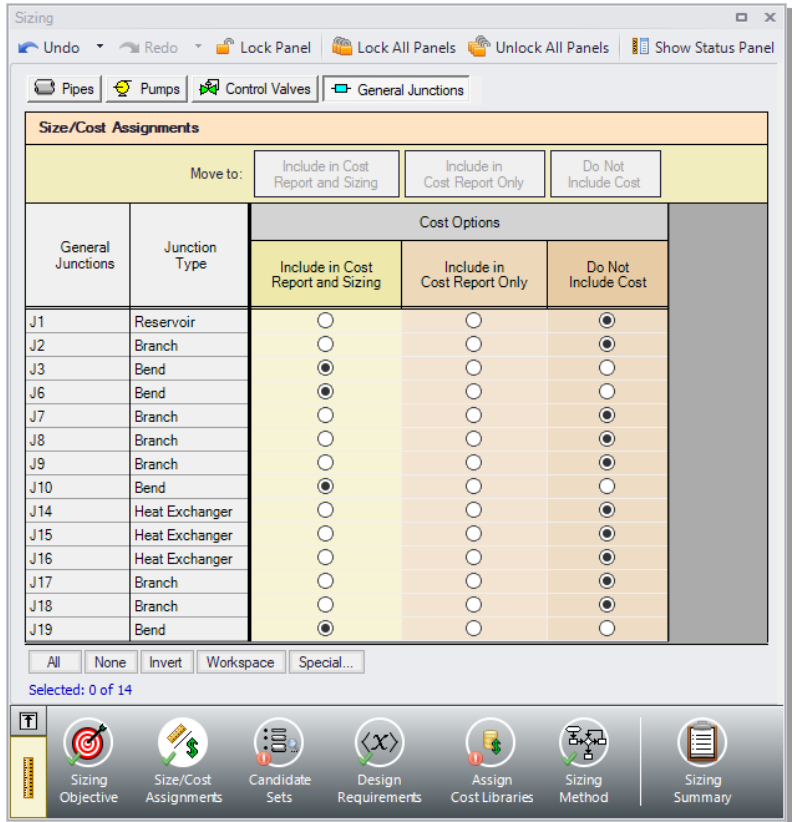
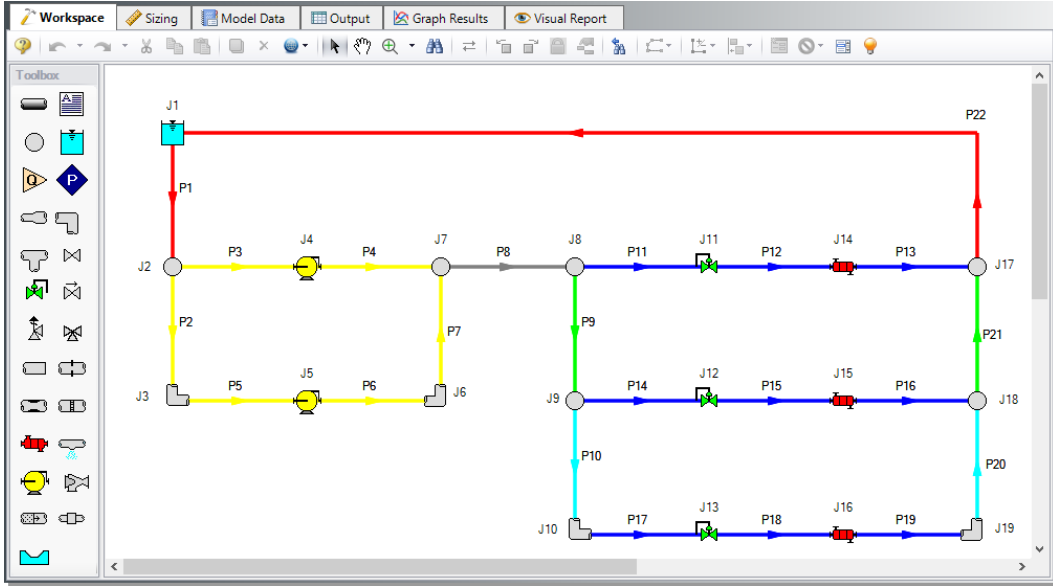


Figure 3.7 General Junctions assignments



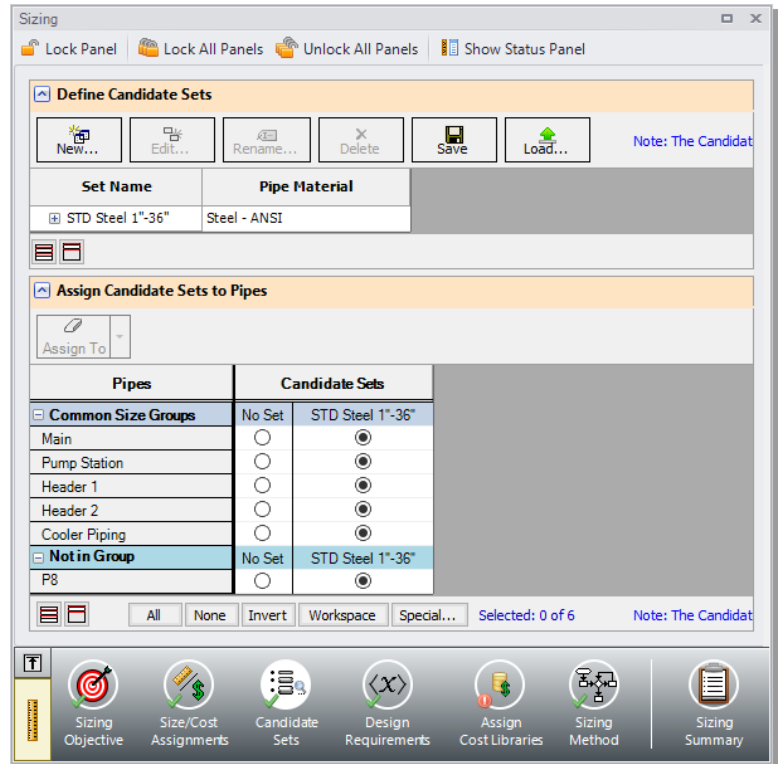
**Figure 3.8 Common Size Groups shown by color in the Workspace**

### C. Candidate Sets

Click on the Candidate Sets button to open the Candidate Sets panel.

Click New under Define Candidate Sets and name it STD Steel 1"-36". In the Select Pipe Sizes window, select Steel - ANSI from the dropdown menu, expand the STD group (make sure the Sort selection on the bottom is Type, Schedule, Class), then add all pipes from 1 inch to 36 inch to the Candidate Set list on the right.

In the bottom section of the window, assign each of the Common Size Groups and Pipe P8 to the STD Steel 1"-36" Candidate Set. The window should appear as shown in Figure 3.9.



**Figure 3.9** Candidate Sets panel fully defined for the model

## D. Design Requirements

Select the Design Requirements button.

Design Requirements can be applied to both sized and unsized pipes and junctions. Design Requirements are design limitations on certain parameters. For example, there may be a Design Requirement that the velocity cannot exceed 12 feet/sec. As the ANS module evaluates different pipe sizes, if a particular size results in a velocity greater than 12 feet/sec, that pipe size is rejected because it causes a Design Requirement violation.

When a pipe that is not sized has a Design Requirement, it means that the sized pipe sizes cannot be such that it violates the Design Requirement for the unsized pipe. There can be multiple Design Requirements defined and applied to a pipe, junction, or group. For

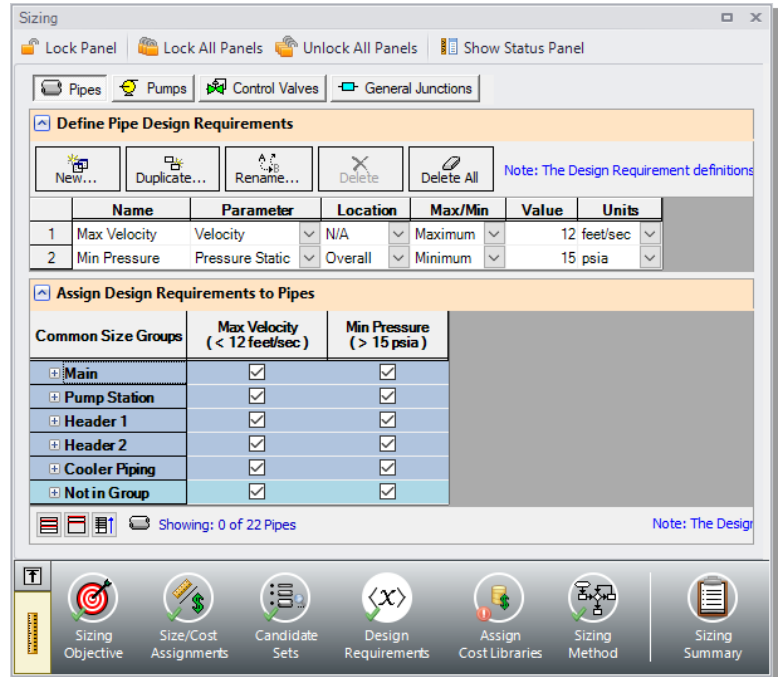


instance, in addition to a maximum velocity limit, a maximum pressure limit may exist. Individual pipes/junctions in a Common Size Group can have different Design Requirements applied.

For this model we have multiple requirements for the system:

1. All pipes have a maximum velocity of 12 feet/sec
2. All pipes have a minimum overall static pressure of 15 psia
3. All pumps must have an NPSHA at least 10 feet above the NPSHR
4. All control valves must have a minimum pressure drop of 5 psid
5. All heat exchangers must receive a minimum flow of 1900 gal/min

Define and assign the first two requirements listed above as Pipe Design Requirements as shown in Figure 3.10, and the third requirement as a Pump Design Requirement as shown in Figure 3.11. Notice that we have accounted for the minimum flow requirement in this system by using flow control valves at each of the heat exchangers. By using assigned flow pumps and flow control valves at the heat exchangers we have incorporated the necessary flow rate as a boundary condition, so we do not need to apply a Design Requirement to account for this item.



**Figure 3.10** Design Requirements panel for pipes

For flow control valves J11 and J12 define and apply the minimum pressure drop requirement in the Control Valves section as shown in Figure 3.12. Note that for pump sizing purposes as discussed earlier control valve J13 has been defined as a Constant Pressure Drop valve, so the pressure drop Design Requirement does not need to be applied to this valve.

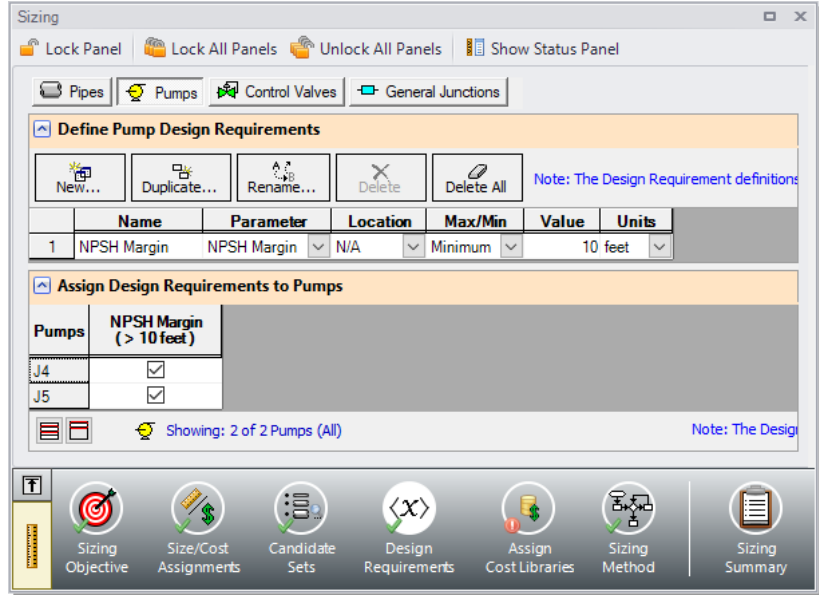


Figure 3.11 Design Requirements panel for pumps

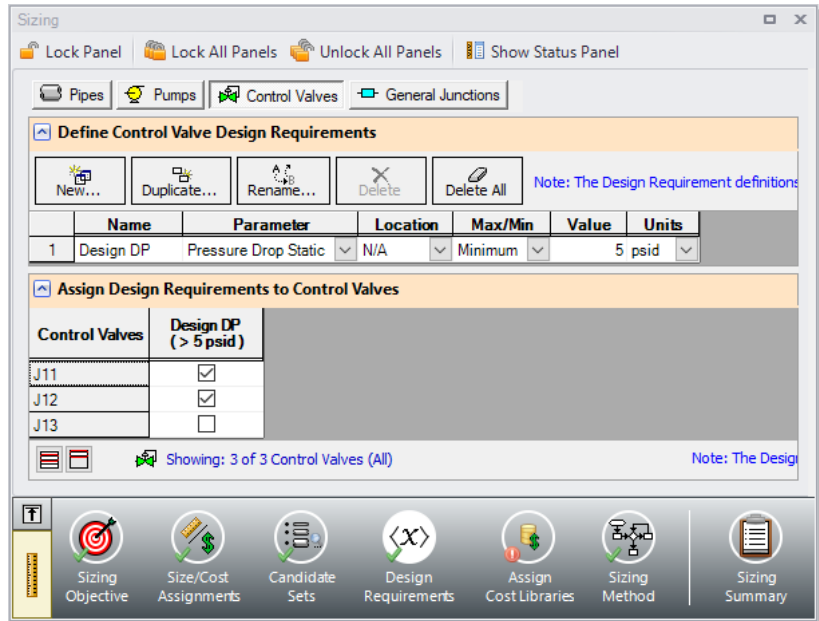


Figure 3.12 Design Requirements panel for control valves

## E. Assign Cost Libraries

Select the Assign Cost Libraries button. The material and installation costs for all pipes and junctions being sized must be entered into cost libraries, which are then assigned to the appropriate components here. The cost libraries needed for this cooling water example have been pre-built, and just need to be accessed.

The Library Manager (opened from the Library menu) shows all of the available and connected libraries. Libraries can either be engineering libraries or cost libraries. Cost libraries are always associated with an engineering library and are thus displayed subordinate to an engineering library in the library lists.

Here we will summarize some key aspects of libraries:

- Cost information for a pipe system component is accessed from a cost library. Cost library items are based on corresponding items in an engineering library. The engineering libraries also include engineering information such as pipe diameters, hydraulic loss factors, etc.
  - To access a cost for a particular pipe or junction in a model, that pipe or junction must be based on items in an engineering library. Moreover, that library must be connected to the model, and to the specific item in the model.
  - There can be multiple cost libraries associated with and connected to an engineering library. This makes it easier to manage costs of items. If multiple cost libraries are assigned to a Candidate Set, then the costs will be stacked to find a cumulative cost.
- **Open the Library Manager** from the Library menu. The AFT INTERNAL LIBRARY, AFT FATHOM LOCAL USER LIBRARY, and default pipe material libraries should be available and connected by default. Available Libraries will be shown in the Library Browser based on libraries that AFT Fathom has identified on your machine. The default connected libraries will be visible here, and additional libraries may be visible from other example files, or from libraries previously built and used on your machine.

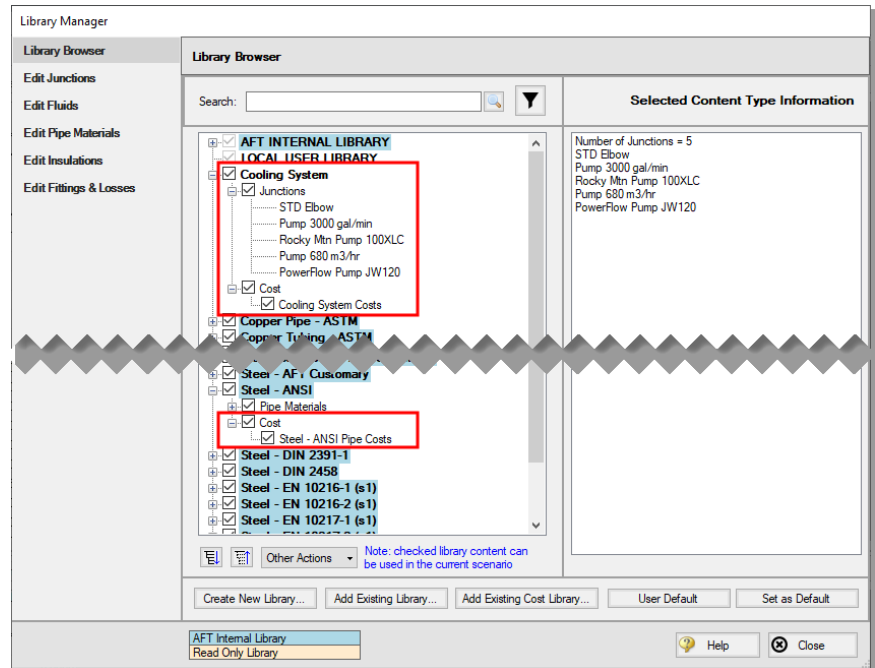
This example uses one user-defined engineering library, *Cooling System.dat*, which contains the junction input data for the pumps and bends. There are also two cost libraries, *Cooling System Costs.cst* and

*Steel - ANSI Pipe Costs.cst*, which contain the cost data for the junctions and the pipe materials, respectively. *Cooling System Costs.cst* was built off of the engineering library *Cooling System.dat*, and *Steel - ANSI Pipe Costs.cst* was built off of the default Steel - ANSI library. To connect these libraries, do the following:

1. Click the Add Existing Library button.
2. Browse to the AFT Fathom 13 Examples folder (located by default in C:\AFT Products\AFT Fathom 13\Examples\), and open the file titled *Cooling System.dat*.
3. Repeat the above steps, but choose Add Existing Cost Library to browse for *Cooling System Costs.cst*, then *Steel - ANSI Pipe Costs.cst*.

Note that it may be possible that the model file already has the cooling system libraries connected, in which case you will be notified that the library you are trying to add is already available. If the libraries are available, you will simply need to connect them by making sure the box next to each library is checked.

Once these steps have been completed, you should now see that the new libraries have been added to the Library Browser, and have been automatically connected to the model as shown in Figure 3.13 for the junction libraries. The junction libraries appear in the Library Browser under the names Cooling System and Cooling System Costs, with the cost library indented beneath the engineering library to denote that they are linked. The cost library for the pipes appears with the name Steel - ANSI Pipe Costs, and is similarly indented under the Steel - ANSI library within the standard pipe material libraries.



**Figure 3.13 Library Manager showing the Cooling System libraries connected and available**

Once you have confirmed that the necessary libraries are connected as shown, click Close to exit the Library Manager.

Since we are connecting a pre-built library, we will need to take an additional step to make sure that the junctions in the Workspace are linked to the Cooling System engineering library that we added.

1. Go to the Workspace, and open Pump J4.
2. From the Library Jct list, select Pump 3000 gal/min. None of the input should change, as this library item is identical to the existing pump. However, AFT Fathom will now recognize that this junction is connected to the engineering and cost library for this pump.
3. Repeat step 2 for Pump J5. Similarly, open each of the Bends (J3, J6, J10, J19), and select STD Elbow from the Library Jct list.

We have now re-connected the junctions that will be considered for the Cost Report and sizing calculations to the engineering library. This is

important, since a junction must be connected to an engineering library before cost information can be assigned to it. We will now return to the Sizing window.

Back in the Assign Cost Libraries panel for the Pipes, the Steel - ANSI Pipe Costs library should be the only visible cost library, since it is the only connected library for the pipe sizes in the Candidate Set. Make sure that the library is checked to be applied for the model as shown in Figure 3.14.

- **Click on the Pumps button**, to view the cost library assignments for the Pumps. The only visible library should be the Cooling System Costs library, as this was the only cost library connected for the associated engineering library. Make sure that the checkboxes are selected under the library name so that the cost data will be applied for each of the pumps (Figure 3.15). To review the cost data for the Bends click the General Junctions button to verify that the Cooling System Costs is being applied to each of the bends (Figure 3.16).

## F. Sizing Method

Select the Sizing Method button to go to the corresponding panel.

- **Select Discrete Sizing** to complete the sizing for a set of commercial pipe sizes.

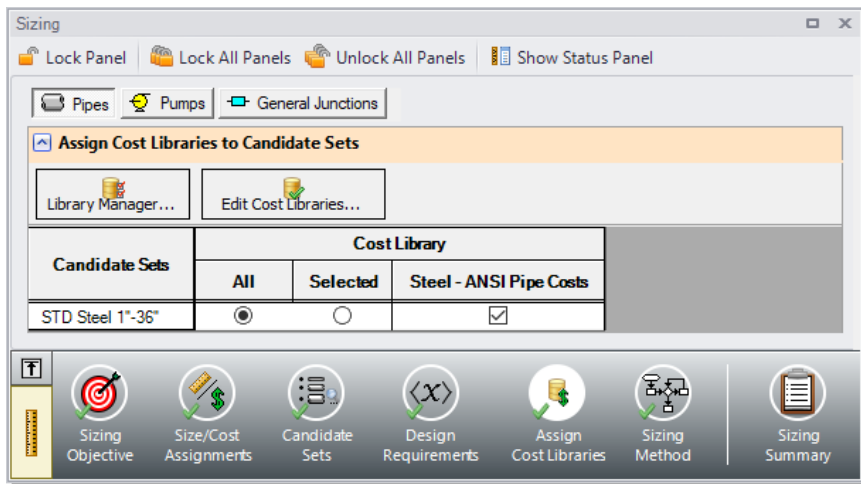


Figure 3.14 Assign Cost Libraries panel for pipes

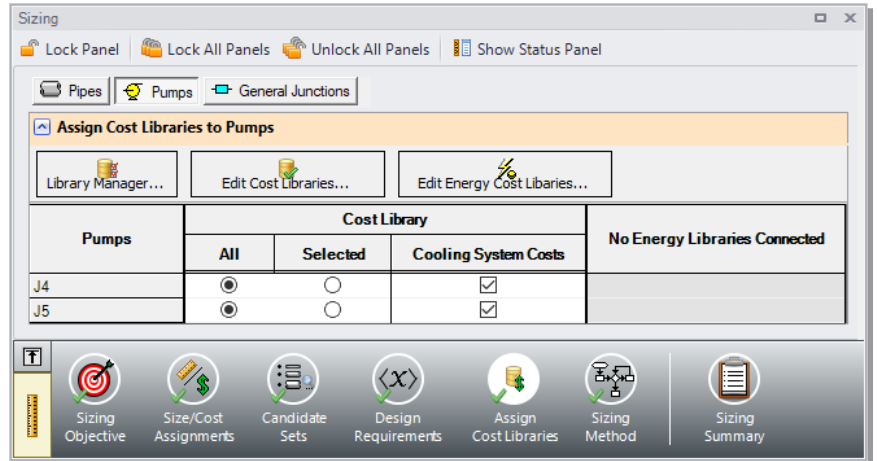


Figure 3.15 Assign Cost Libraries panel for pumps

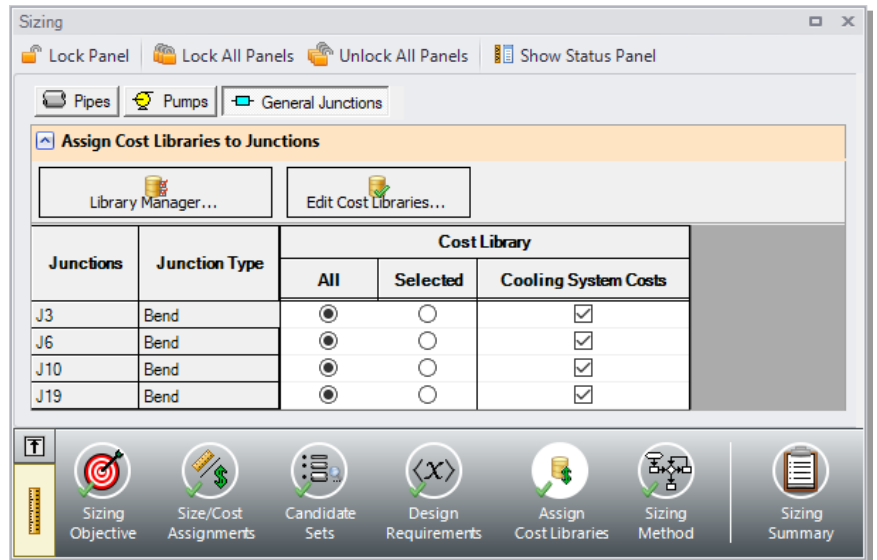
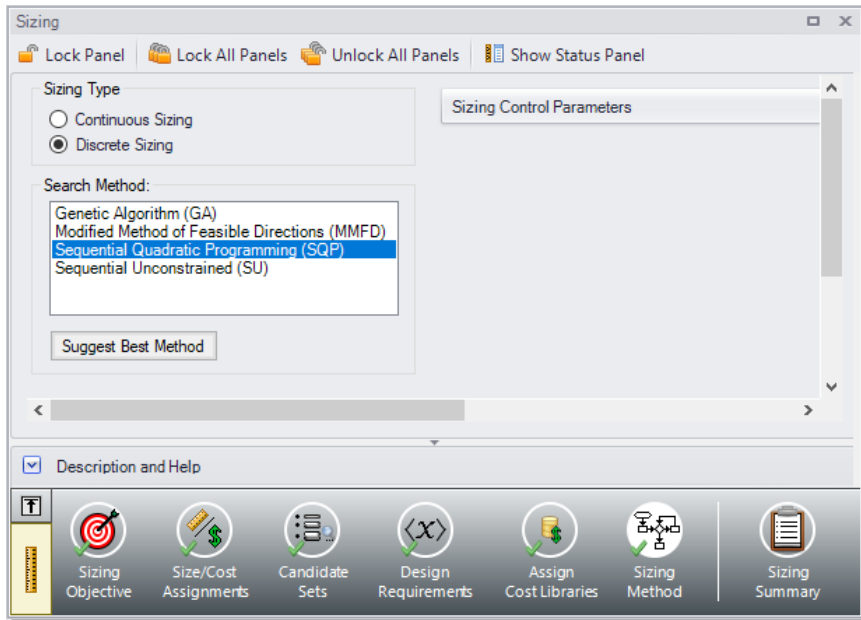


Figure 3.16 Assign Cost Libraries panel for junctions

For this model we have six independent pipe sizes as noted on the Size/Cost Assignments panel when the Pipes button is selected (five groups and Pipe P8), and 48 design requirements (two pipe design requirements applied to all of the pipes, the pump NPSH requirement,



and the minimum pressure drop for control valves). Due to the small number of independent sizes, it would be recommended to try the MMFD or SQP search method. Though it is not shown here, if both methods are run for this scenario the same solution will be obtained, though the Sequential Quadratic Programming (SQP) Method is slightly faster. Select this method from the list as shown in Figure 3.17.



**Figure 3.17** Sizing Method panel defined for Discrete sizing with the Sequential Quadratic Programming method

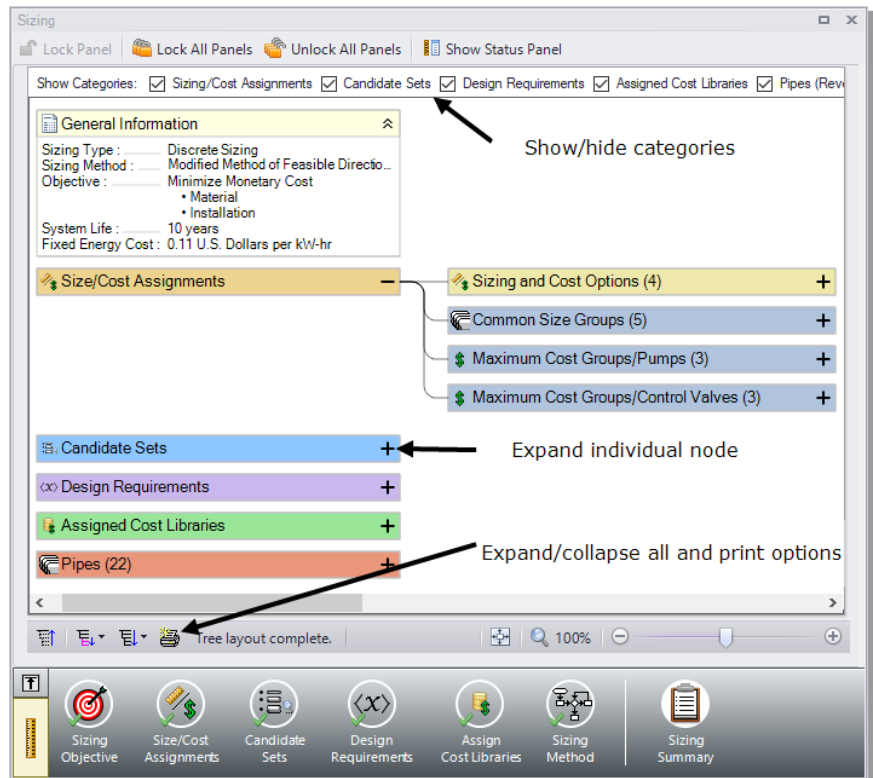
## G. Sizing Summary

From the Sizing Navigation Panel select the Sizing Summary button.

The Sizing Summary panel allows the user to view all of the sizing input for the model in a tree view layout, which is shown in Figure 3.18. Items can be organized by sizing parameters (Design Requirements, Candidate Sets, etc.), or information can be viewed for an individual pipe. For clarity these categories can be shown/hidden using the checkboxes at the top of the panel.

Each tree node can be expanded/collapsed individually by using the “+” and “-” buttons on the node. Alternatively, the buttons on the bottom of

the panel can be used to collapse/expand all items. Right-clicking on the nodes provides additional options to collapse/expand items, view related nodes, or to copy information to the clipboard. The Sizing Summary panel can be printed from the printer button at the bottom of the panel.



**Figure 3.18 Sizing Summary panel with the Size/Cost Assignments expanded**

## Step 4. Run the model

Select Run Model from the Common Toolbar. This will open the Solution Progress window. This window allows you to watch as the AFT Fathom Solver and the ANS module converge on a solution.

After the run has been completed, the results can be reviewed clicking the Output button at the bottom of the Solution Progress window.

## Step 5. Review the output

The Cost Report is shown in the General Section of the Output window as shown in Figure 3.19.

Table Units: U.S. Dollars		Type	Name	Material	Installation	Non-Recurring Sub Total	Maintenance	Operation/Energy	Recurring Sub Total	TOTAL
<b>TOTAL OF ALL MODEL COSTS</b>										<b>2,287,193</b>
<b>Total of All Shown Costs</b>				105,846	53,803	159,649	0	2,127,544	2,127,544	2,287,193
<b>Items In Sizing</b>				105,846	53,803	159,649	0	0	0	159,649
<b>Items Not In Sizing</b>				0	0	0	0	2,127,544	2,127,544	2,127,544
<b>Pipe Subtotal</b>				58,013	36,820	94,833	0	0	0	94,833
o	P1	Pipe	Pipe	2,476	1,518	3,994	0	0	0	3,994
o	P2	Pipe	Pipe	227	178	405	0	0	0	405
o	P3	Pipe	Pipe	378	297	675	0	0	0	675
o	P4	Pipe	Pipe	378	297	675	0	0	0	675
o	P5	Pipe	Pipe	378	297	675	0	0	0	675
o	P6	Pipe	Pipe	378	297	675	0	0	0	675
o	P7	Pipe	Pipe	227	178	405	0	0	0	405
o	P8	Pipe	Pipe	24,762	15,176	39,938	0	0	0	39,938
o	P9	Pipe	Pipe	227	178	405	0	0	0	405
o	P10	Pipe	Pipe	164	139	302	0	0	0	302
o	P11	Pipe	Pipe	545	462	1,007	0	0	0	1,007
o	P12	Pipe	Pipe	273	231	504	0	0	0	504
o	P13	Pipe	Pipe	273	231	504	0	0	0	504
o	P14	Pipe	Pipe	545	462	1,007	0	0	0	1,007
o	P15	Pipe	Pipe	273	231	504	0	0	0	504
o	P16	Pipe	Pipe	273	231	504	0	0	0	504
o	P17	Pipe	Pipe	545	462	1,007	0	0	0	1,007
o	P18	Pipe	Pipe	273	231	504	0	0	0	504
o	P19	Pipe	Pipe	273	231	504	0	0	0	504
o	P20	Pipe	Pipe	164	139	302	0	0	0	302
o	P21	Pipe	Pipe	227	178	405	0	0	0	405
o	P22	Pipe	Pipe	24,762	15,176	39,938	0	0	0	39,938
<b>Bend Subtotal</b>				736	1,562	2,298	0	0	0	2,298
o	J3	Bend	Bend	217	426	643	0	0	0	643
o	J6	Bend	Bend	217	426	643	0	0	0	643
o	J10	Bend	Bend	151	355	506	0	0	0	506
o	J19	Bend	Bend	151	355	506	0	0	0	506
<b>Pump Subtotal</b>				47,097	15,421	62,518	0	2,127,544	2,127,544	2,190,062
o	J4	Pump	Pump	23,422	7,664	31,086	0	1,059,984	1,059,984	1,091,070
o	J5	Pump	Pump	23,675	7,757	31,432	0	1,067,560	1,067,560	1,098,991

**Figure 3.19 The Cost Report in the Output window shows the total and individual costs for the sized system**

The ANS module shows all costs in the Cost Report, including those that were calculated but not used in the automated sizing. The total cost for this system is \$2,287,193. This includes all costs over 10 years. The initial cost, which was the basis for the automated sizing, was the total of the material and installation costs (\$159,649). This total is listed as the total for the Items in Sizing line, since it was specified to only include the initial costs (material and installation) in the Sizing Objective section. Individual items that were included in the automated

sizing have their costs highlighted in green, which can be turned on/off in the Format & Action tab of the Output Control window.

Other costs that are displayed in the Cost Report are Items Not in Sizing. These are items that were set to have their costs calculated but were not included in the automated sizing. Note that the Items Not in Sizing total to \$2,127,544. Looking across at the subtotal, one can see that all of this cost is in Operation/Energy column (i.e., pump power costs). This cost will be included in the automated sizing later for comparison.

In the Pipes section of the Output window the final pipe sizes from the automated sizing can be seen in the Sizing tab, along with the Design Requirements status. The only active Design Requirement for this scenario was the minimum NPSH margin for pump J5, as is indicated by the highlighting (Figure 3.20).

For this model, the final system used pipe sizes varying from 10 to 16 inches, as seen in Figure 3.21. Data on the Common Size Groups and pipe costs can also be viewed from here. The information for the pumps can be seen in the Pump Summary tab in the General Section, which is also shown in Figure 3.21.

When a monetary cost objective is selected, additional tabs are available that display the Library Sources used for the Cost Report for each of the pipes/junctions. In this case both the Pipe Material and Pipe Installation costs for all of the pipes came from the Steel - ANSI Pipe Costs library which was connected earlier. Information for the Pumps and Bends came from the Cooling System Costs library. If multiple cost libraries are used for the same cost type they will all be listed separated by commas. This is useful for model verification.

On the General tab of the Output window at the bottom of the report, the initial cost of the items included in the sizing can be seen, which was \$437,988 for this design, showing that the initial costs were reduced by about 64% from the initial design. We can also see that the initial design was feasible, meaning all of the design requirements were met (Figure 3.22).

Though not shown here, if the model is run using the objective to Calculate Costs, Do Not Size, it can be seen that the total cost for the system before sizing was \$2,414,738, which is only slightly more than the system that has been sized for initial costs. This is due to the fact

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that the larger pipe sizes in the initial system allowed for lower energy costs over the ten year system life. The original design is weighted towards energy costs, so any change in the energy costs will have an impact on the overall life cycle cost.

<span>⤴</span> Pipes <span>Sizing</span> <b>Pipe Design Requirements</b> <span>Library Sources</span>			
Pipe	Velocity Maximum < 12 feet/sec [Max Velocity]	Pressure Static Overall Minimum > 15 psia [Min Pressure]	⤴
1	10.539	25.91	
2	8.510	26.15	
3	8.510	26.14	
4	8.510	85.15	
5	8.510	25.93	
6	8.510	85.36	
7	8.510	85.15	
8	10.539	83.31	
9	11.347	83.15	
10	8.137	83.55	⤵

<span>⤴</span> All Junctions <span>Pump Design Requirements</span> <span>CV Design Re</span> <span>⤵</span>		
Jct	NPSH Margin Minimum > 10 feet [NPSH Margin]	
4	10.66	
5	10.17	

**Figure 3.20 Pump and Pipe Design Requirements for the Initial Cost sizing scenario**

Output

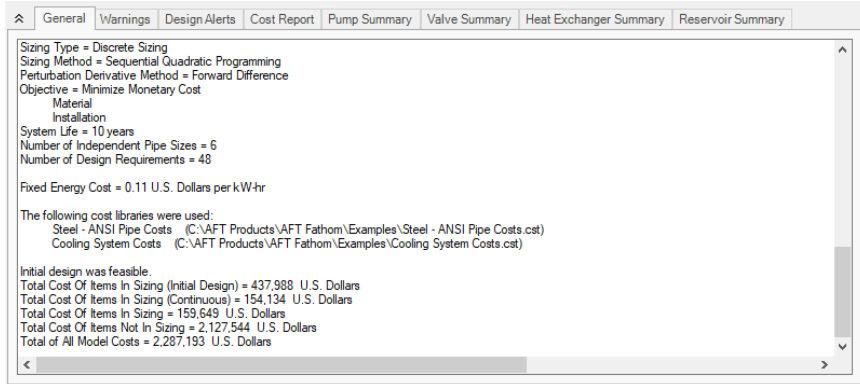
General Warnings Design Alerts Cost Report Pump Summary Valve Summary Heat E

Jct	Results Diagram	Name	Vol. Flow (gal/min)	Mass Flow (lbm/sec)	dP (psid)	dH (feet)	Overall Efficiency (Percent)	Speed (Percent)	Overall Power (hp)
4	Show	Pump	3,000	416.7	59.05	136.4	70.00	N/A	147.6
5	Show	Pump	3,000	416.7	59.47	137.4	70.00	N/A	148.6

Pipes Sizing Pipe Design Requirements Library Sources

Pipe	Name	Sized - Material	Sized - Nominal Size	Sized - Type/Schedule	Sized - Hyd. Diameter (inches)
1	Pipe	Steel - ANSI	16 inch	STD (schedule 30)	15.25
2	Pipe	Steel - ANSI	12 inch	STD	12.00
3	Pipe	Steel - ANSI	12 inch	STD	12.00
4	Pipe	Steel - ANSI	12 inch	STD	12.00
5	Pipe	Steel - ANSI	12 inch	STD	12.00
6	Pipe	Steel - ANSI	12 inch	STD	12.00
7	Pipe	Steel - ANSI	12 inch	STD	12.00
8	Pipe	Steel - ANSI	16 inch	STD (schedule 30)	15.25
9	Pipe	Steel - ANSI	12 inch	STD	12.00
10	Pipe	Steel - ANSI	10 inch	STD (schedule 40)	10.02
11	Pipe	Steel - ANSI	10 inch	STD (schedule 40)	10.02
12	Pipe	Steel - ANSI	10 inch	STD (schedule 40)	10.02
13	Pipe	Steel - ANSI	10 inch	STD (schedule 40)	10.02
14	Pipe	Steel - ANSI	10 inch	STD (schedule 40)	10.02
15	Pipe	Steel - ANSI	10 inch	STD (schedule 40)	10.02
16	Pipe	Steel - ANSI	10 inch	STD (schedule 40)	10.02
17	Pipe	Steel - ANSI	10 inch	STD (schedule 40)	10.02
18	Pipe	Steel - ANSI	10 inch	STD (schedule 40)	10.02
19	Pipe	Steel - ANSI	10 inch	STD (schedule 40)	10.02
20	Pipe	Steel - ANSI	10 inch	STD (schedule 40)	10.02
21	Pipe	Steel - ANSI	12 inch	STD	12.00
22	Pipe	Steel - ANSI	16 inch	STD (schedule 30)	15.25

Figure 3.21 Pump and pipe sizes after initial cost sizing is performed



**Figure 3.22** General section of Output window showing initial status of Items in Sizing

## Step 6. Size the system for life cycle cost over 10 years

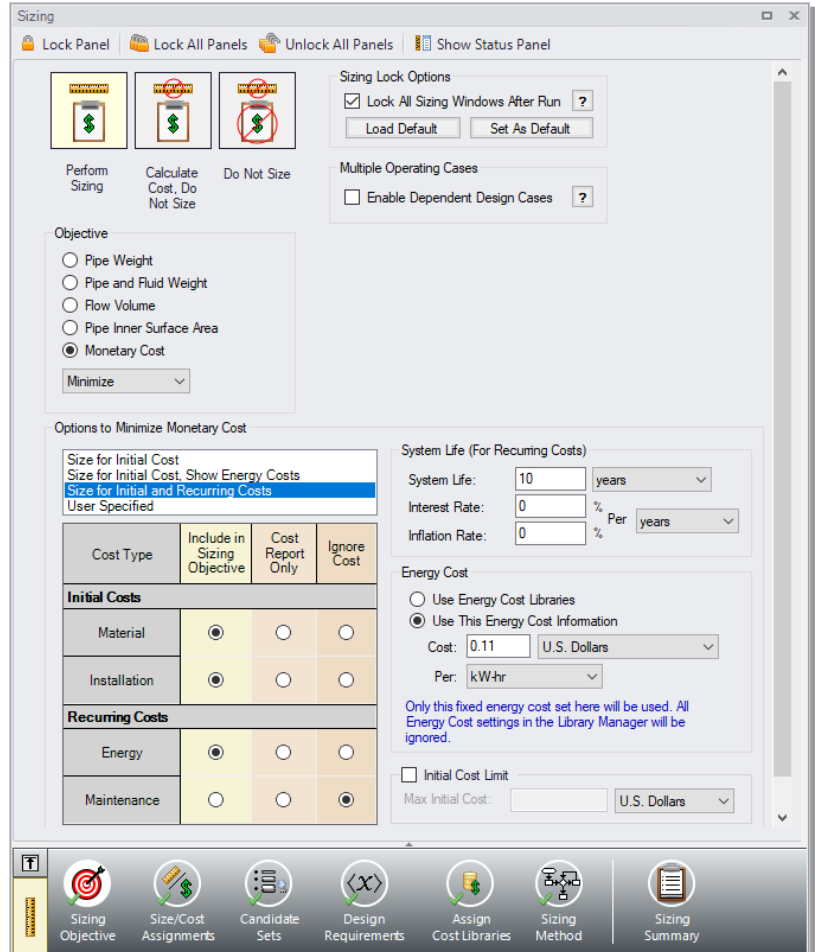
Now we want to size the system based on life cycle costs, rather than just minimizing the initial costs of the system. As previously discussed, the energy costs can often be weighted much more heavily than the initial cost of the system components. This means that sizing based on recurring costs will often result in larger pipes with higher material/installation costs being chosen so that smaller pumps with lower energy costs can be used.

From the Scenario Manager in the Quick Access Panel, we will create two child scenarios from the Base Scenario. Name the new scenario Initial Cost. This scenario will store the initial cost sizing results we just obtained. Repeat this process to create a second child scenario and name it Life Cycle Cost. The Life Cycle Cost scenario should now be active, as indicated by the green check mark symbol. For this scenario the only change that will need to be made is to update the Sizing Objective.

- **Go to the Sizing window**, and make sure that the Sizing Objective panel is selected. Under Options to Minimize Monetary Cost, choose Size for Initial and Recurring Costs. This will move the Energy costs selection to Include in Sizing Objective as shown in Figure 3.23. The scenario is now complete.

- **Click Run Model from the Common Toolbar** to run the automated sizing. When the calculations have finished, click Output to view the results. The new Cost Report can be seen in Figure 3.24.

After viewing the Cost Report, it can be seen that the overall cost is now \$2,216,402. The Items Not in Sizing line now has a value of zero, and the Operation/Energy column is highlighted green, reflecting the changes made to include these costs in the Objective.



**Figure 3.23 Sizing Objective defined for life cycle cost sizing – Energy cost in table was moved from the Cost Report Only column to the left column Include in Sizing Objective**



Output										
<span>General</span>   <span>Warnings</span>   <span>Design Alerts</span>   <span>Cost Report</span>   <span>Pump Summary</span>   <span>Valve Summary</span>   <span>Heat Exchanger Summary</span>   <span>Reservoir Summary</span>										
Table Units: U.S. Dollars	Type	Name	Material	Installation	Non-Recurring Sub Total	Maintenance	Operation/Energy	Recurring Sub Total	TOTAL	
<b>TOTAL OF ALL MODEL COSTS</b>										<b>2,216,402</b>
<b>Total of All Shown Costs</b>			133,229	62,957	196,186	0	2,020,216	2,020,216	2,216,402	
<b>Items In Sizing</b>			133,229	62,957	196,186	0	2,020,216	2,020,216	2,216,402	
<b>Items Not In Sizing</b>			0	0	0	0	0	0	0	
<b>Pipe Subtotal</b>			<b>87,926</b>	<b>45,862</b>	<b>133,788</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>133,788</b>	
o P1	Pipe	Pipe	3,695	1,861	5,556	0	0	0	5,556	
o P2	Pipe	Pipe	458	254	712	0	0	0	712	
o P3	Pipe	Pipe	764	423	1,187	0	0	0	1,187	
o P4	Pipe	Pipe	764	423	1,187	0	0	0	1,187	
o P5	Pipe	Pipe	764	423	1,187	0	0	0	1,187	
o P6	Pipe	Pipe	764	423	1,187	0	0	0	1,187	
o P7	Pipe	Pipe	458	254	712	0	0	0	712	
o P8	Pipe	Pipe	36,948	18,612	55,560	0	0	0	55,560	
o P9	Pipe	Pipe	458	254	712	0	0	0	712	
o P10	Pipe	Pipe	458	254	712	0	0	0	712	
o P11	Pipe	Pipe	755	594	1,349	0	0	0	1,349	
o P12	Pipe	Pipe	378	297	675	0	0	0	675	
o P13	Pipe	Pipe	378	297	675	0	0	0	675	
o P14	Pipe	Pipe	755	594	1,349	0	0	0	1,349	
o P15	Pipe	Pipe	378	297	675	0	0	0	675	
o P16	Pipe	Pipe	378	297	675	0	0	0	675	
o P17	Pipe	Pipe	755	594	1,349	0	0	0	1,349	
o P18	Pipe	Pipe	378	297	675	0	0	0	675	
o P19	Pipe	Pipe	378	297	675	0	0	0	675	
o P20	Pipe	Pipe	458	254	712	0	0	0	712	
o P21	Pipe	Pipe	458	254	712	0	0	0	712	
o P22	Pipe	Pipe	36,948	18,612	55,560	0	0	0	55,560	
<b>Bend Subtotal</b>			<b>1,792</b>	<b>2,982</b>	<b>4,774</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>4,774</b>	
o J3	Bend	Bend	525	852	1,377	0	0	0	1,377	
o J6	Bend	Bend	525	852	1,377	0	0	0	1,377	
o J10	Bend	Bend	525	852	1,377	0	0	0	1,377	
o J19	Bend	Bend	217	426	643	0	0	0	643	
<b>Pump Subtotal</b>			<b>43,510</b>	<b>14,113</b>	<b>57,623</b>	<b>0</b>	<b>2,020,216</b>	<b>2,020,216</b>	<b>2,077,839</b>	
o J4	Pump	Pump	21,728	7,047	28,774	0	1,009,286	1,009,286	1,038,061	
o J5	Pump	Pump	21,783	7,067	28,849	0	1,010,930	1,010,930	1,039,779	

Figure 3.24 Cost Report for life cycle cost sizing scenario

Taken on its own, this new cost represents a savings of \$198,335 (8%) compared to the initial design prior to sizing. Compared to the Initial Cost scenario, which was sized to minimize initial cost only, this new scenario represents a savings of \$70,791. This represents a total 3% cost reduction. In the Initial Cost scenario, the non-recurring cost was \$159,649, while the overall cost was \$2,287,193. Now the non-recurring cost is \$196,186 while the overall cost is \$2,216,402. The initial cost thus increased by \$36,537 in order to reduce the operating cost from \$2,127,544 to \$2,020,216 (a reduction of \$107,328). The source of the

operating cost is the cost of power for the pumps. To reduce pump power usage, it makes sense to increase the pipe size and thus reduce frictional losses. The larger pipe sizes can be reviewed by looking at the Sizing tab in the Pipe Output section. From the Pump Summary tab it can be seen that the pump power usage decreased slightly from 148 hp to 141 hp at each of the pumps, which is approximately a 5% power requirement decrease at each pump.

## Step 7. Apply initial cost limit

While the energy cost savings from life cycle cost sizing are desirable, the budget for the project may not support the higher initial cost that is required. In that case, we can apply an initial cost limit to the life cycle cost sizing.

- **Create a new child scenario** from the Life Cycle Cost scenario and name it Initial Cost Limit. Load the scenario.
- **Return to the Sizing Objective panel** and select the option for Initial Cost Limit. We will set the limit as \$175,000, which is slightly more than the initial cost of the scenario that minimized initial cost at the expense of an increased life cycle cost. Run the model and go to the Output tab. The Cost Report can be seen in Figure 3.25.

A summary of the difference between each of the initial and life cycle cost sizing scenarios for a 10 year life cycle can be seen in Table 3.1. Notice that while the material and installation costs were limited, the total cost decreased by about \$181,000 over 10 years. These energy costs were achieved by increasing the Main pipes, Pipe P8, and several of the header pipes at the coolers while decreasing the pipe sizes at the coolers. Figure 3.26 shows a comparison of the pipe and pump sizes throughout the system for the initial design, the system sized for initial cost only, and the system sized for life cycle cost with an initial cost limit.

**Table 3.1 Cost summary of automated sizing runs for Cooling System**

Scenario	Material	Installation	Total non-recurring	Energy	Overall Total	Reduction
Not Sized	335,997	101,991	437,988	1,976,749	2,414,738	
Initial Cost	105,846	53,803	159,649	2,127,544	2,287,193	-127,545
Sized for life cycle cost	133,229	62,957	196,186	2,020,216	2,216,402	198,336
Sized for life cycle cost with initial cost limit	117,520	57,713	175,233	2,058,681	2,233,913	180,825

### Discussion on sizing with pump curve data

One can consider the previous discussion in this chapter as Phase 1 of the pump and pipe sizing process. Phase 2 involves using the Phase 1 results in order to select actual pumps which have pump curve data. The actual pump should closely match the sizing results in the generated head at the design flow, efficiency at the design flow, and cost. If it does not, then it may be advisable to repeat the Phase 1 sizing with updated information from actual pumps (e.g., monetary costs, nominal efficiency, nominal NPSHR, etc.). A complete Phase 2 analysis will run the automated sizing again for each actual pump considered. The pipe sizing may change slightly for each pump considered.

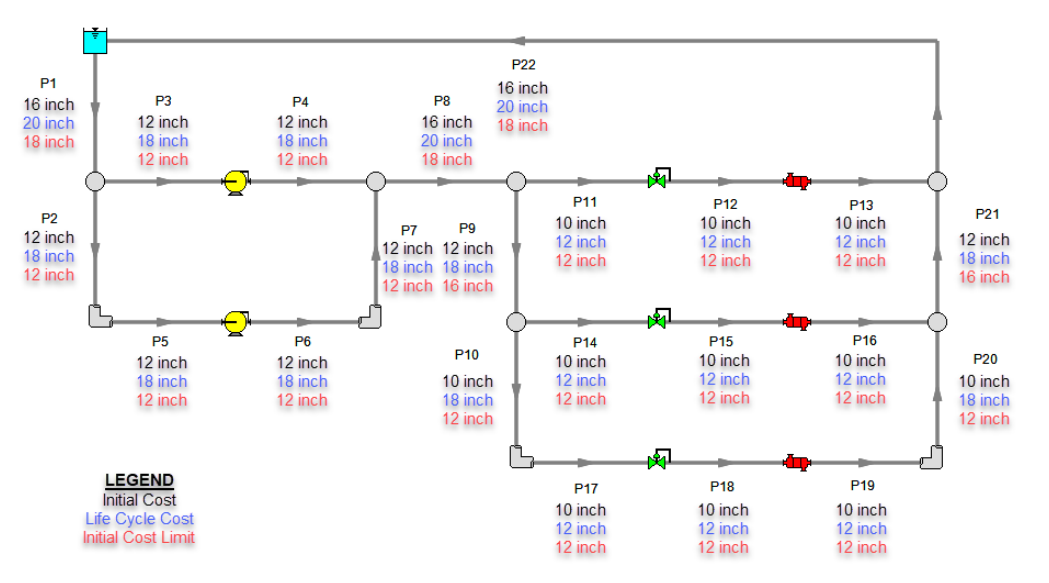
By reviewing the Pump Summary for the life cycle cost sizing with an initial cost limit, one can see that the ideal system calls for a pump of about 143 hp that generates about 132 feet of head at 3000 gal/min. The nominal efficiency used in the sizing part of the analysis was 70%. The material cost for such a pump was about \$22,400, and the installation cost was about \$7,300. Note that if no actual pumps can be found that reflect these requirements, then the Phase 1 process should be repeated with better performance and/or cost data for the pump.

Output										
<span>General</span>   <span>Warnings</span>   <span>Design Alerts</span>   <span>Cost Report</span>   <span>Pump Summary</span>   <span>Valve Summary</span>   <span>Heat Exchanger Summary</span>   <span>Reservoir Summary</span>										
Table Units: U.S. Dollars	Type	Name	Material	Installation	Non-Recurring Sub Total	Maintenance	Operation/Energy	Recurring Sub Total	TOTAL	
<b>TOTAL OF ALL MODEL COSTS</b>										<b>2,233,913</b>
<b>Total of All Shown Costs</b>			117,520	57,713	175,233	0	2,058,681	2,058,681	2,233,913	
<b>Items In Sizing</b>			117,520	57,713	175,233	0	2,058,681	2,058,681	2,233,913	
<b>Items Not In Sizing</b>			0	0	0	0	0	0	0	
<b>Pipe Subtotal</b>			<b>71,856</b>	<b>41,427</b>	<b>113,283</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>113,283</b>	
o	P1	Pipe	Pipe	3,056	1,691	4,746	0	0	0	4,746
o	P2	Pipe	Pipe	227	178	405	0	0	0	405
o	P3	Pipe	Pipe	378	297	675	0	0	0	675
o	P4	Pipe	Pipe	378	297	675	0	0	0	675
o	P5	Pipe	Pipe	378	297	675	0	0	0	675
o	P6	Pipe	Pipe	378	297	675	0	0	0	675
o	P7	Pipe	Pipe	227	178	405	0	0	0	405
o	P8	Pipe	Pipe	30,556	16,908	47,464	0	0	0	47,464
o	P9	Pipe	Pipe	371	228	599	0	0	0	599
o	P10	Pipe	Pipe	227	178	405	0	0	0	405
o	P11	Pipe	Pipe	755	594	1,349	0	0	0	1,349
o	P12	Pipe	Pipe	378	297	675	0	0	0	675
o	P13	Pipe	Pipe	378	297	675	0	0	0	675
o	P14	Pipe	Pipe	755	594	1,349	0	0	0	1,349
o	P15	Pipe	Pipe	378	297	675	0	0	0	675
o	P16	Pipe	Pipe	378	297	675	0	0	0	675
o	P17	Pipe	Pipe	755	594	1,349	0	0	0	1,349
o	P18	Pipe	Pipe	378	297	675	0	0	0	675
o	P19	Pipe	Pipe	378	297	675	0	0	0	675
o	P20	Pipe	Pipe	227	178	405	0	0	0	405
o	P21	Pipe	Pipe	371	228	599	0	0	0	599
o	P22	Pipe	Pipe	30,556	16,908	47,464	0	0	0	47,464
<b>Bend Subtotal</b>			<b>868</b>	<b>1,704</b>	<b>2,572</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>2,572</b>	
o	J3	Bend	Bend	217	426	643	0	0	0	643
o	J6	Bend	Bend	217	426	643	0	0	0	643
o	J10	Bend	Bend	217	426	643	0	0	0	643
o	J19	Bend	Bend	217	426	643	0	0	0	643
<b>Pump Subtotal</b>			<b>44,796</b>	<b>14,582</b>	<b>59,377</b>	<b>0</b>	<b>2,058,681</b>	<b>2,058,681</b>	<b>2,118,058</b>	
o	J4	Pump	Pump	22,271	7,245	29,516	0	1,025,552	1,025,552	1,055,068
o	J5	Pump	Pump	22,524	7,337	29,861	0	1,033,128	1,033,128	1,062,989

Figure 3.25 Cost Report for life cycle cost automated sizing scenario with initial cost limit

## Conclusions

Using cost libraries in the automated sizing process involves increased complexity from simple non-monetary automated sizing as discussed in Chapter 2. However, it allows more powerful automated sizing options including the ability to size costs over a system life cycle.



**Figure 3.26** Pipe sizes selected by the ANS module for initial cost sizing, life cycle cost sizing, and life cycle cost sizing with initial cost limit

# Multiple Design Case Example

This example will size the pipes for a gravity-fed water supply system to a housing development. The objective will be to minimize monetary cost while considering several design cases simultaneously, where fire hydrants may be opened or closed.

## Topics covered

- How Dependent Design Cases (DDCs) are used to satisfy two different operating modes for a system
- Understanding Common Size Groups and their effect on how well the ANS module can size a system

## Required knowledge

This example assumes that the user has some familiarity with AFT Fathom and the ANS module such as placing junctions, connecting pipes, entering pipe and junction properties, and creating and using Candidate Sets and Design Requirements. Refer to the Weight Sizing Example in Chapter 2 for more information on these topics.

### Model files

A partially completed model file will be utilized as the starting point for this example. A completed version of the model file can be referenced if desired. Both the initial and final model files can be found in the Examples folder as part of the AFT Fathom installation:

C:\AFT Products\AFT Fathom 13\Examples

- *US - Housing Project.fth* - initial model file
- *US - Housing Project - ANS.fth* - completed model file (3 Pipe Sizes scenario)
- *Housing Project Costs.cst* - cost library for PVC - ASTM pipes

### Problem statement

This example uses an existing model to investigate a single system with several operating cases. The cases are as follows:

1. Normal flow to houses and North Hydrant closed. Supply to each house must be at least 10 gal/min with a minimum static pressure of 60 psig.
2. North Hydrant open with at least 100 gal/min and at least 90 psig minimum static pressure. During fires the supply to each house must be at least 2 gal/min with no minimum pressure requirement.
3. South Hydrant open with at least 100 gal/min and at least 90 psig minimum static pressure. During fires the supply to each house must be at least 2 gal/min with no minimum pressure requirement.

For this example, we will evaluate all operating cases assuming the pipes can be at most three different sizes.

## **Step 1. Open model file**

For this example we will be starting from a pre-built model file that is fully defined for a normal AFT Fathom run. We will add automated sizing settings to find a more cost effective design. From either the Startup Window or the File menu, browse to the model file *US - Housing Project.fth* at the location listed above. We will not need the existing child scenarios for this example; right-click on the Base Scenario in the Scenario Manager and select Delete All Children. Then, save the file to a new location under a new filename. The newly saved file should be opened automatically.

This example consists of a reservoir (i.e., West Lake) at an elevation of 235 feet that supplies water to 10 houses and one fire hydrant. All of the pipes in the system are Schedule 40 PVC pipe. The supply line to each house is set to 1 inch PVC. The automated sizing of this system will be used to size the supply line from the reservoir, the neighborhood mains, and the hydrant lines. The model should appear as shown in Figure 4.1.



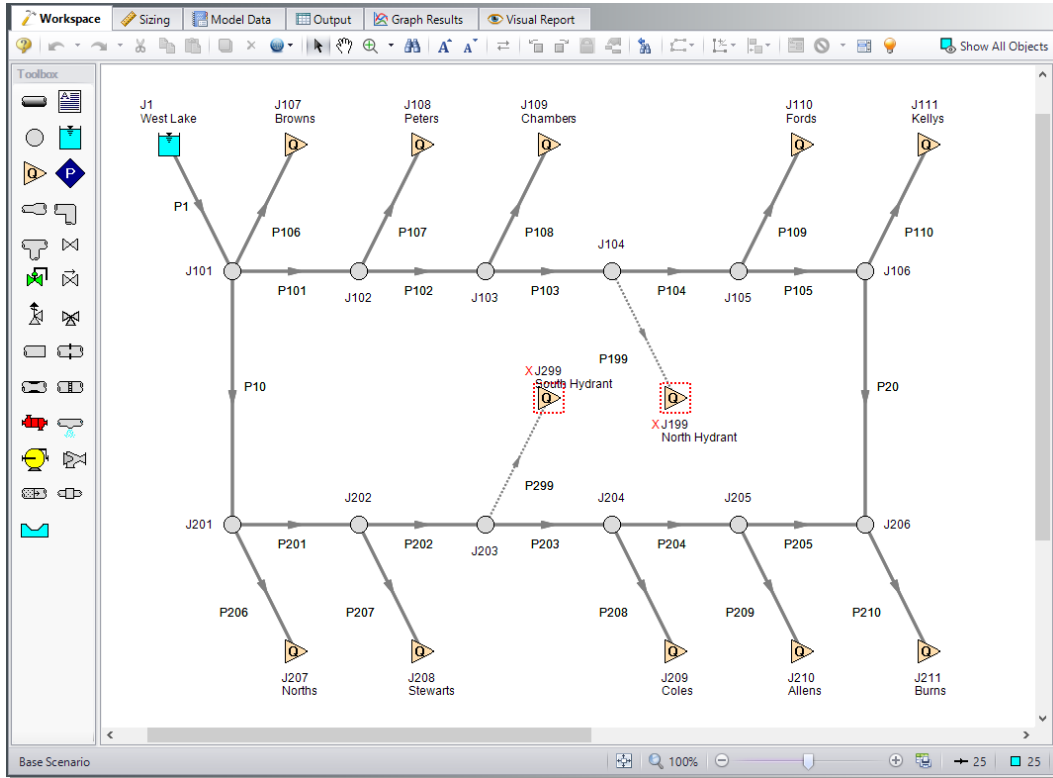


Figure 4.1 The Base Scenario for the Housing Project example

## Step 2. Define the Modules Group

Navigate to the Modules Panel in Analysis Setup. Check the box next to Activate ANS. The Network option should automatically be selected, making ANS enabled for use.

## Step 3. Review model settings

### A. Sizing Objective

Go to the Sizing window by selecting the tab. The Sizing Objective panel should be selected by default from the buttons along the bottom.

For this analysis, we are interested in sizing the system considering the monetary cost for the initial costs only.

1. Set the calculation to Perform Sizing.
2. For the Objective, choose Monetary Cost, and select the Minimize option from the drop-down list.
3. Under Options to Minimize Monetary Cost, choose Size for Initial Cost, which will automatically configure the table to include all non-recurring costs in the sizing while ignoring the recurring costs.

### B. Size/Cost Assignments

On the Sizing Navigation Panel select the Size/Cost Assignments button.

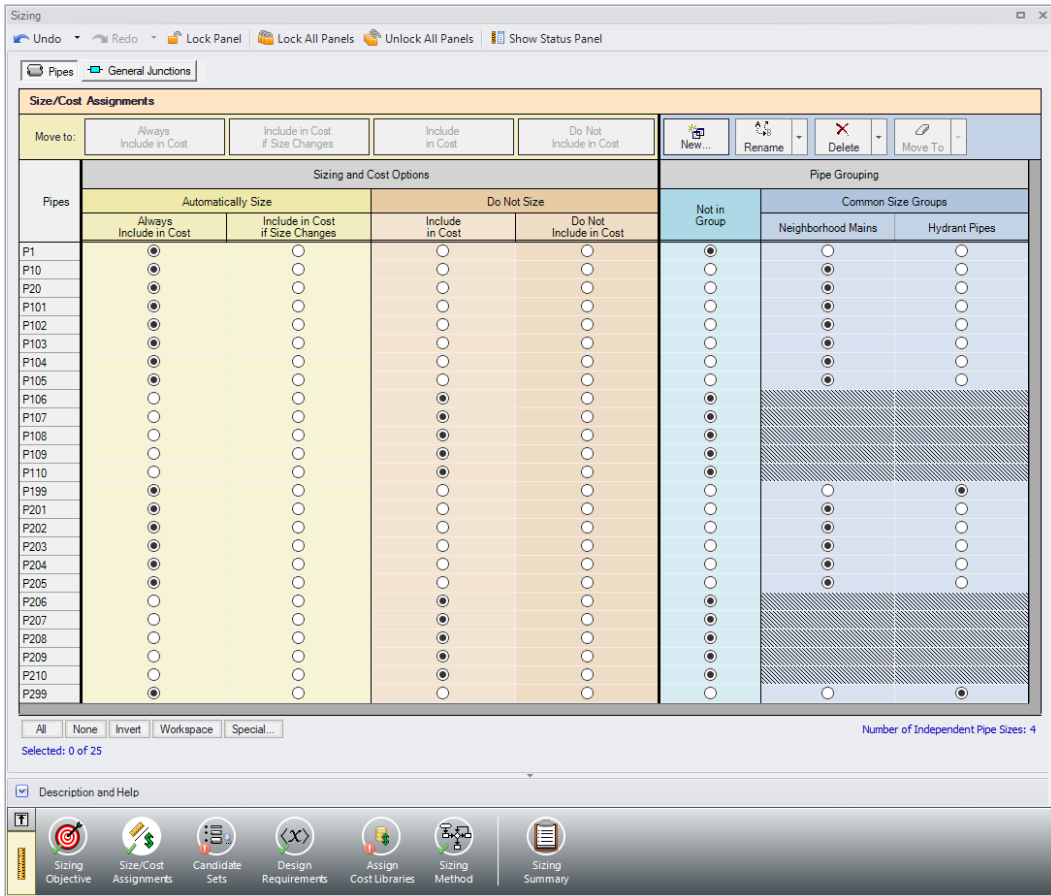
For the supply lines to each house (Pipes P106-P110 and P206-P210), the pipe size is fixed to 1 inch and will not be sized. Move each of the house supply lines to Do Not Size - Include in Cost. All of the pipes can be moved at once by using the SHIFT key to highlight all of the rows, then clicking the Include in Cost button.

We want to find the three pipe sizes that will serve for the supply from the reservoir (Pipe P1), the neighborhood mains (Pipes P10, P20, P101-P105, and P201-P205), and the hydrant supply pipes (Pipes P199 and P299). To do this, we have to establish one Common Size Group for the neighborhood mains, one Common Size Group for the hydrant lines, and leave reservoir supply Pipe P1 to be sized separately.

In the Size/Cost Assignments panel select the rows for all pipes other than the house supply lines that were already set to Do Not Size - Include in Cost (multiple rows can be selected using the SHIFT or CTRL keys). We will first need to set the pipes to be included in the sizing calculation.

- **Move the selected pipes** to Automatically Size - Always Include in Cost by clicking the Always Include in Cost button above the Sizing and Cost Options table. Now we will need to create a Common Size Group for the neighborhood mains.
- **Click New above the Pipe Grouping table** and name the group Neighborhood Mains. Select Pipes P10, P20, P101-P105, and P201-P205 and use the Move To button above the Pipe Grouping table to add them to the Common Size Group.

- Click **New** above the **Pipe Grouping** table and name the group Hydrant Pipes. Select pipes P199 and P299 and add them to the Hydrant Pipes Common Size Group. The Size/Cost Assignments panel should now appear as shown in Figure 4.2.



**Figure 4.2** Size/Cost Assignments panel for the primary design case

### C. Candidate Sets

Click on the Candidate Sets button to display the Candidate Sets panel.

In this case we will be considering schedule 40 PVC pipe within the range of 1 to 10 inch.

1. Select New and name it PVC sch 40.
2. Choose PVC - ASTM from the material list.
3. Expand the schedule 40 type, then double click each of the sizes from 1 inch to 10 inch to add them to the Candidate Set.
4. Click OK to accept the defined set.

In the bottom section of the window make sure that both Common Size Groups and Pipe P1 are assigned to use the new PVC sch 40 Candidate Set as shown in Figure 4.3.

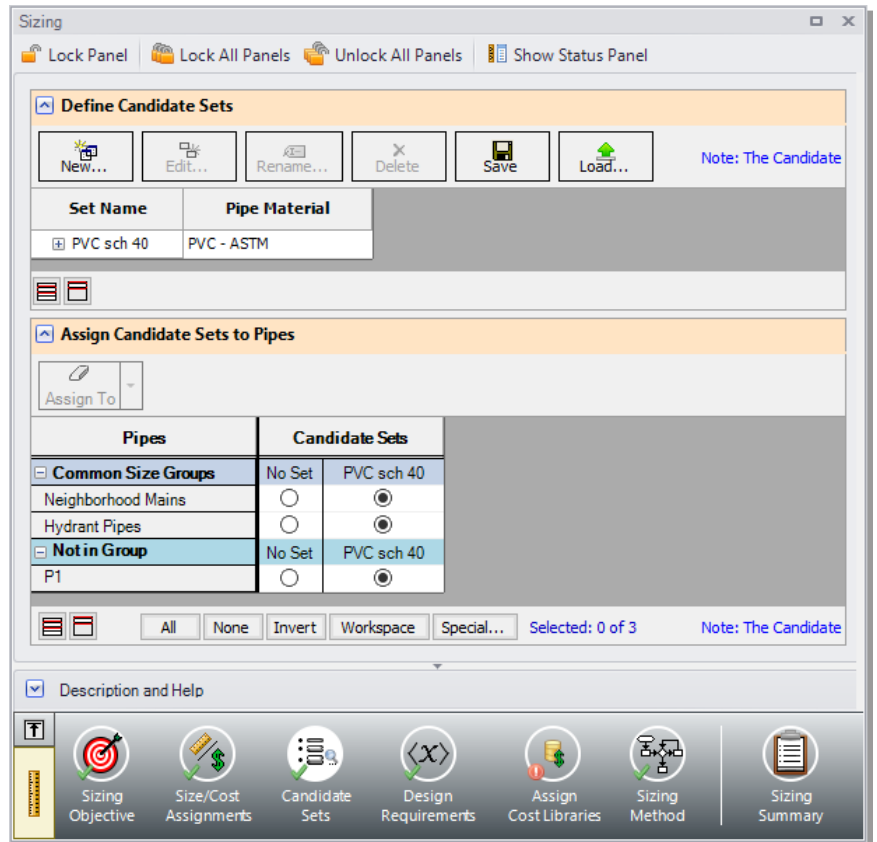


Figure 4.3 Candidate Sets panel for the primary design case

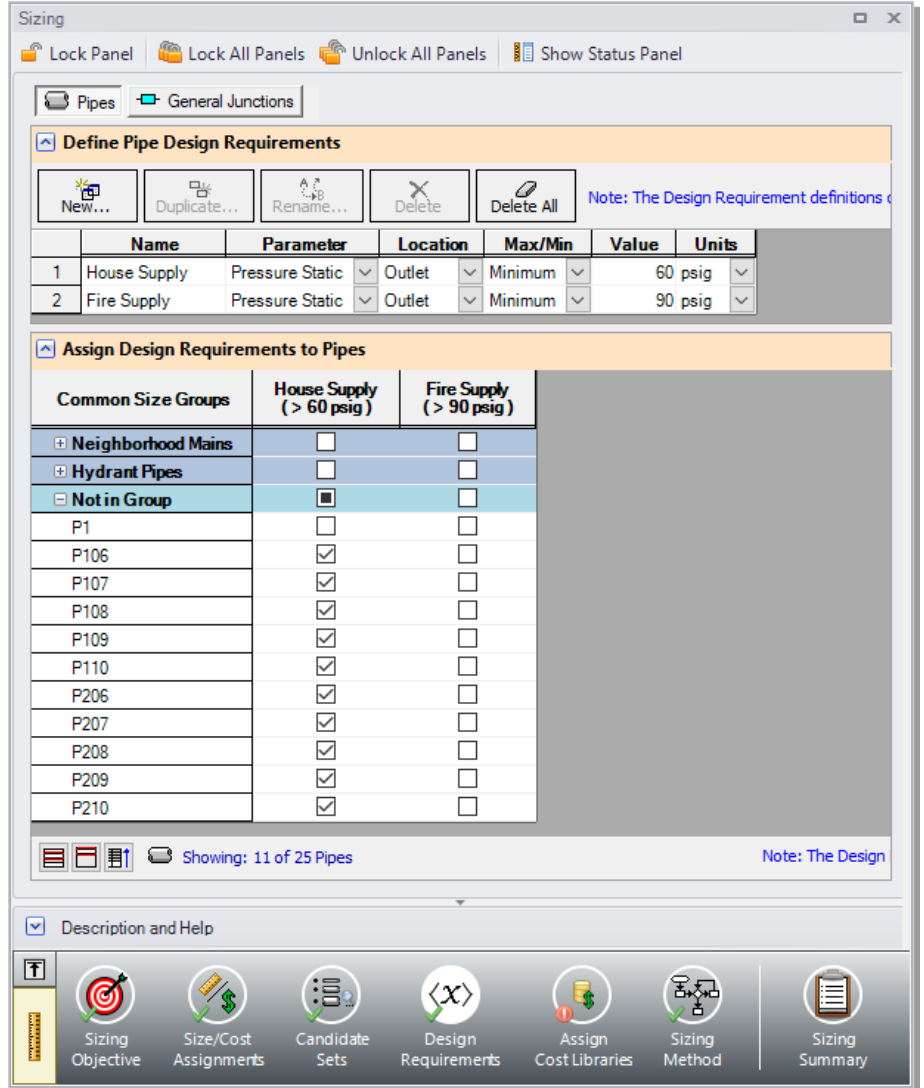
## D. Design Requirements

Select the Design Requirements button.

For the primary design case the only design requirement is for the minimum supply pressure of 60 psig to each of the houses. With the Pipes button selected click new to add a House Supply Design Requirement specifying the static pressure at the outlet of the pipe to a minimum value of 60 psig.

In the bottom section of the window, make sure that the 60 psig design requirement is applied to each of the supply lines to the houses, as shown in Figure 4.4.

Create a second Design Requirement named “Fire Supply” specifying the static pressure at the outlet of the pipe to a minimum value of 90 psig. We will apply this requirement later when the dependent design case is created.



**Figure 4.4** House Supply pressure Design Requirement defined for the primary case

## E. Assign Cost Libraries

Select the Assign Cost Libraries button. The actual material and installation costs are contained in cost libraries.

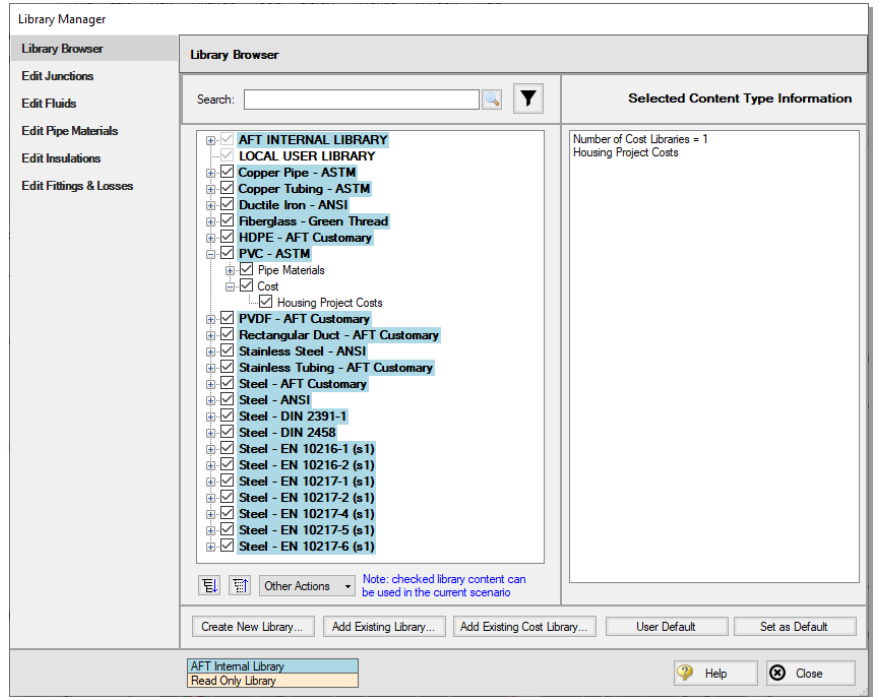
- **Open the Library Manager** by clicking the Library Manager button to see which libraries are connected.

This example uses a pre-built cost library for the pipes containing the PVC material costs. To connect the library do the following:

1. Click the button to Add Existing Cost Library.
2. Browse to the Fathom 13 Examples folder (located by default in C:\AFT Products\AFT Fathom 13\Examples\), and open the file titled *Housing Project Costs.cst*.

The new library should now be visible in the Library Browser and be automatically connected to the model, as shown in Figure 4.5. Once you have confirmed that the library is connected, click Close to exit the Library Manager.

Back in the Assign Cost Libraries panel for the Pipes the Housing Project Costs library should be the only available cost library, and should be selected to show that it is being applied to the PVC sch 40 Candidate Set.



**Figure 4.5** Library Manager showing the PVC schedule 40 cost library connected and available in the model

## F. Sizing Method

Select the Sizing Method button to go to the Sizing Method panel.

Ensure that Discrete Sizing is selected with the Modified Method of Feasible Directions (MMFD) chosen for the Search Method.

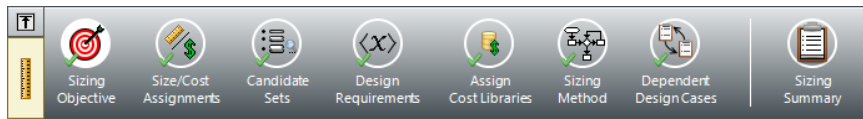


## G. Dependent Design Cases

Now that we have defined the primary design case model shown in Figure 4.1, we will create two *dependent design cases* to account for situations in which either the north or south hydrant are in use. A dependent design case (or DDC) in the ANS module is a system that models the same physical pipes and junctions as the primary design but with different operating requirements. The first dependent design case for this model is for when the North Hydrant is opened and the second dependent design case is for when the South Hydrant is in use. When either hydrant is opened, the flow out of the hydrant is 100 gal/min and the homes are allowed to drop to 2 gal/min each. The water pressure supplied to the houses is no longer a concern in such an emergency, so the House Supply pressure design requirement will not be applied to the dependent design cases.

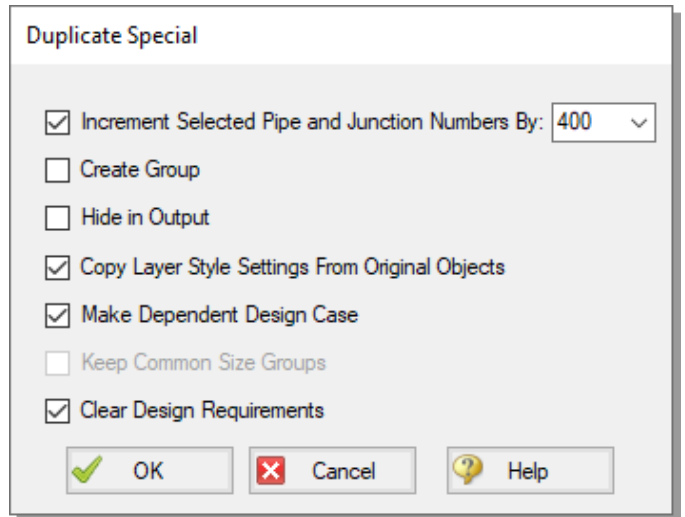
Here are the steps to create this Dependent Design Case:

1. Go to the Sizing Objective panel and select the Enable Dependent Design Cases option. A new button will now be available for the Dependent Design Cases panel in the Sizing Navigation Panel as shown in Figure 4.6.



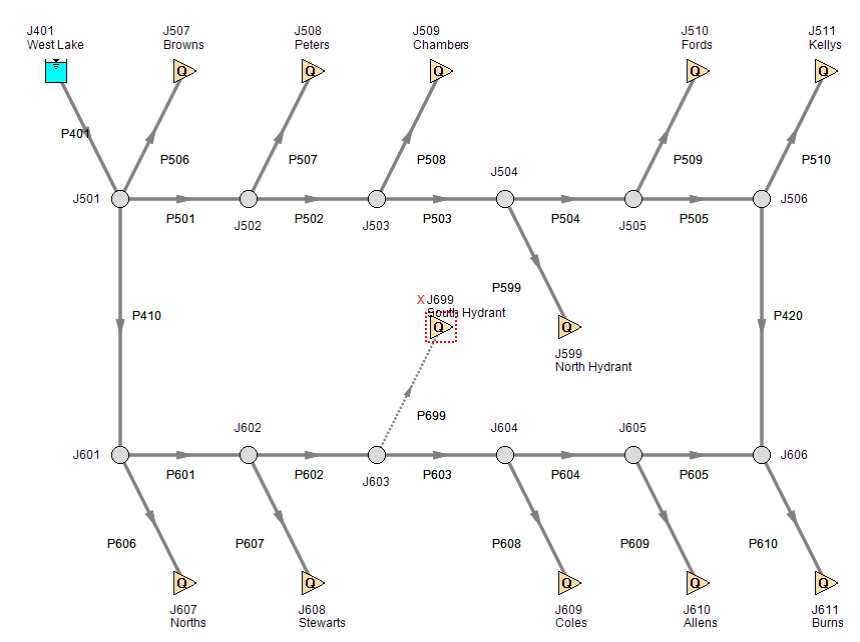
**Figure 4.6 Sizing Navigation Panel with Dependent Design Cases enabled**

2. Select the Dependent Design Cases button. You should now see instructions displayed to create the Dependent Design Case, along with a summary table of dependent design settings. We will need to use the Duplicate Special tool to create the dependent design case.
3. Go to the Workspace and choose Select All from the Edit menu.
4. Open Duplicate Special from the Edit menu, enter an increment of 400 and select Copy Layer Style Settings From Original Objects, Make Dependent Design Case, and Clear Design Requirements (Figure 4.7). Click OK.



**Figure 4.7 Duplicate Special is the easiest way to create a dependent design case**

5. Move the duplicated pipes and junctions below the original ones on the Workspacce to distinguish them from the Primary Design Case (Figure 4.8).



**Figure 4.8 North Hydrant Dependent Design Case**

6. Select only the primary design case model and repeat steps 4 and 5 to create a second dependent design case, incrementing the pipe numbers by 1000 to avoid conflicting pipe numbers (Figure 4.9). Place these below the North Hydrant submodel. There should now be two copies of the original model in the Workspace which will be used to represent the alternate operating cases.
7. Open the hydrants to flow in the Dependent Design Case (DDC) by selecting J599 and J1299 in the Workspace and toggling the Special Condition setting on the toolbar to None (or using the F4 keyboard shortcut).
8. Use Global Junction Edit (from the Edit menu) to change all of the assigned flow junctions at the DDC homes (junctions J507-511, J607-J611, J1107-J1111, and J1207-J1211) from 10 gal/min to 2 gal/min (Figure 4.10).
9. In the Sizing window navigate to the Design Requirements panel. Expand the Hydrant Pipes group and assign the Fire Supply Design

Requirement created earlier to Pipes P599 and P1299 by checking the adjacent boxes.

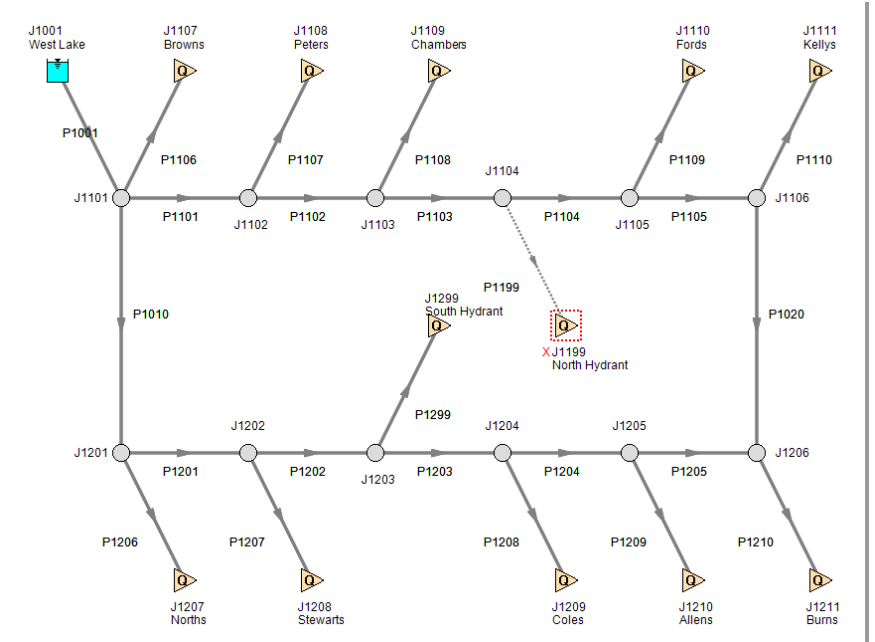
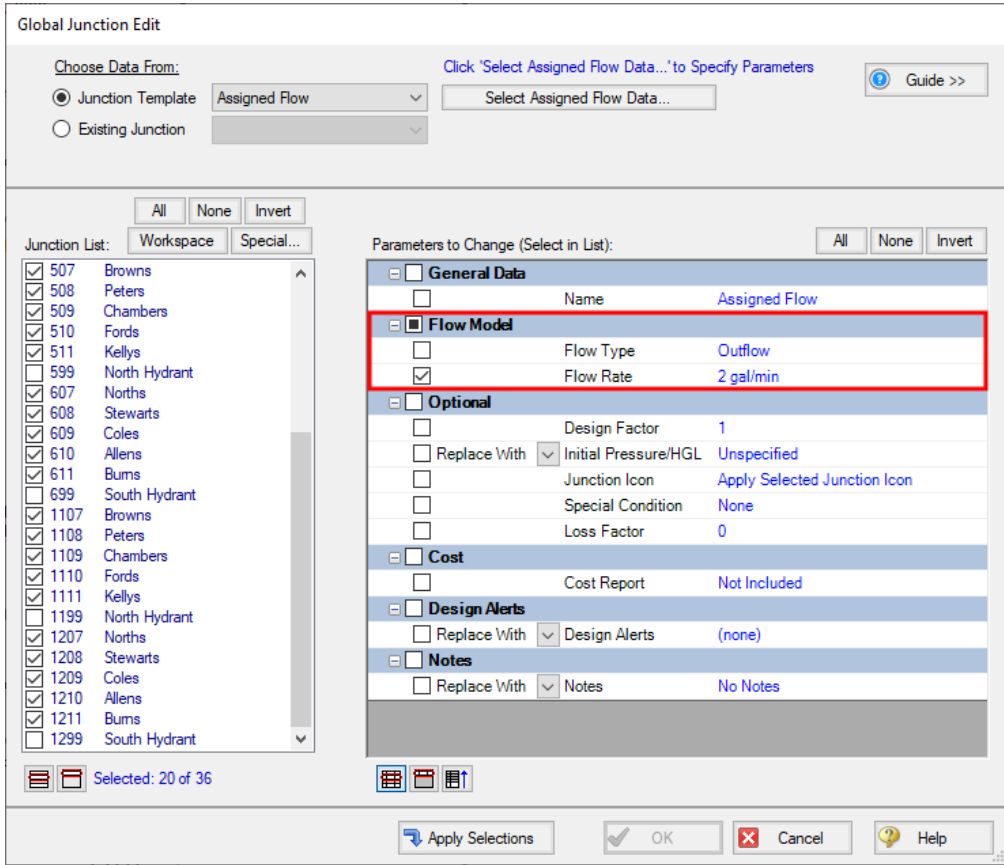


Figure 4.9 South Hydrant Dependent Design Case



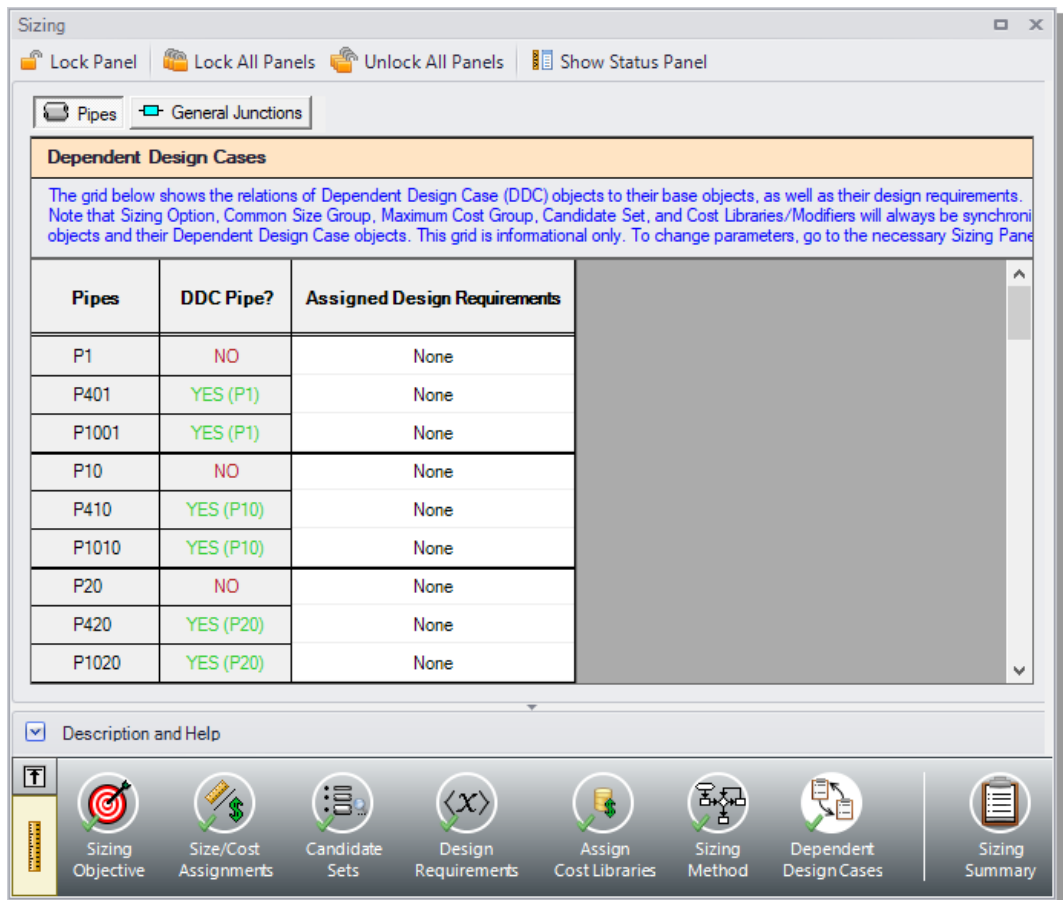
**Figure 4.10** Global Junction Edit is used to change the flows to 2 gal/min in the homes for the fire flow DDC

Return to the Dependent Design Cases panel.

When Duplicate Special was performed with the Dependent Design Case option selected, each of the duplicated pipes was created with a special type of grouping. For example, Pipes P401 and P1001 are grouped with Pipe P1 as a DDC pipe (see Figure 4.11). This type of assignment allows the dependent design pipes to be sized, but to not be counted in the cost so that the cost will not be duplicated.

It should also be noted that the dependent design grouping causes each of the dependent pipes to inherit their Common Size Groups, Candidate Sets, and Cost Library settings from the pipes in the primary case. The

DDC pipes are therefore hidden on all sizing panels except for the Design Requirements and Dependent Design Cases panels.



**Figure 4.11** Pipes in Dependent Design Cases have a special grouping relationship with pipes in the primary case

## Step 4. Run the automated sizing

Select Run from the Analysis menu to perform the automated sizing.

After the run finishes, examine the final pipe sizes calculated by the ANS module. One can see that the resultant size is 3-1/2 inch PVC for the neighborhood mains, 2-1/2 inch PVC for the hydrant pipes, and larger 4 inch PVC pipe for the reservoir line, as shown in Figure 4.12.

The fixed 1-inch house supply lines were not sized are not shown in this table, as they were set to be excluded using Output Control.

Pipe	Name	Sized - Material	Sized - Nominal Size	Sized - Type/Schedule	Sized - Hyd. Diameter (inches)
1	Pipe	PVC - ASTM	4 inch	schedule 40	4.026
10	Pipe	PVC - ASTM	3-1/2 inch	schedule 40	3.548
20	Pipe	PVC - ASTM	3-1/2 inch	schedule 40	3.548
101	Pipe	PVC - ASTM	3-1/2 inch	schedule 40	3.548
102	Pipe	PVC - ASTM	3-1/2 inch	schedule 40	3.548
103	Pipe	PVC - ASTM	3-1/2 inch	schedule 40	3.548
104	Pipe	PVC - ASTM	3-1/2 inch	schedule 40	3.548
105	Pipe	PVC - ASTM	3-1/2 inch	schedule 40	3.548
199	Pipe	PVC - ASTM	2-1/2 inch	schedule 40	2.469
201	Pipe	PVC - ASTM	3-1/2 inch	schedule 40	3.548
202	Pipe	PVC - ASTM	3-1/2 inch	schedule 40	3.548
203	Pipe	PVC - ASTM	3-1/2 inch	schedule 40	3.548
204	Pipe	PVC - ASTM	3-1/2 inch	schedule 40	3.548
205	Pipe	PVC - ASTM	3-1/2 inch	schedule 40	3.548

**Figure 4.12 Results for sized pipes for the case with three Independent Pipe Sizes**

### Step 5. Review the results

The automated sizing we just ran had three operating cases. One was for normal water supply, and the other two were for situations in which a hydrant is supplying water for fire fighting. The normal flow case is modeled by the network shown in Figure 4.1. The submodel shown in Figure 4.8 is the North Hydrant case and the submodel shown in Figure 4.9 models the South Hydrant fire flow case.

The cost for all pipes is \$69,212 (see Cost Report in Figure 4.13), with the sized pipes comprising \$61,924 of the total. The sized pipes have their material and installation cost highlighted in green, which can be toggled in Output Control.

The pipes and junctions in the fire flow cases are separate entities for modeling purposes, but represent the same pipes and junctions as the normal flow case. Thus when performing automated sizing, we only count the cost of the pipes and junctions once. This occurs in the primary design case, which in our model is the normal flow case. This is why Pipes P401-P1299 are not shown in the Cost Report.

<span>General</span> <span>Warnings</span> <span>Design Alerts</span> <span>Cost Report</span> <span>Reservoir Summary</span>										
Table Units: U.S. Dollars	Type	Name	Material	Installation	Non-Recurring Sub Total	Maintenance	Operation/Energy	Recurring Sub Total	TOTAL	
<b>TOTAL OF ALL MODEL COSTS</b>										<b>69,212</b>
<b>Total of All Shown Costs</b>			<b>23,186</b>	<b>46,026</b>	<b>69,212</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>69,212</b>
<b>Items In Sizing</b>			<b>21,279</b>	<b>40,645</b>	<b>61,924</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>61,924</b>
<b>Items Not In Sizing</b>			<b>1,907</b>	<b>5,381</b>	<b>7,288</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>7,288</b>
<b>Pipe Subtotal</b>			<b>23,186</b>	<b>46,026</b>	<b>69,212</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>69,212</b>
o	P1	Pipe Pipe	9,900	18,000	27,900	0	0	0	0	27,900
o	P10	Pipe Pipe	1,305	2,595	3,900	0	0	0	0	3,900
o	P20	Pipe Pipe	1,305	2,595	3,900	0	0	0	0	3,900
o	P101	Pipe Pipe	870	1,730	2,600	0	0	0	0	2,600
o	P102	Pipe Pipe	870	1,730	2,600	0	0	0	0	2,600
o	P103	Pipe Pipe	870	1,730	2,600	0	0	0	0	2,600
o	P104	Pipe Pipe	870	1,730	2,600	0	0	0	0	2,600
o	P105	Pipe Pipe	870	1,730	2,600	0	0	0	0	2,600
	P106	Pipe Pipe	186	525	711	0	0	0	0	711
	P107	Pipe Pipe	140	394	533	0	0	0	0	533
	P108	Pipe Pipe	233	656	889	0	0	0	0	889
	P109	Pipe Pipe	140	394	533	0	0	0	0	533
	P110	Pipe Pipe	186	525	711	0	0	0	0	711
o	P199	Pipe Pipe	35	78	112	0	0	0	0	112
o	P201	Pipe Pipe	870	1,730	2,600	0	0	0	0	2,600
o	P202	Pipe Pipe	870	1,730	2,600	0	0	0	0	2,600
o	P203	Pipe Pipe	870	1,730	2,600	0	0	0	0	2,600
o	P204	Pipe Pipe	870	1,730	2,600	0	0	0	0	2,600
o	P205	Pipe Pipe	870	1,730	2,600	0	0	0	0	2,600
	P206	Pipe Pipe	279	788	1,067	0	0	0	0	1,067
	P207	Pipe Pipe	233	656	889	0	0	0	0	889
	P208	Pipe Pipe	186	525	711	0	0	0	0	711
	P209	Pipe Pipe	140	394	533	0	0	0	0	533
	P210	Pipe Pipe	186	525	711	0	0	0	0	711
o	P299	Pipe Pipe	35	78	112	0	0	0	0	112

Figure 4.13 Cost Report is shown in Output window

By applying different pressure and flow requirements between the normal and fire flow cases, we performed an automated sizing that selected the best pipe size which simultaneously met the requirements of both cases.



Finally, since the previous case only selected three pipe sizes to be used for all sized pipes, there were only three design variables. By creating more Common Size Groups, a better solution is possible.

### Other possibilities

To obtain the best possible design for the system, one can allow each pipe to be sized independently by removing all pipes from the common size group.

This final automated sizing takes much longer to run (a few minutes vs. a few seconds previously). Since all the pipes are sized independently, the practical result is that ordering and installing the pipe is more complicated because there are so many more sizes involved.

Alternatively, this sizing could be performed by using weight as the objective instead of monetary cost to simplify the setup. Using a non-monetary objective can produce less accurate sizing results in cases where the energy costs or costs of equipment such as pumps need to be accounted for. However, since this is a gravity-fed system only the pipe sizes need to be considered for the sizing calculations.

# Other AFT Fathom ANS Module Capabilities

This Quick Start Guide necessarily omitted coverage of a number of ANS module capabilities. This chapter briefly describes some of the important capabilities not covered.

## **Size with operating costs spread over multiple cases**

For systems with multiple design cases, the system may operate a significant portion of the time in each design case mode. The ANS module allows one to assign a percentage of the operating cost to each relevant design.

For example, assume you are designing a two-pump cooling system which uses both pumps in the summer but only one in the winter (because of reduced demand for cooling water). The winter operating cost is thus much less than in the summer. You can account for this by assigning the percentage of the time the pump operates in each design case. This allows a proper accounting of annual operating costs and a proper life cycle automated sizing to be performed.

### Vary recurring costs over time

The use of Scale Tables in AFT Fathom allows you to input recurring data for pipes or junctions that vary over time. For instance, perhaps the maintenance cost of a piece of equipment is low at first but requires increased maintenance over some time period. The cost for maintenance can be varied over time to match the anticipated maintenance schedule.

### Time value of money (present vs. future value)

An important consideration in evaluating recurring cost items is the cost of money for future expenses. The ANS module allows you to enter an interest rate and inflation rate to account for actual value of future expenses based on today's currency value. This data is entered in the Sizing Objective panel of the Sizing window.

### Determine cost effectiveness of replacing existing piping

The ANS module can determine the cost effectiveness of leaving existing piping in place or replacing it with new piping. This can be defined on the Size/Cost Assignments panel.

### Working with different currencies

Cost data can be entered in any currency you wish. Different currencies can be defined from the Tools menu > User Options > Unit System > Show/Hide Unit Names > Monetary unit family > Custom Units dropdown > New, and then used as a basis for cost libraries.

### Costs vs. size

Scale Tables can be used to model how equipment costs vary with pipe diameter. For instance, a 4-inch valve will cost more than a similar 2-inch valve. This can be accounted for in the cost library with Scale Tables.

Generic pump costs can be modeled as a function of power, and generic control valve costs can be modeled as a function of maximum Cv.

## **Sizing rectangular duct systems**

The ANS module can size systems with only rectangular ducts or a combination of rectangular and cylindrical ducts. Rectangular ducts have two space dimensions, and thus two design variables are required for each independent duct size.

## **Compare VFD vs. FCV sized systems**

Variable Frequency Drive (VFD) control methods are frequently compared to Flow Control Valve (FCV) methods. However, this is typically only evaluated in the context of a given pipe system. The ANS module allows one to size the system for each of these methods. This allows a more meaningful comparison.

## **Maximum cost groups**

When evaluating multiple operating cases, one of the pump operating modes will drive the pump selection for all cases. This is by virtue of the fact that the cost will be based on the mode requiring the most power and/or largest head. This can be modeled in the ANS module with Maximum Cost Groups. A Maximum Cost Group allows one to couple costs together for all pumps that will eventually be of the same design (and thus cost the same). This allows the proper cost information to be used for each design case.

Maximum cost groups can also be used for Control Valves.

## **Discrete costs**

For sizing items such as pump motors, a discrete cost table can be created. This allows costs to be reported based on the discrete motor sizes available for the pump, rather than reporting an interpolated cost, which assumes that motors are available for purchase at any capacity.

## **Network libraries**

Engineering and cost libraries can be located on local PC's or deployed across local or wide area networks. The Library Manager allows users to connect to relevant libraries for their specific pipe system design.

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# Additional AFT Fathom Modules



## Goal Seek & Control

Identifies input parameters that yield desired output values and simulates control functions



## Extended Time Simulation

Models dynamic system behavior and how critical system parameters vary over time



## Settling Slurries

Models the effects of pumping fluids containing settling solids using the Wilson/GIW method



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