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## Comparison with Previous Pull-Planner Software Versions

### General information

The Pull-Planner 4.0 follows the same conduit system data approach as previous Pull-Planner Software versions. Data are input by “segments” where a segment is a straight conduit section followed by a conduit bend.

In Version 4.0, the data are on tab screens rather than the multiple menu/data screens of previous versions. Instructions boxes are minimized in favor of more intuitive operation.

Pull-Planner 4.0 fully integrates metric and English units. There is a single cable database and only one type of saved pull data file (.xpil). If the software is set to metric units, it will only bring in cable data that were entered as metric. If a saved pull is imported, the software will adapt to the units used on that pull (a metric pull will set the software to metric and an English pull will set the software to English).

In Pull-Planner 4.0, the COF (coefficient of friction) can be changed for each segment component without requiring any special mode. To change the COF, double-click on the COF cell to be changed. For more information, see the Coefficient of Friction section of this document.

### Importing “pull files” saved from previous software versions

The Pull-Planner 4.0 can use both metric and English unit pull files (\*.plm and \*.ppl files respectively) saved from previous software versions. Once imported, Pull-Planner 4.0 will convert and save them in the new xml format.

To import a saved pull file, use the Open icon on the top menu bar. Set the file type to ppl (or the metric plm) and navigate to the directory where the pull is saved. Click on the pull and open it. Note that if the file is a saved metric pull (.plm), you must choose the optional metric force units of kilonewtons or kilograms before opening the pull. It will be tagged with those units when saved as an \*.xpil file.

Once imported, the pull details will appear on the screen and the pull will be saved with the same name but with the .xpll file designator. For future use, the pull will be in this format. Use the Save As icon to save the pull to another desired directory; change the name; etc.

### Existing custom cable database to Pull-Planner 4.0

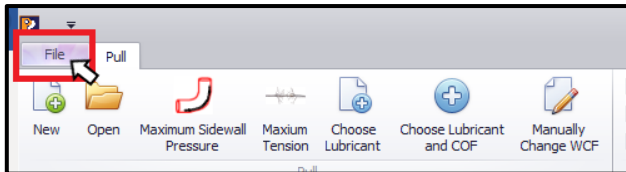
The Pull-Planner 4.0 is supplied with a small sample cable database including 5 cable types in English units and 5 types in metric units. Pre-existing cable databases can be added to this Pull-Planner cable data. In the Pull-Planner 4.0, both English and metric cable types are saved in a single xml file named “cable.xdat”. In earlier versions, the English and metric cables were stored separately in either “cable.dat” or “cablem.dat” files.

For information on how to add these data, see the Cable Database section of this document.

## File Pathways

### Finding Pull-Planner file default directories

To determine location of Pull-Planner files, go to the File tab:



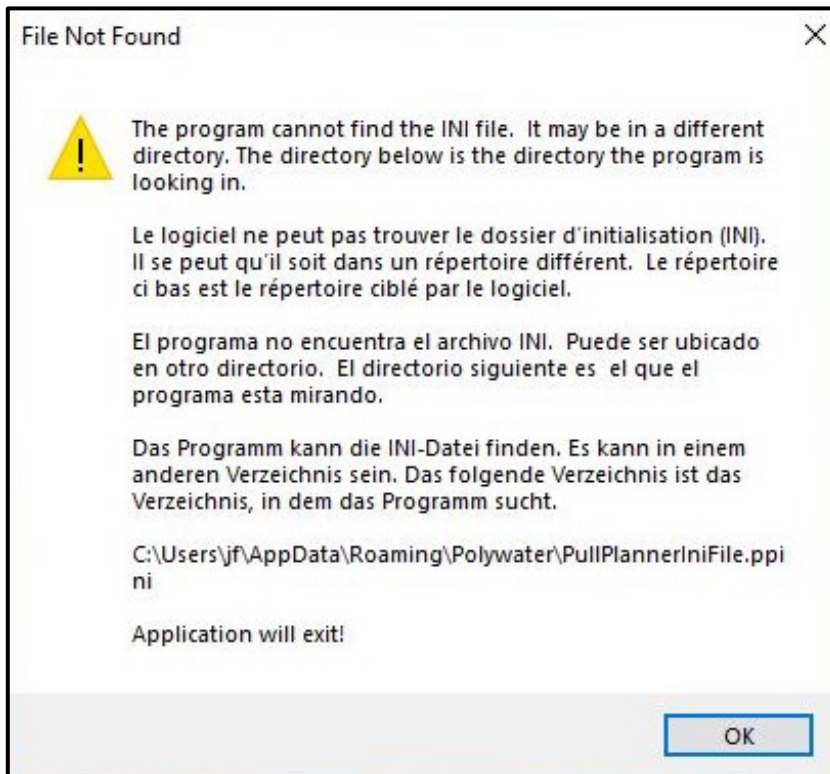
This will give you the current path, the path for the Cable Database, and the initial user path:



The “Current path for Pull files” is where the last saved pull (.xpll) was placed. The “Path for the Cable Database” is the directory that contains the cable.xdat file being used to populate the cable data. The “Initial Path for User” is the location of the PullPlannerIniFile.ppini file. That is the initialization file for the specific user. It provides information on language, units, previous pull locations, and numerous other details. The software will not run without this “ini” file.

### User Pull-Planner Boot without an Initialization File

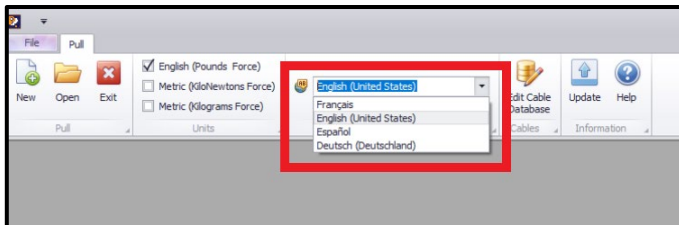
The Pull-Planner 4.0 looks for an initialization file in the specific users file under AppData\Roaming\Polywater\. The software will not run without this ini file. If the ini file is not found, the software will show the following message before shutting down:



The ini file is created when the software is first installed. Please contact American Polywater for help if there is an issue with the ini file that results in the error message above.

## Setting Language in the Pull-Planner 4.0

The Pull-Planner 4.0 displays screens in multiple languages (English, Français, Español, Deutsch). Language is selected using the Change Language dropdown option on the top ribbon.



The language can be changed at any time. However, when changing language in the middle of a pull entry, the pull must be saved and then reimported after the language change. A language change boots to the initial default screen.

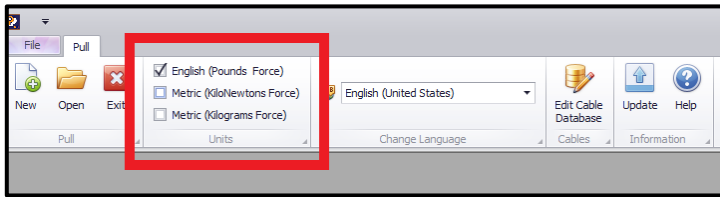
When opened for the first time, the program boots in English. After that it boots in the last language used before shutdown. Note that user input is not translated and can be in any language supported by the keyboard and Windows® system.

## Setting Units in the Pull-Planner 4.0

The Pull-Planner 4.0 will calculate using three different measurement systems:

- English (Pounds Force)
- Metric (KiloNewtons Force)
- Metric (Kilograms Force)

Unit type may be selected using the Units dropdown option on the top ribbon.

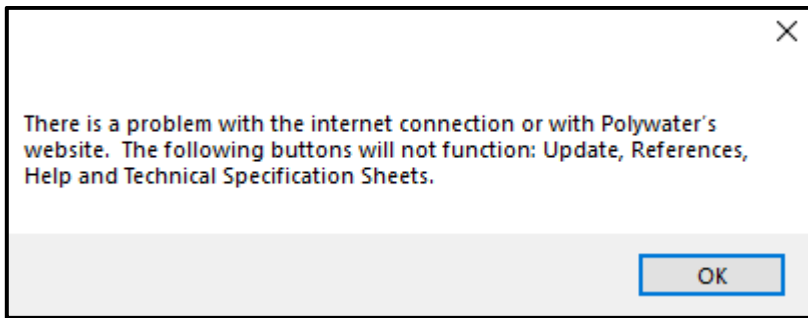


Units must be chosen using the options box before a new pull is started. Once a pull is started, this units option is inactivated, and units cannot be changed. When opened for the first time, the program boots in English (Pounds Force) units. After that it boots with the last units used before shutdown.

## Internet Connections in the Pull-Planner 4.0

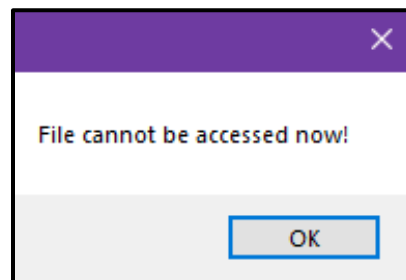
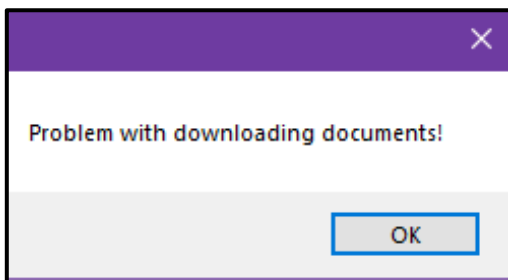
The Pull-Planner 4.0 requires an internet connection to import Lubricant Technical Data Sheets and to establish active links to Help, References, and Upgrade. No pull data detail, or user activity detail are saved or tracked by the software. The software is functional without an internet connection, but will not have the features mentioned above.

The software establishes an internet connection by “pinging” [www.polywater.com](http://www.polywater.com). If the ping does not go through, a message is displayed warning of no internet connection and that internet-supported features are disabled. The following message may appear if the program is booted without internet:



If this type of message appears and an internet connection exists, the usual problem is a firewall blocking internet access from the software. Reset your firewall to allow Pull-Planner 4.0 to access the internet or consult with your IT department.

If the internet is unavailable once the program is running, other errors may appear:



If it is not possible to establish an internet connection for the software, please contact Polywater and we will provide direct links to check Upgrade status and to view Help and the other internet-linked features.

## Cable Database

### About the cable database

The Pull-Planner 4.0 Software features a cable database as a repository for cable information. The database stores basic information on each cable entered: cable weight, cable diameter, a general description (name), and a cable “type” used for sorting the file. As cable usage changes with time, you can enter or change the names, types,

diameters, or weights for cable data you store with the program. These cable data are available for convenient input as you enter pull data.

The program comes with sample cable databases containing several types and sizes of cable. The electrical sample database includes 600V building wire (type B); control cable (type C); medium voltage cable (type M); high voltage cable (type H); and fiber optic cable (type F). The communications cable database includes high-fiber-count fiber optic cable (type H); Multi-mode fiber optic cable (type M); single-mode fiber optic cable (type S); coaxial distribution cable (type C); and 4-pair Cat 6 data cable (type D). See Cable Types for information on how to use the "type" designator.

The sample database should be changed and supplemented with specific values for your situation. It is only provided as an example.

### Cable database location

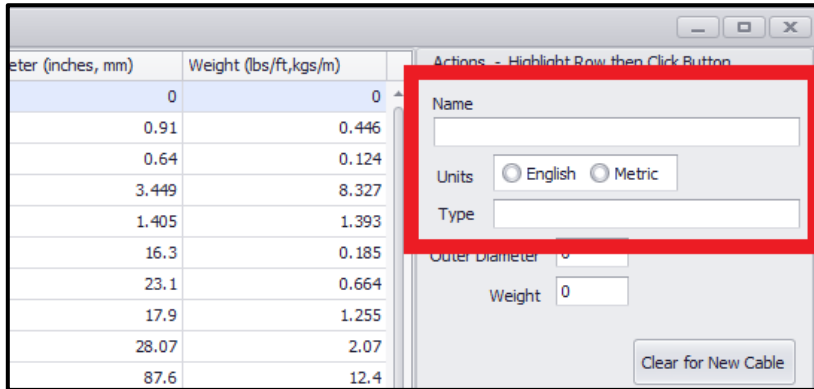
The default location for the cable database (cable.xdat) is in the Window's users file under "appdata/roaming/polywater/data". The location can be changed using the Edit Cable Database button on the top ribbon followed by the Save Cable DB to a Different Location button. If the database is moved in any other way, the program will not know its location and will generate a "Could not find file" exception error.

The location of the cable database is shown on the File tab on the main menu under Default Directories.

The most common reason for resetting the location of the cable database file is to create a common network database available to multiple users. The construction of a common database must be properly planned so the final reset places the desired database.

### Cable unit, type, and name (description)

Cables are stored with either English (imperial) or metric units for the weight and diameter. When adding cables, this is a radio button choice just after the cable is named. Set the appropriate units when adding cable weight and diameter.

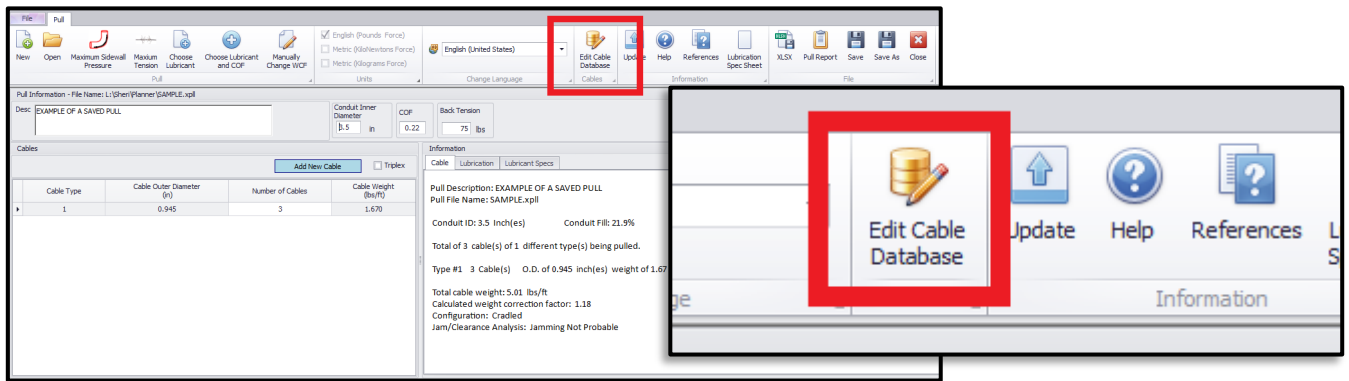


When entering a new cable for a pull, only the cables appropriate for the units you are running will appear in the cable selection area.

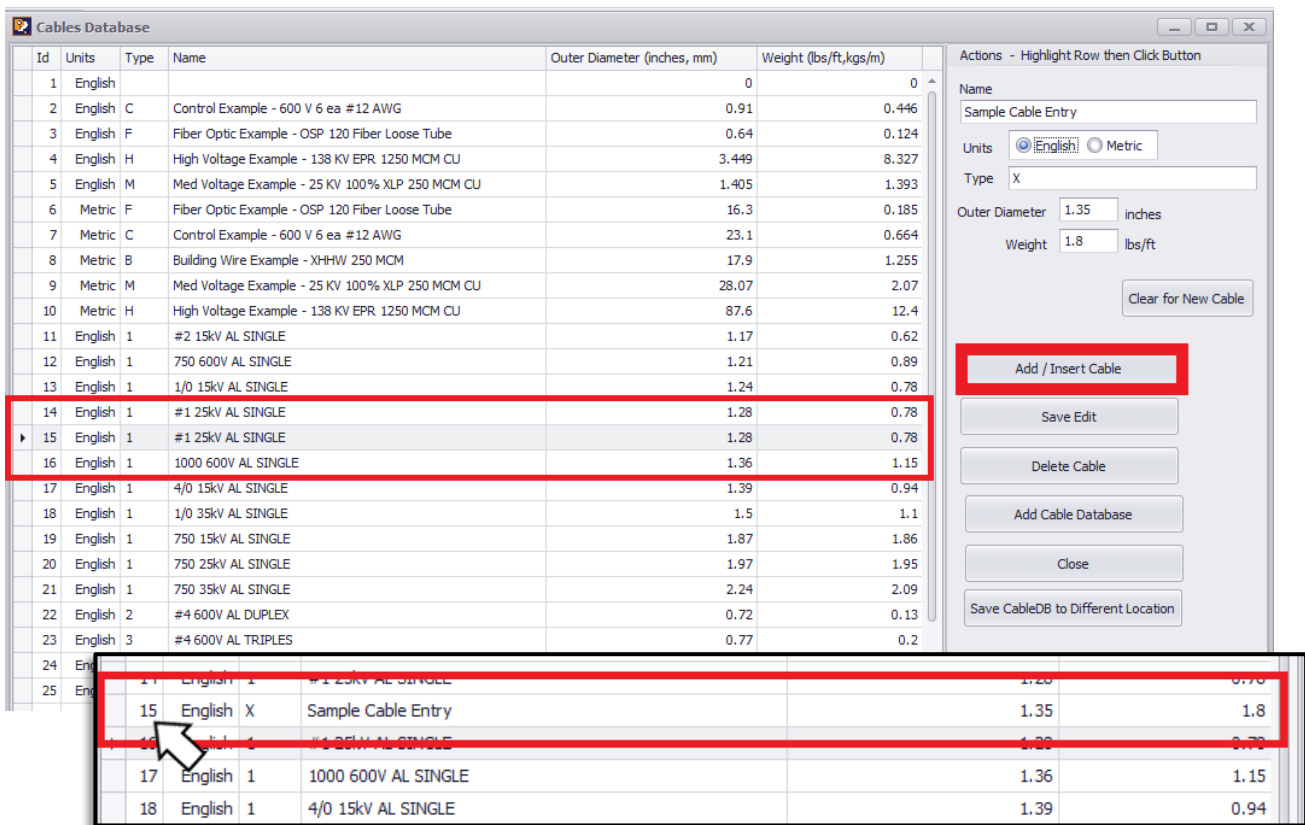
Cable type is entered in the box just below the units. This is a single alphanumeric designator that you assign to each cable. It is to help you sort and organize your cable database. Because the type is a primary sort field, you should select your own type designators to help you organize your cable database. The type is changed in the same manner as the other cable database fields, that is, by double-clicking on the appropriate cell in the database table.

### Managing cable data

To add to the existing cable data, click the Edit Cable Database icon.

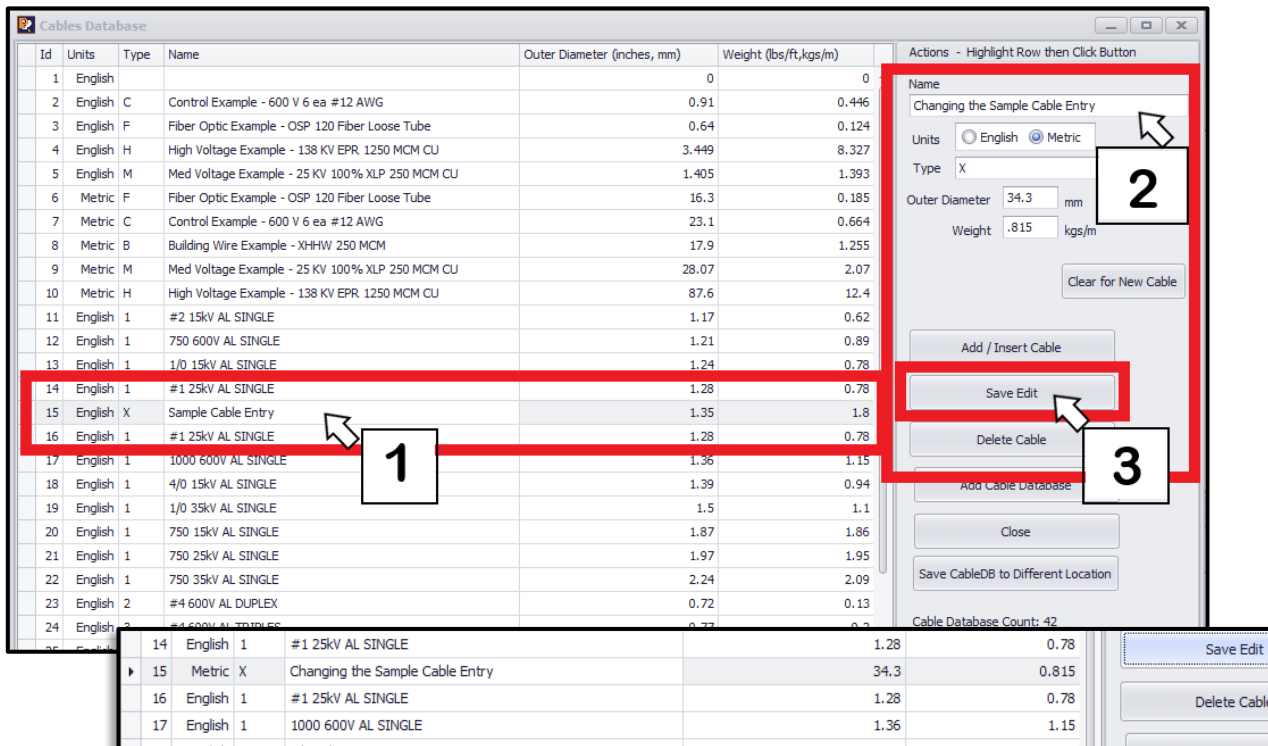


The Cable Database will appear on the screen. Fill in the Name, click the radio button for Units (English or metric), fill in the Type, Outer Diameter (inches, mm), and Weight (lbs/ft, kgs/m). Click the Add/Insert Cable button, and the new cable will be added to the line where the cursor is resting.



The cable Outer Diameter (OD) and cable weight will be rounded to 3 decimal places by the program. The cable OD (metric system) will be rounded to 2 decimal places. Once new cable information is entered, it can be changed. To modify, highlight the cable row, edit the detail screen on the right with data you wish to change, and then click the Save Edit button.





## Sorting cable data

You can sort the cable data (arrange list presentation order) by any of the columns. Simply click the top cell in the column you want to sort.

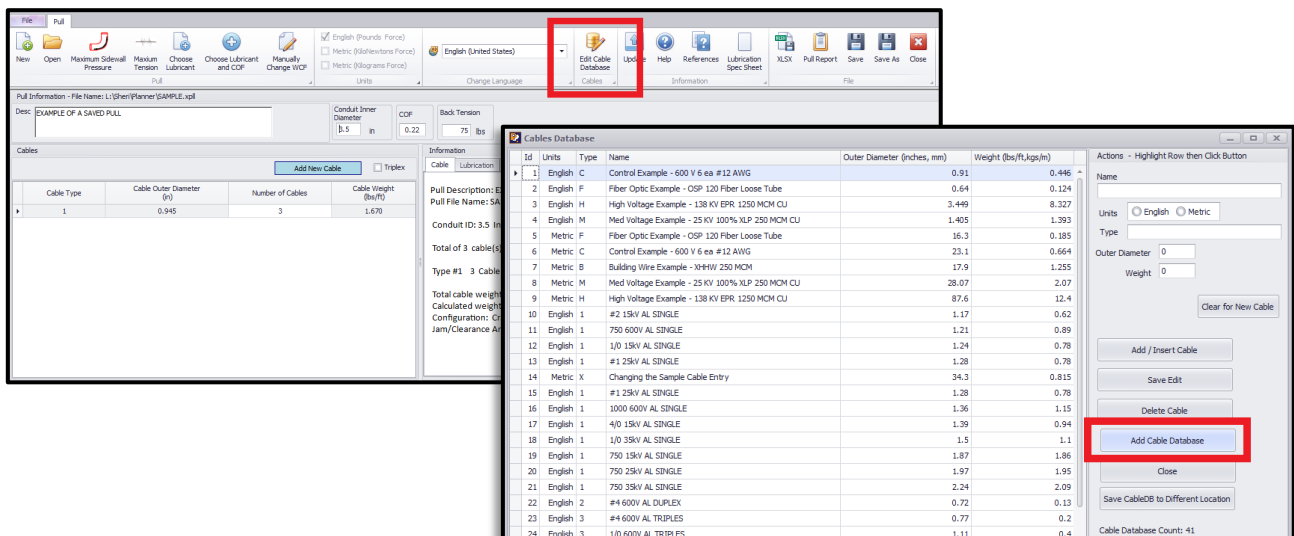
If you add or change cables that are not consistent with your sort, sorting is not automatic. This lets you construct the database in any order you wish. Another sort will be required if you wish to change the order of the new addition.

Note that a sort of the full database is not saved. However, the cable input into a pull offers the same sort features to help find the desired cable at that point in data entry.

## Importing an existing cable database

Another Pull-Planner 4.0 cable database or a cable database used with Pull-Planner 3000 can be added to the Pull-Planner 4.0 cable data. The Pull-Planner 4.0 saves the cable database as "Cable.xdat" with both English and metric cable types in a common file. The Pull-Planner 3000 stored English cable units as "cable.dat" and metric cable units as cabledat.dat.

To add your saved cable database, click on the Edit Cable Database icon on the top ribbon. On the edit menu, choose the Add Cable Database button on the right side.



Set the file type to XDAT (Pull-Planner 4.0) or DAT (Pull-Planner 3000) and navigate to the cable.xdat, cable.dat, or cabledat you wish to add.



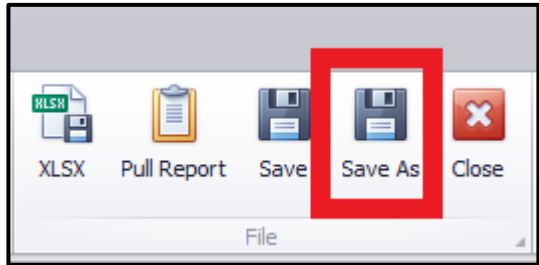
Simply click on and open that file, and it will be added to the end of the new database. This addition does not check for duplicates. All cables in the selected file will be added.

## Starting New Cable Raceway Design Entry

### Entering a pull file name

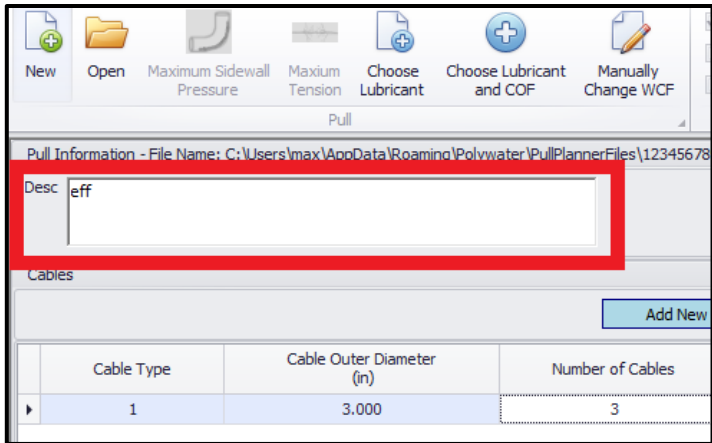
You can use alphanumeric, underscore, and hyphen in the file name. Any other characters will give an error.

The pull name and description should be entered when requested. The file name or location can be changed by clicking Save As.



### Entering a pull description

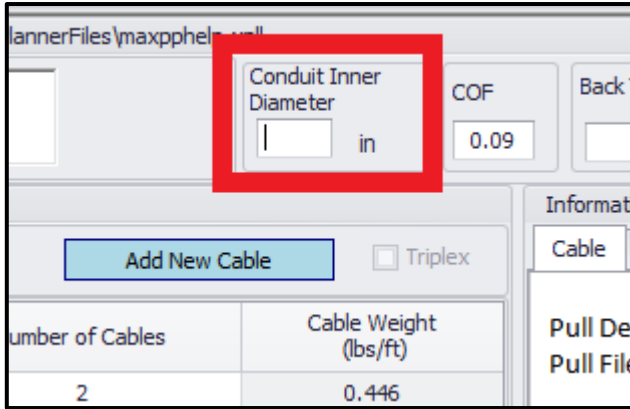
The pull description can be any text you would like it to be. It may be changed by clicking on the Desc box.



### Entering Conduit Inner Diameter

The next entry required is the conduit inner diameter (ID) in millimeters (metric) or inches (English). Conduit ID will be rounded to two decimal places by the program.

The conduit ID may be changed by clicking on the Conduit Inner Diameter box.



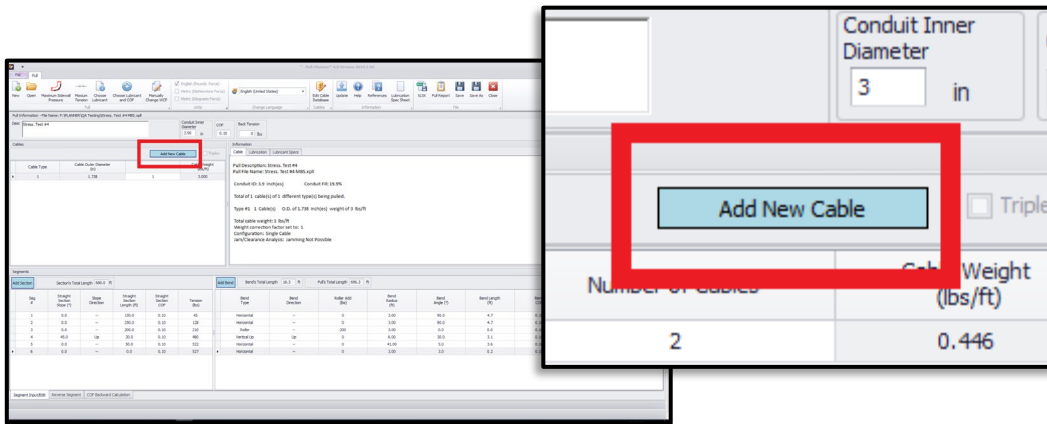
## Cable Entry, Configuration, Clearance, and Fill

### How to enter cable information

The dimensions, weight, and number of cables pulled into a conduit affect pulling tension directly through weight, and indirectly through weight correction or occupancy factors.

After entering the conduit ID you will be prompted to enter cable information. Choose a cable from the cable database or enter the cable OD, weight, and number of cables separately.

You may add more cables by entering them when prompted after entering your first cable or by clicking the Add New Cable button.



You may select a cable from the database using the dropdown list or inputting your own cable OD, weight, and number of cables. Input for OD should be in millimeters (metric) or inches (English) and will be rounded to 2 decimal places (metric) or 3 decimal places (English). Weight data should be in kgs/m (metric) or lbs/ft (English), and will be rounded to three decimal places.

The cable details will appear in the Cables Table shown below.

Cables					
				<input type="button" value="Add New Cable"/>	<input type="checkbox"/> Triplex
	Cable Type	Cable Outer Diameter (in)	Number of Cables	Cable Weight (lbs/ft)	
	1	1.738	1	3.000	
▶	2	0.917	1	0.446	

Once cable data are accepted and shown in the Cables Table, they can be changed or deleted.

To change a value on a previously entered cable, double-click on the cell you would like changed, input your new value, and hit enter. You may delete an entire row in the Cables Table by right-clicking on the row and selecting Delete Cable Type. You may also add new cable types by right-clicking in the Cables Table and choosing Insert Cable, or by using the Add New Cable button.

### Cable fill calculation and display

Cable fill for the pull is calculated and displayed on the Information Cable tab. It is the sum of the cable area (based on the cable OD) as a percentage of the conduit area (based on the conduit ID).

**Information**

Cable    Lubrication    Lubricant Specs

**Pull Description: EXAMPLE - Push/Pull Device and Roller in pull**  
**Pull File Name: Example push-pull and roller in pull.xpll**

Conduit ID: 3.5 Inch(es)      **Conduit Fill: 21.9%**

Total of 3 cable(s) of 1 different type(s) being pulled.

Type #1   3 Cable(s)   O.D. of 0.945 inch(es) weight of 1.67 lbs/ft

Total cable weight: 5.01 lbs/ft  
 Calculated weight correction factor: 1.18  
 Configuration: Cradled  
 Jam/Clearance Analysis: Jamming Not Probable

Conduit fill is rounded up to the nearest 0.1%. Conduit fill may be regulated by electrical code or other standards. For example, the National Electric Code (NEC, US) regulates conduit fill based on number of cables. Chapter 9, Table 1 of the NEC shows a maximum cable fill of 53% for 1 cable, 31% for 2 cables, and 40% for more than 2 cables. For certain conditions, a lower fill is recommended [Reference 18]. The Pull-Planner 4.0 always rounds percent fill up (to the nearest tenth of a percent). It is up to the user to determine whether the design is within any regulated parameters.

Some cable manufacturers have recommendations on maximum cable fill. High conduit fill may increase pulling tension. Studies show that pulling multiple small cables (data, instrument, control, etc.) with a conduit fill exceeding 70% will impact cable pulling tensions [Reference 16].

## Cable clearance calculation

Clearance is the amount of space between the cable(s) and the top of the conduit. Minimum allowable clearance can vary by cable and conduit size as well as engineering practice. Clearances specified in utility pulling are typically 10% to 20% of the conduit inner diameter to allow for conduit ovalization, cable expansion, neck down at bends and connections, or other minor obstructions in the conduit. Another source suggests a minimum clearance of 0.5 inch [Reference 11]. The user may consult with the cable manufacturer to determine acceptable clearance.

Clearance can be calculated as follows:

1 Cable,	Clearance = $D - d$
2 Cables,	Clearance = $D - 2d$
3 Cables (Triangular),	Clearance = $\frac{D}{2} - 1.366d + \frac{(D-d)}{2} \sqrt{1 - \left(\frac{d}{D-d}\right)^2}$
4 Cables (Diamond),	Clearance = $(D - d) - \frac{2d^2}{(D-d)}$

Where  $D$  is the conduit inner diameter and  
 $d$  is the average cable outer diameter

Clearance is typically not an issue when cables are installed in conformance with national electrical code conduit fill maximums. These maximums result in adequate clearance.

## Cable clearance treatment in the Pull-Planner

When user data result in a clearance of zero or less (meaning the cables will not fit in the conduit), Pull-Planner 4.0 warns that the cables will not fit in the conduit. It will either delete the last cable entered if that resulted in the overfill, or it will not allow the conduit size change that produced an overfill. However, these checks are limited and cannot cover complex cable configurations. The user must ensure adequate clearance.

Pull-Planner 4.0 calculates  $\frac{D}{d}$  to issue guidance as follows:

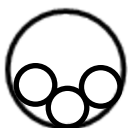
- 1 cable,  $\frac{D}{d} \leq 1$  --Program warns user and will not run calculations.
- 2 cables,  $\frac{D}{d} \leq 2$  -- Program warns user and will not run calculations.
- 3 cables,  $\frac{D}{d} \leq 2.15$  -- Program warns user and will not run calculations.
- 3 cables,  $2.15 \leq \frac{D}{d} \leq 2.5$  -- Program will warn user to check clearance only. It will still run the calculation.
- 4 or more cables -- Program will warn user if cable fill is >60%. It will still run the calculation.
- 4 or more cables -- Program will not run calculation if cable fill is >90%.

Where  $D$  is the conduit inner diameter and  
 $d$  is the average cable outer diameter

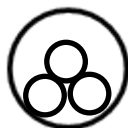
When the Pull-Planner 4.0 issues a “check clearance” warning, it is recommended that the user evaluate the clearance. This can be done using either graphical or mathematical methods.

## Cable configuration, triplex and cradled cable

When three cables are pulled, the relative diameters can influence both the configuration and the likelihood of jamming. Cable configuration is an important influence on cable jamming and the weight correction factor (WCF). Three cables may pull through the conduit in a cradled or triangular configuration.



3 Cables, Cradled



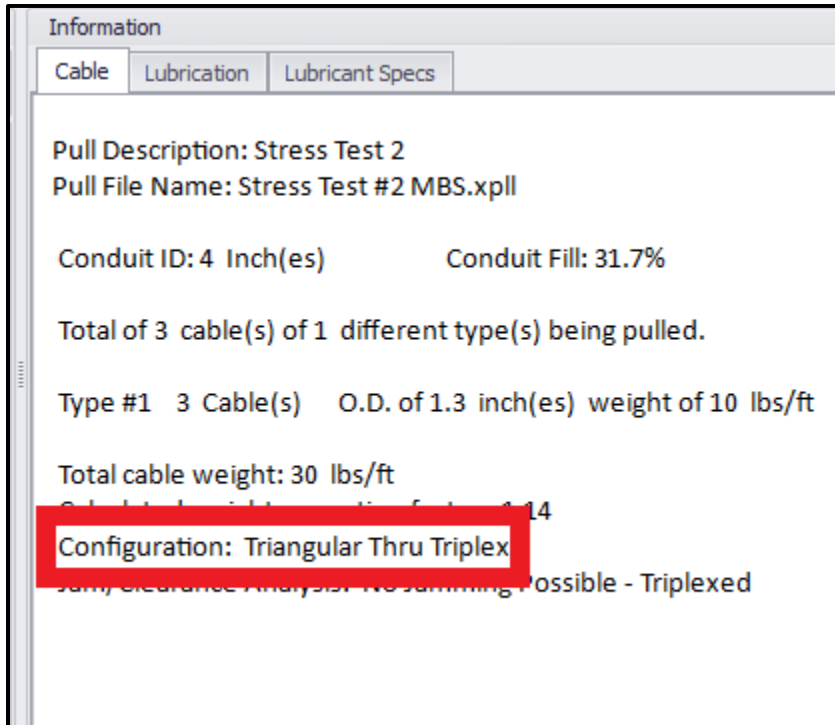
3 Cables, Triangular

The ratio of the conduit inner diameter (D) to the average cable outer diameter (d) will influence cable configuration.

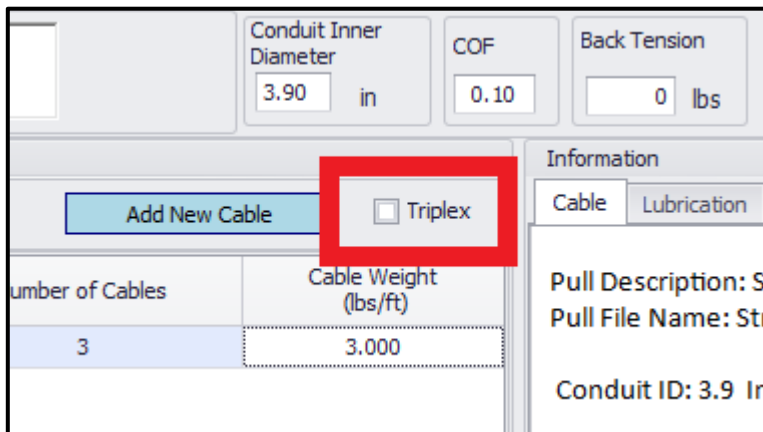
Pull-Planner 4.0 uses a relatively conservative conversion to triangular when  $\frac{D}{d} \leq 2.4$ . Otherwise, the configuration is set to cradled with its higher WCF. However, specifying three cables as triplexed (wrapped) will result in a triangular configuration WCF, regardless of the diameter ratio.

Some sources suggest probabilities for these three-cable configurations. See References (1) and (11) for more information.

The cable configuration determined by the software can be found on the Cable tab of the Information box shown below.



When a total of three cables are being pulled, the Triplex box will be activated. Select this if your cables are triplexed (wrapped helically around each other and fed off a single reel). Triplexed cables cannot assume a "cradled" riding position and are calculated with a "triangular" WCF.



## Cable configuration, quadruplexed (diamond) configuration

When 4 cables are pulled into a duct, they can form a diamond configuration or a cradled configuration. Configuration will depend on the ratio of the average cable outer diameter ( $d$ ) to the conduit inner diameter ( $D$ ).



4 cables, Diamond;  $D/d < 3.0$



4 cables, Cradled;  $D/d \geq 3.0$

The Pull-Planner 4.0 Software will default to a conservative weight correction factor of 1.4 for 4 or more cables. There are equations available [Reference 19] to calculate the weight correction factor (WCF) for these two 4-cable configurations.

For information on overriding the weight correction factor (WCF) in the Pull-Planner 4.0, see the help topics on that subject.

## Cable jamming

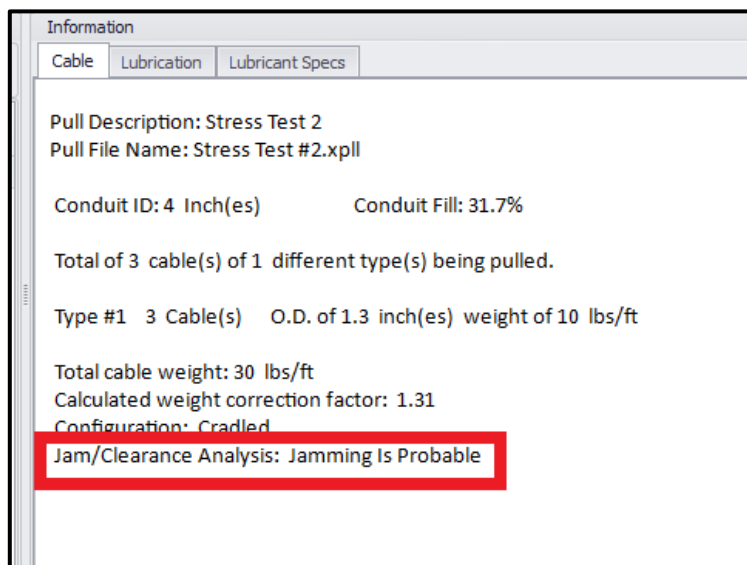
The Pull-Planner 4.0 assesses jamming for three-cable pulls. Jamming is a probability of the three cables wedging together (linearly) in a bend to jam and produce unexpectedly high pulling tensions. When the combined diameter of three cables are roughly equal to the interior conduit diameter, the cables can shift and line up linearly to jam as they are pulled around a bend. Pulling cables to get them “unstuck” usually damages the cable.

Equations used to calculate an estimation of the likelihood of cable jamming are found in multiple references. The Pull-Planner 4.0 calculates the jam ratio for three cables as follows:

$$\text{(Jam) Ratio, } J = \frac{D}{d} \quad \text{Where } D \text{ is the conduit inner diameter and } d \text{ is the average cable outer diameter}$$

For  $2.7 \leq J \leq 3.1$ , the program will flag jamming as probable. It will still run the calculation.

Jamming is not assessed for pulls with more than three cables. However, when a four-cable pull consists of three power cables with a smaller ground, the jamming assessment through the temporary elimination of the ground should be valid. See “Reasons to change a weight correction factor” for the same issue in the calculated WCF.



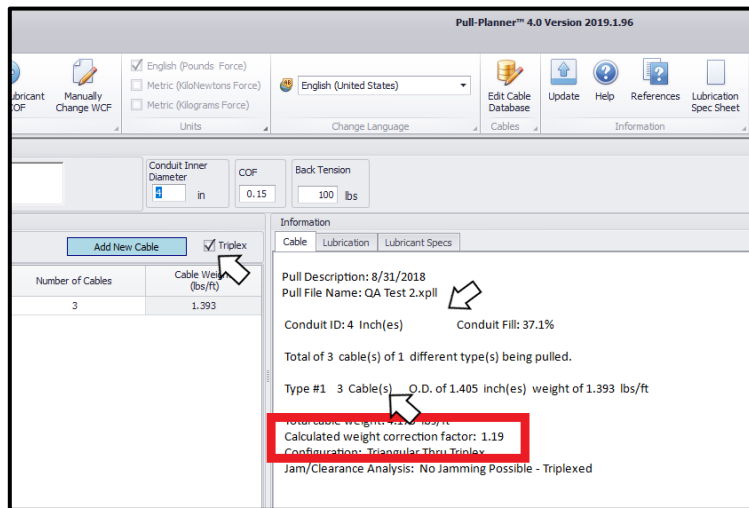
## Weight correction factor (WCF)

Weight correction factor (WCF) represents the "positional" increase in normal rubbing force on a cable in multiple cable pulls, where the cable does not rub on the bottom of the conduit. This factor is a variable that increases both the tension and the sidewall pressure based on the uneven weight distribution of individual cables in a multiple cable pull. Weight correction is mathematically defined based on number and geometry of cables. Equations used in the Pull-Planner 4.0 Software are below.

1 Cable	$w = 1$
2 Cables	$w = \frac{1}{\sqrt{1 - \left(\frac{d}{D-d}\right)^2}}$
3 Cables (Triangular)	$w = \frac{1}{\sqrt{1 - \left(\frac{d}{D-d}\right)^2}}$
3 Cables (Cradled)	$w = 1 + \frac{4}{3} \left(\frac{d}{D-d}\right)^2$
4 Cables, or more	$w = 1.4$

Where  $D$  is the conduit inner diameter and  $d$  is the average cable outer diameter

The WCF is automatically calculated by the Pull-Planner 4.0 Software based on inputs on cable number, cable, and conduit diameter, as well as the geometry such as a triplexed cable. The cable WCF can be found in the cable tab:



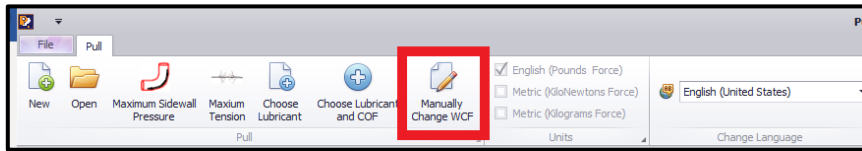
## Reasons to change a weight correction factor

The user can change the weight correction factor (WCF) used in the calculations. One common reason for changing the WCF is when three power cables are pulled with a fourth smaller ground cable. Some users wish to assume the less conservative WCF of the three power cables, rather than the 1.4 assumed for 4 cables in a complex configuration. Graphically determined or diamond-configuration calculations for WCF for 4 or more cables in a pull can also be input by the user.

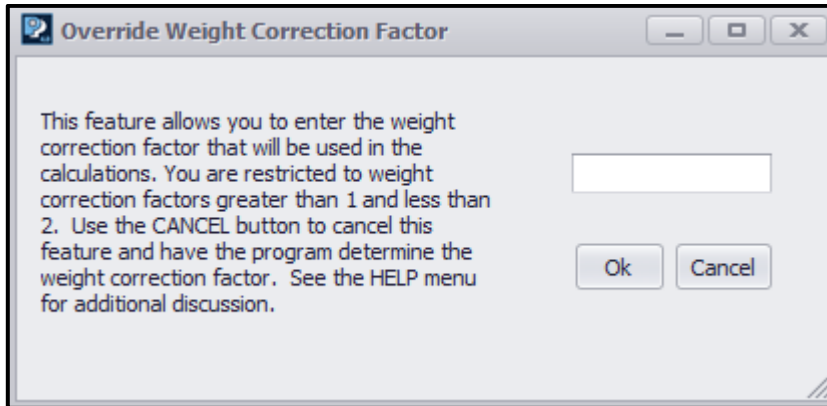
## Changing the Weight Correction Factor

To manually override the calculated weight correction factor (WCF), click on the Manually Change WCF button on the top ribbon:





You will get an override WCF box feature:



Once this feature is used, weight correction factor “set by user” is noted within the program. The weight correction factor is updated to “calculated” if cable or conduit information is updated. It will have to be reset by user if desired.

### Effect of cable weight correction factor on tension calculations

The weight correction factor (WCF) raises the apparent cable weight, which increases the cable pulling tension. The Pull-Planner 4.0 Software defaults to a conservative WCF. Caution should be used when making manual changes to any of these factors.

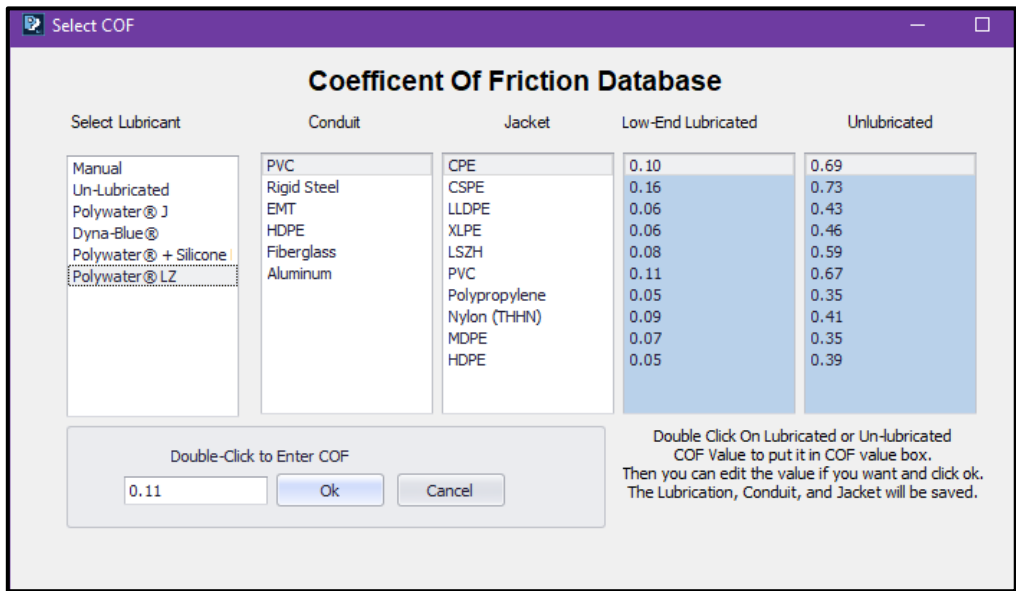
A user input WCF will be noted on the Cable Tab as “Weight Correction Factor Set by User.”

If you have set a user-determined WCF, you can change back to a program-determined WCF by using Calculate WCF on the top ribbon.

## Coefficient of Friction

### Using the friction database

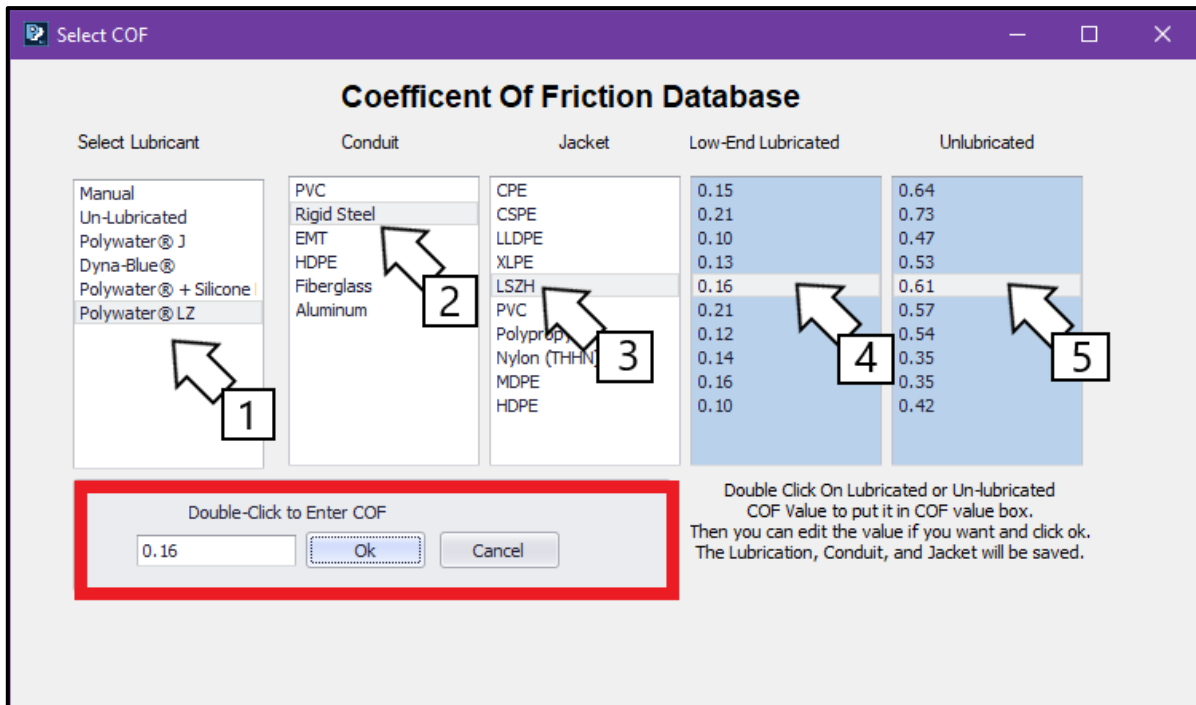
The decision on an appropriate coefficient of friction (COF) to use in the calculations is an important one. COF is a dimensionless variable that is a measure of the frictional resistance to movement of the cable jacket against the conduit wall. It has been shown that the coefficient of friction in cable pulling depends on the jacket type, the conduit type, the conduit condition, the specific lubricant used, the temperature, and the number of cables being pulled. There is no single COF that is appropriate for all occasions.



These data reflect years of Polywater’s laboratory testing, and include the cable jacket, conduit type, and lubricant variables.

How to select a COF based on cable, conduit, and lubricant

It is recommended that you calculate with several coefficient of frictions (COFs), using the laboratory measured value for the low end and the unlubricated value for the high end. Use the Coefficient Of Friction Database to select these values as follows:



- 1) Click on the lubricant to highlight
- 2) Click on the conduit choice to highlight
- 3) Click on the cable jacket description to highlight
- 4) Double-click on the lubricated COF value to enter the *low-end* COF
- 5) Double-click on the un-lubricated COF value to enter the *high-end* COF

The COF must be a positive number. While coefficients of friction greater than 2.0 can be entered, coefficients greater than 2 have not been measured in the lab or field. Since the COF is an exponent in several equations, the use of an artificially high COF will rapidly inflate tension beyond reason.

### Test method and determination of coefficient of friction

An important factor in using the pulling equations for cable tension prediction is using a meaningful value for the Coefficient of Friction (COF). The COF database in this program presents "unlubricated" versus "lubricated" with the more popular American Polywater cable pulling lubricants. COF data used in this software were measured using American Polywater's Friction Table and Telcordia Standard GR-356-CORE [Reference 15].

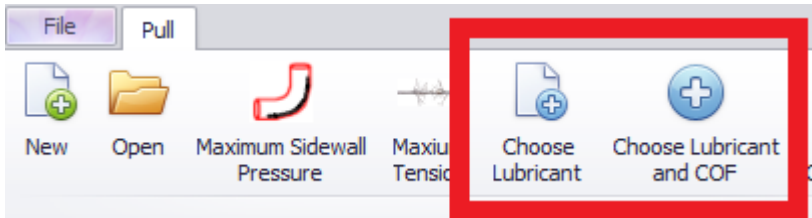
The Friction Table Test Method developed by American Polywater is an important source for COF data. The equipment and measurement techniques are described in the White Paper, "[Coefficient of Friction Measurement on Polywater's Friction Table](#)," linked in the references section of the Pull-Planner 4.0 Software. The COFs developed using this test were measured using normal forces of 100 to 200 lbs/ft (1450 to 2900 N/m). They represent heavy cables in multiple-bend pulls. Studies have shown reasonable correlation of these coefficients of friction with field-measured tensions in heavy cable pulling [Reference 13].

Data shown for communications lubricants were developed using the Telcordia (Reel) test. In this method, communication cable is pulled through a 420° bend in continuous duct. An incoming tension, 25 lbs. (11 kg), is attached to the cable and the pulling tension is measured to determine the COF.

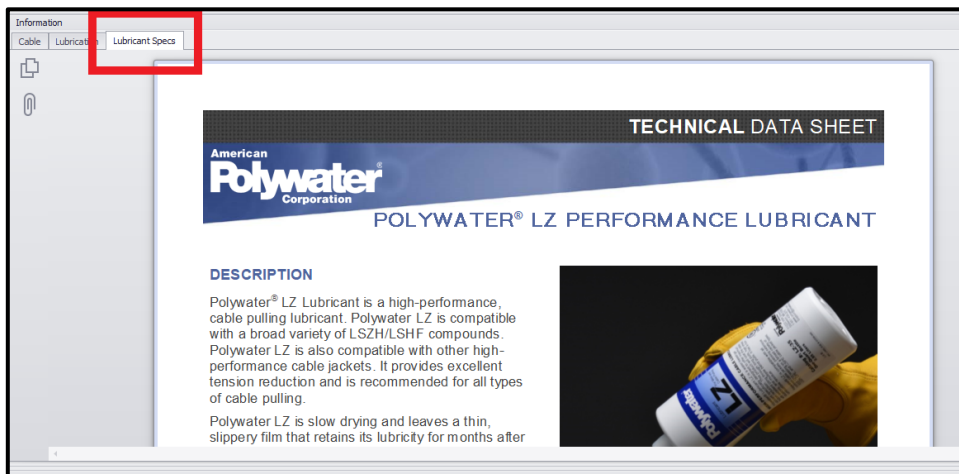
In both test methods, tension is measured as the cable is moving through or across the conduit. This pulling force, required to maintain sliding movement, produces a kinetic COF. Stopping a pull is poor procedure. The "kinetic" coefficient of friction is the appropriate one for a moving cable. If a stop is unavoidable, the "static" coefficient of friction is usually 10% to 25% higher than the kinetic for cables lubricated with American Polywater lubricants.

### Choosing a lubricant

Choosing a lubricated coefficient of friction (COF) requires the choice of one of the Polywater® Lubricants in the database.



Once a lubricant is chosen, its Technical Data Sheet is linked to the Lubricant Spec tab.



More than one Polywater® Lubricant can be appropriate for a pull. The decision is influenced by conduit and cable details, the working environment, and application considerations. For more discussion on lubricant properties, visit [www.polywater.com](http://www.polywater.com) or contact American Polywater.

## Factors affecting coefficient of friction (COF)

Field factors may affect the apparent COF, and ultimately, cable pulling tension. These factors and their effect on friction are discussed as follows:

**LUBRICANTS** - Not all lubricants are the same, and the coefficients of friction they produce can vary by factors of two or more. The values presented for Polywater Lubricants are among the lowest from commercially available lubricants. Do not assume that all pulling lubricants produce friction values as low.

**LUBRICATION TECHNIQUES** - The effectiveness of a lubricant is only as good as the method of lubrication. Using lubricated coefficients of friction in calculations assumes lubricant is present at all points in the conduit. Unlubricated, or inadequately lubricated conduit will significantly increase pulling tension, especially at conduit bends.

**JACKET/CONDUIT TYPES** - The friction database shows differences in coefficient of friction with both cable jacket and conduit type. These data were developed from common commercially available cables and conduits. However, the compounding, extruding, and base polymer can all affect the coefficient of friction within a generic polymer type. For instance, significant differences in COF have been measured amongst PVC jackets, depending on their hardness, and differences have also been observed between LD, MD, and HD polyethylene. Conduit types may also show high variance depending on the way the conduit is manufactured. For example, galvanized steel and EMT conduit friction testing show a larger standard deviation based on internal duct variations.

**CONDUIT CONDITION** - Dirt, sand, etc. in the conduit can increase the coefficient of friction substantially. Offsets, neckdowns, and crushed conduit can also make cable pulling unpredictably difficult.

**MULTIPLEX CABLES** - The equations in this software use a weight correction factor to describe the forces created when cables do not ride on the bottom of the conduit. However, there is some indication that these theoretical adjustments do not completely describe the increased tension from pulling multiple cables, especially at jam ratios less than 3.0 [References 1 and 12]. The most practical way to correct for the difference between single and multiple cable pulls is to raise the coefficient of friction on the multi-cable pull.

**TEMPERATURE** - Studies show that the effective COF increases at higher temperature. The magnitude of the increase is dependent on the jacket type and temperature, and can be as much as 50%. See References (1) and (11) for additional information. In cold temperatures, cable stiffness may increase and have an impact on pull tension as the cable moves through bends.

**STIFF CABLES** - Stiff cables can require significant force to bend and unbend as they go around curved conduit sections. The pulling equations make no allowance for these forces. These forces make stiff cable harder to pull; they pull with an apparent increased effective COF [Reference 12].

**NORMAL PRESSURE** - Some research [Reference 6] indicates that the coefficient of friction of cable against conduit can vary with the magnitude of the force pushing the cable against the conduit (the normal pressure or sidewall pressure). There is no consensus on the magnitude of these differences nor the transition point. Both obviously make a difference in the "average" coefficient of friction. The Pull-Planner 4.0 Software allows the adjustment of the coefficient of friction by conduit segment, so the coefficient of friction can be varied based on sidewall pressure if desired.

**OTHER FACTORS** - Additional factors have been shown to have some effect on pulling tension and apparent coefficient of friction. These include conduit fill, pulling speed, and quality of conduit installation.

The real power of Polywater's Pull-Planner is the ability to quickly vary the coefficient of friction to see the effect, as well as to determine a "field" coefficient--which presumably includes the above factors--through back calculation.

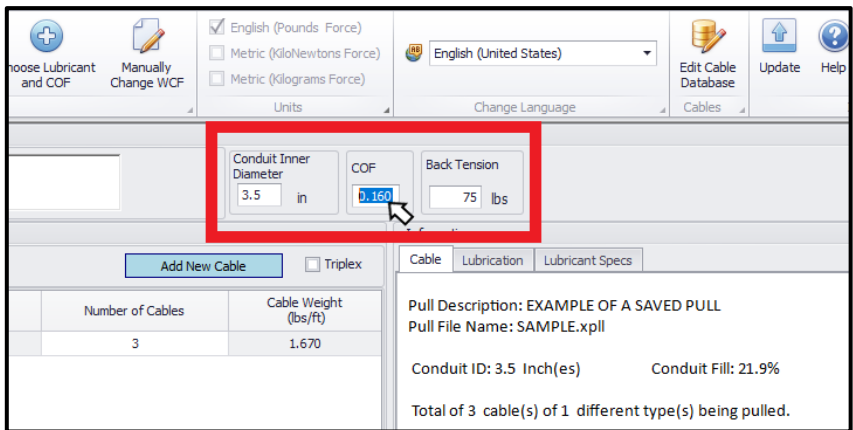
As a starting point, based on the planned lubricant, use the laboratory-measured lubricated friction values in the database to calculate a lower limit for expected tension. Then use the unlubricated values to calculate an upper limit. Consider the factors that influence tension and adjust the lubricated coefficient upward to calculate an anticipated value for specific field conditions.

Experience indicates that field friction values are typically 25% to 80% above laboratory-measured values. Use field experience to make the best adjustment for your situation.

Remember that good lubricants and good lubrication practice produce the lowest tension.

### Changing coefficient of friction

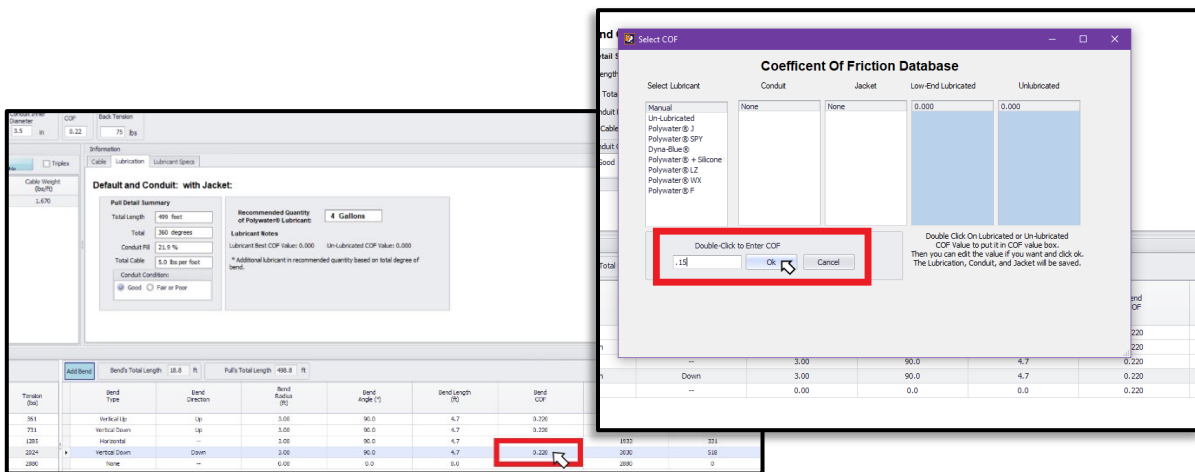
At any time, you can directly enter a Coefficient of Friction (COF) by clicking on the COF box.



This new number will populate the COF values for all segment entries.

### Variable (high shear/low shear) coefficient of friction

Early versions of the Pull-Planner Software included a high shear/low shear Coefficient of Friction (COF) mode. The Pull-Planner 4.0 allows friction to be varied by segment. To do this, double-click the COF cell on the segment you want to change. This will bring up the friction database. Manually enter a new COF or use the friction database to help determine a value. When done this way, the COF will only change in that segment.



Click okay and the new segment COF value will be entered.

Bend Length (ft)	Bend COF	Tension (lbs)	Sidewall Pressure (lbs/ft)
4.7	0.220	555	95
4.7	0.220	1123	192
4.7	0.220	1933	331
4.7	0.150	2659	455
0.0	0.220	2508	0

This new COF is used to calculate the tension for that straight section and/or bend. Other segments continue to use the original COF as assigned.

Studies show that COF may vary based on the sidewall pressure. In straight sections and bends with low sidewall bearing pressure, a higher COF may be used. References (1) and (9) suggest that higher COF be used for sections with sidewall pressure less than 150 lbs/ft (2190 N/m), while Reference (3) presents data indicating an increase in COF begins to occur at much lower sidewall pressures than 150 lbs/ft.

The variable friction feature can be used for sections of the raceway with different duct materials, such as specialty elbows. The variable friction function can be used to account for the cable buoyancy effect when part of the raceway is flooded and cables appear to “have less weight” when surrounded by water.

### Lubricant quantity recommendation

The Lubrication Tab on the Information box summarizes details of the pull, estimates a volume of lubricant appropriate for the pull, and presents lubricant application information and suggestions.

The summary presents the total pull length (including the length of cable in the bends), the total degree of bend, the conduit fill, and the cable bundle weight. These parameters were established by earlier entries and cannot be changed.

Conduit condition can be specified using an option box. Conduits in poor condition are harder to pull into and more lubricant is recommended. However, no amount of lubricant can replace proper conduit preparation before pulling. Conduits should be mandreled to ensure integrity, and cleaned to provide a suitable friction surface, before any cable pull. This is especially true with "existing" older conduits.

Lubricant quantity recommendation begins with a calculation that determines the volume of a minimal lubricant coating that completely coats the interior walls of the conduit. Our research indicates that the following equation provides a satisfactory quantity of lubricant for an average cable pull:

### Recommended Lubricant Quantity:

$$Q = k \times L \times D$$

Where:

Q = quantity in gallons (liters)

L = length of conduit run in feet (meters)

D = inner diameter (ID) of the conduit in inches (mm)

k = 0.0015 (0.0008 if metric units)

The recommended lubricant quantity is directly proportional to both the total length of conduit and the inner diameter of the conduit. Appropriate quantity for any given pull can vary from this recommendation by 50%, depending on the complexity of the pull. Consider the following factors:

1. Heavy (weight) cable or very long pulls
2. High conduit fill or multiple-bend pulls
3. Poor conduit condition (dirt, rust, etc.)

The adjustment factors used are noted on the screen.

Follow this link to access Polywater's Lubricant Quantity Calculator:

[Polywater Lubricant Calculator](#)

### Lubricant application recommendation

The lubricant Technical Data Sheet includes useful information on lubricant application. Further information and videos on the Polywater Front End Pack™ system; Polywater's LP-D5 Pump; and much more can be found on our website at [www.polywater.com](http://www.polywater.com).

### Use of Pull-Planner COF in the field

Polywater Lubricants have been used in many important cable installations. Data from these installations confirm the validity of the estimation software. Tension estimations from the Pull-Planner Software support the planning of complex installations. One such study can be found at the following link:

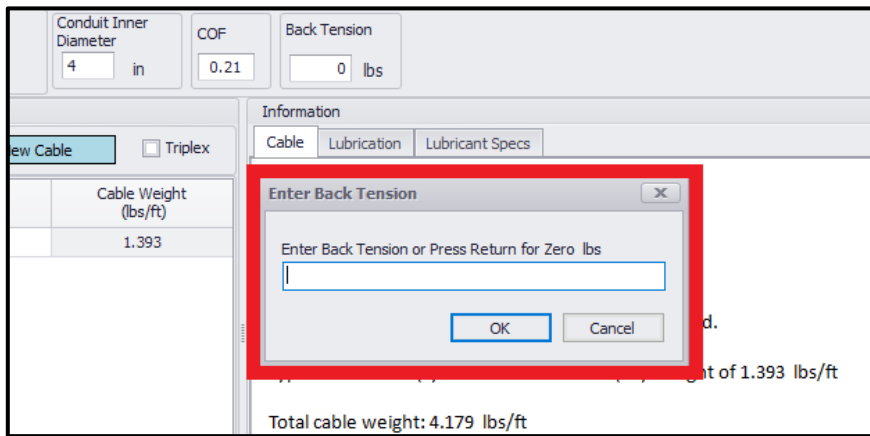
<https://www.polywater.com/en/knowledge-hub/hawaiian-electrical-company-heco-and-the-pearl-harbor-cable-pull>

## Back Tension or Incoming Tension

### Entering a back tension

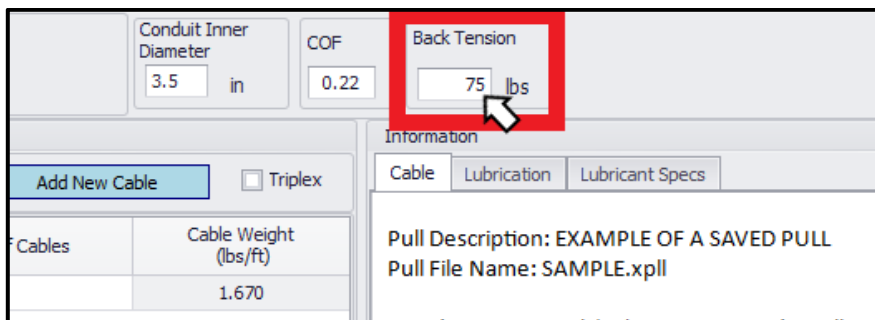
When entering a new pull, you must set the Back Tension (or incoming tension) after accepting the Coefficient of Friction (COF). This is the tension on the cable as it enters the first section of conduit. Back tension can come from the weight of the cable (gravity) if it must be lifted, or it can come from the force required to turn the cable reel.

Enter the tension value (lbs, kg, or kN) into the cell and click OK.



Negative back tensions cannot be entered. A Push/Pull device must be entered to produce a negative incoming tension (pushing forces) as part of the calculation.

The back tension (or incoming tension) can be changed later to see the effect. Click into the cell and modify the value with a return, and the program will recalculate the tensions throughout the pull.



## Back tension guidance

Back tension will depend on a number of factors:

1. The total cable reel weight being turned.
2. The diligence of the workers hand-turning the reel and hand-feeding the cable.
3. The use and quality of reel feeders for very heavy cable reels.
4. The distance and gravitation directional from the reel to the conduit entrance.
5. The reel stand and unwinding spindle.
6. Any braking system on the reels.

Consider these factors when estimating reel back tension.

As the calculations will show, minimizing back tension can significantly lower the estimated pulling tension. Back tension control in the field is an important part of good cable pulling procedure.

## Conduit Segment Approach

### General segment entry approach

The Pull-Planner 4.0 uses the same conduit system data approach as previous Pull-Planner Software versions. Data are input by “segments” where a segment is a straight conduit section followed by a conduit bend.

This approach is practical from a tension calculation standpoint. Straight sections add to incoming tension on a linear basis and bends multiply incoming tension. So, each straight section adds to the tension from the previous bend, and each bend multiplies the tension from the previous straight section.

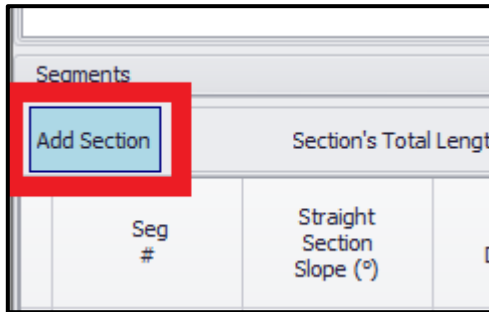


Seg #	Slope Direction	Straight Section Length (ft)	Straight Section COF	Tension (lbs)	Sideload Pressure (lbs/ft)
1	0.0	220	0.220	361	
2	Up	30	0.220	731	
3	--				
4	Vertical Down				
5					

Each segment is numbered and contains a straight section followed by a bend section.

### Straight section length, angle, angle direction

To input a straight section, click the Add Section button on the left of the Pull-Planner 4.0 Software.



Click on the 0° or 90° button if the straight section is at either of those slopes; otherwise click Theta, and enter in the straight section slope in the pop-up box (must be between 0 and 90 degrees). The Straight Section Slope entry is the gravitational slope of the conduit straight section. It is the angle from a horizontal line (in degrees). If the conduit is horizontal, enter "0" (zero) for the Straight Section Angle. If there is no conduit straight section, enter "0" (zero) for the Straight Section Slope.

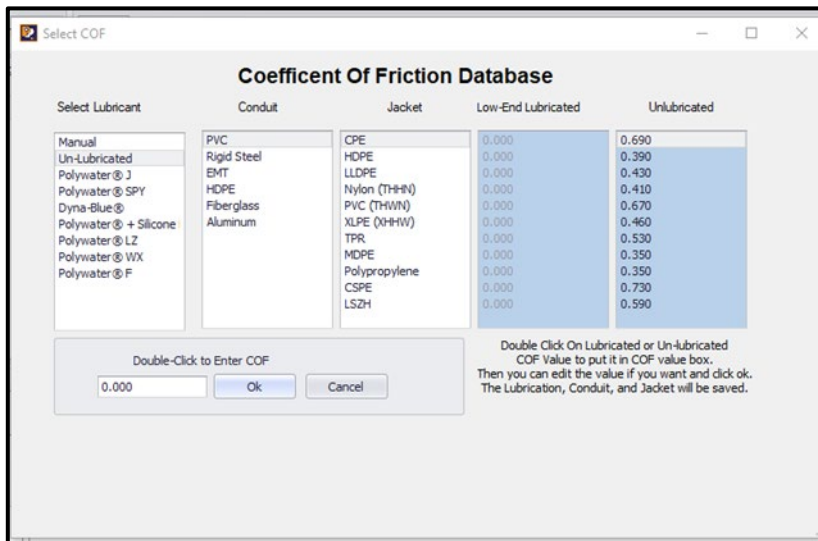
For any Straight Section Slope greater than 0 (zero), a Slope Direction entry is required, and another box will pop up. Click on whether the Slope Direction is up or down. This is the gravitational direction of cable movement through the angled straight section, uphill or downhill.

Then you will enter the conduit Straight Section Length (in feet or meters). If there is no straight section, enter a "0" (zero) for both the Straight Section Slope and the Straight Section Length.

If you would like to change any of the inputs shown in the box below, simply double-click on the cell you would like to change and input your desired value.

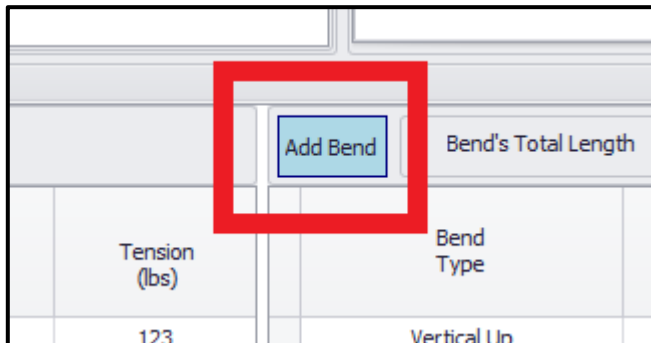
Seg #	Straight Section Slope (°)	Slope Direction	Straight Section Length (ft)	Straight Section COF	Tension (lbs)
1	1.0	Up	10.0	0.11	123
2	41.0	Down	500.0	0.11	-8044
3	0.0	--	200.0	0.11	868
4	15.0	Up	40.0	0.11	1488
5	90.0	Up	50.0	0.11	2988

If you are changing the Straight Section COF, the Coefficient of Friction Database will pop up and help you select the COF appropriate for this section. Otherwise you may input the COF yourself and click OK.



### Bend type, direction, radius, angle

After you finish a straight section you will be asked to input a bend section. If you would like to immediately add a bend section with no straight section, click the Add Bend button shown below.



You will first be asked to select the Bend Type from a pop-up menu.

Bend Types are divided into the following types:

- No bend (in this section)
- Bend in a horizontal plane
- Bend with a vertical component where the inside of the bend faces gravitationally up
- Bend with a vertical component where the inside of the bend faces gravitationally down
- Large-radius bend (covered in the Large Radius Bend section)
- A roller displacement rather than a bend (covered in the Rollers and Sheaves section)
- A push-pull device rather than a bend (covered in the Push/Pull Devices section)

If a vertical concave up or down bend was specified, then input of the cable gravitational direction of pull through the bend is required. Is the cable being pulled "Up" through the bend (against gravity) or "Down" through the bend (with gravity)?

You will then input the bend radius. Bend radius is the radius of the conduit bend (in feet or meters). It is the radius of the circle formed if the bend were continued for 360 degrees. The bend radius is available in conduit specifications for factory-made bends, and it can be calculated for field-made bends.

Note that if the bend radius is 6 inches (or 15 cm), the proper entry is "0.5 feet" (or "0.15" meters). The radius entry will be rounded to 2 decimal places.

You will then input the bend angle. Bend angle is the angle of the bend (in degrees). The Bend Angle must be a number between "0" and "90" degrees. The Bend Angle is the bend's angular displacement from a continuing straight line. For example, a bend that redirects the cable 45 degrees from a straight line is called a "45 degree" bend, even though the actual angle in the conduit is 135 degrees (180 minus 45). The bend angle will be rounded to 1 decimal place.

The Bend Length will automatically be calculated from the bend radius and angle.

If you would like to change any of the inputs shown in the box below, simply double-click on the cell you would like to change and input your desired value.

Add Bend		Bend's Total Length	18.4 ft		Pull's Total Length	758.4 ft	
Bend Type	Bend Direction	Bend Radius (ft)	Bend Angle (°)	Bend Length (ft)	Bend COF	Tension (lbs)	Sidewall Pressure (lbs/ft)
Vertical Up	Up	30.00	10.0	5.2	0.11	166	4
Vertical Down	Down	0.02	50.0	0.0	0.11	3	97
Vertical Up	Up	50.00	15.0	13.1	0.11	1010	13
None	--	0.00	0.0	0.0	0.11	1488	0

If you would like to change the Bend COF, double-click on the cell you would like to change, and the Coefficient of Friction Database will pop up and help you select the COF appropriate for this section. Otherwise you may input the COF yourself and click OK.

### Complex bends and azimuth angles

Some bends can be "complex", that is, have both horizontal and vertical components. While the forces in such complex bends could be vectored out, the calculational differences are minimal compared to other factors. Rather than add the complexity of calculations with an azimuth angle, it is recommended that you use the horizontal equation if the bend is within 10 degrees of horizontal, and the appropriate vertical equation is within 10 degrees of vertical. Otherwise, you can calculate both the horizontal and vertical and use the most conservative (highest tension) alternative. You will note that there is not much difference in the vertical versus horizontal unless the bends are very large-radius bends.

## Large-Radius Bends

### Entering a large-radius bend

For the large-radius bends common in directional drilling, the radius and bend angle input required in the equations can be calculated from typical available data. Available field data may include the radius of the bend, the total arc length, the depth of the bore, or the distance between entry and exit points. When a bore placement can be treated as a large-radius bend (partial circle), the bend angle and radius can be determined from any two known parameters using the Large-Radius Bend insert tool.

To insert the Large-Radius Bend, start by clicking the Add Bend button and then choosing the Large-Radius Bend option.

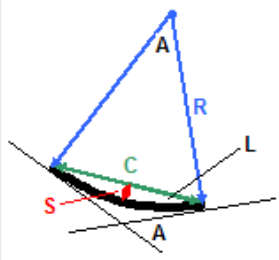
The screenshot shows a software interface with a table of sections and a 'Conduit Bend Options' menu. The 'Add Bend' button is highlighted in red in the top right of the sections table. The 'Conduit Bend Options' menu is open, showing various bend types: No Bend, Horizontal Bend, Vertical Up, Vertical Down, Roller, Large Bend Radius (highlighted in red), and Push/Pull Device.

This action will bring up the Large-Radius Bend Calculator.

### Large-radius bend calculator


**Large Radius Bend Calculator**

Any two variables below can be used to determine the angle and radius of the bend required for software input. Please fill in two of the input boxes and calculations are automatic.




L = Bend Length (feet)	<input type="text"/>
R = Bend Radius (feet)	<input type="text"/>
A = Bend Angle (degrees)	<input type="text"/>
C = Bend Chord (feet)	<input type="text"/>
S = Bend Sagitta (feet)	<input type="text"/>


Bend Types



**Horizontal**

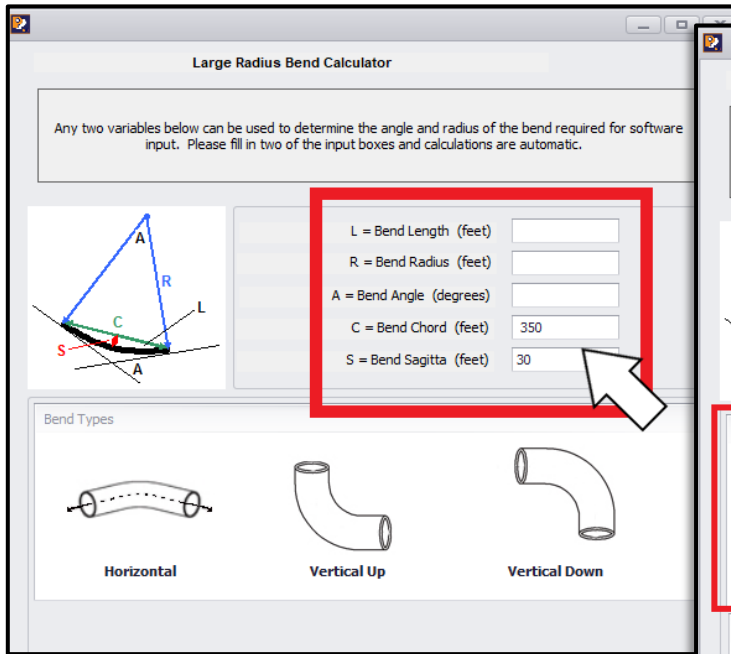


**Vertical Up**

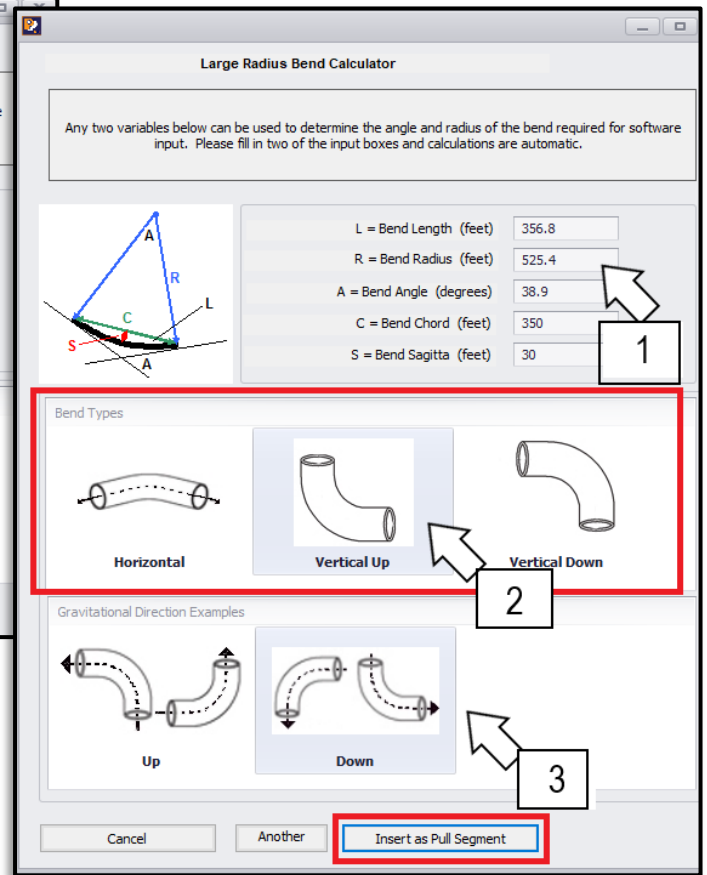


**Vertical Down**

Fill in two of the five parameters so that the program can calculate the bend length, radius, and angle for calculation.



For example, if you know the bend chord and the sagitta (depth of the bend), enter these values and hit return to calculate.



The program will calculate the remaining three parameters, in this case the bend length, bend radius, and bend angle. You will then have to choose a bend type and for vertical bends, you will have to choose a bend direction. Once you have done this, you can insert as a pull segment.

Add Bend		Bend's Total Length	375.6	ft	Pull's Total Length	855.6	ft
Bend Type	Bend Direction	Bend Radius (ft)	Bend Angle (°)	Bend Length (ft)			
Vertical Up	Up	3.00	90.0	4.7			
Vertical Down	Up	3.00	90.0	4.7			
Horizontal	--	3.00	90.0	4.7			
Vertical Down	Down	3.00	90.0	4.7			
▶ Vertical Up	Down	524.10	39.0	356.7			

If the bend angle is greater than 90° and less than 180°, the program will break the bend into two segments. The first will include the first 90° of bend with appropriate bend length, and the second segment will include the remainder.

Add Bend		Bend's Total Length	491.4	ft	Pull's Total Length	971.4	ft
Bend Type	Bend Direction	Bend Radius (ft)	Bend Angle (°)	Bend Length (ft)			
Vertical Up	Up	3.00	90.0	4.7			
Vertical Down	Up	3.00	90.0	4.7			
Horizontal	--	3.00	90.0	4.7			
Vertical Down	Down	3.00	90.0	4.7			
None	--	0.00	0.0	0.0			
Vertical Up	Down	62.00	90.0	97.4			
Horizontal	--	62.00	90.0	97.4			
Horizontal	--	62.00	17.0	18.4			

However, since a vertical bend cannot maintain a direction for more than 90°, the second bend will always be described as horizontal. The user must adjust the two segment bend data to accurately represent the pull.

Care should be used in describing large-radius bends. For instance, a conduit that goes into the ground at point A and comes up at point B might be described as a large-radius bend, but it is actually two bends with the first being gravitational direction down and the second gravitational direction up. See Reference (21) or [Appendix D](#) for additional information on large-radius bend calculations.

## Rollers and Sheaves

Rollers or roller blocks are used to redirect cable at an access point such as a manhole. The Pull-Planner 4.0 inserts a roller as a separate bend segment in the pull, and initial input is the segment location of the roller. The software treats a roller as a fixed tension add-on. The user should set the Roller Add tension based on input from the roller manufacturer, the cable manufacturer, or field experience. The radius of the roller is required for sidewall pressure calculations through the roller. For an appropriate radius for quadrant blocks (multiple in-line rollers), consult the cable or block manufacturer.

### Inserting a roller/sheave into the pull

To insert a Roller/Sheave, start by clicking the Add Bend button and then choosing the Roller option.

This brings up a Roller Add column:

Add Bend		Bend's Total Length	18.8	ft	Pull's Total Length	498.8	ft	
Bend Type	Bend Direction	Roller Add (lbs)	Bend Radius (ft)	Bend Angle (°)	Bend Length (ft)	Bend COF	Tension (lbs)	Sidewall Pressure (lbs/ft)
Vertical Up	Up	0.0	3.00	90.0	4.7	0.220	555	95
Vertical Down	Up	0.0	3.00	90.0	4.7	0.220	1123	192
Horizontal	--	0.0	3.00	90.0	4.7	0.220	1933	331
Vertical Down	Down	0.0	3.00	90.0	4.7	0.220	3030	518
None	--	0.0	0.00	0.0	0.0	0.220	2880	0
Roller	--	0.0	0.00	0.0	0.0	0.000	0	0

Input the roller tension in the Roller Add column and then input the roller radius for the Bend Radius. Bend Angle, Bend Length, and Bend COF are not active for this add-on.

### Guidelines for typical add-on roller tension

The coefficient of a well-lubricated sheave approaches zero so that the primary tension add-on is used to account for the force required to bend the cable around the sheave. This value can be determined through experience and will depend on the weight and flexibility of the cable, as well as the condition of the roller. Since rollers are not perfect frictionless bearings, typical calculations add a fixed tension for each roller. Typical add-on tension is 75 to 200 lbs (35-90 Kgs). See the rollers in the cable tray section for more information. Regardless, rollers (versus a hard conduit bend) usually lower the overall tension of a pull, since they act as an added tension rather than a multiplier.

There is still an inward force on the cable going around a roller (sidewall pressure), and the common approach is to divide tension coming out of the roller by the radius, just as is done with conduit bends. The Pull-Planner 4.0 Software uses the radius of the roller to calculate the resulting sidewall pressure. It is important that the radius input is the actual roller radius. Small radius rollers can result in high sidewall pressure.

### Effect of the roller on pull and sidewall tensions

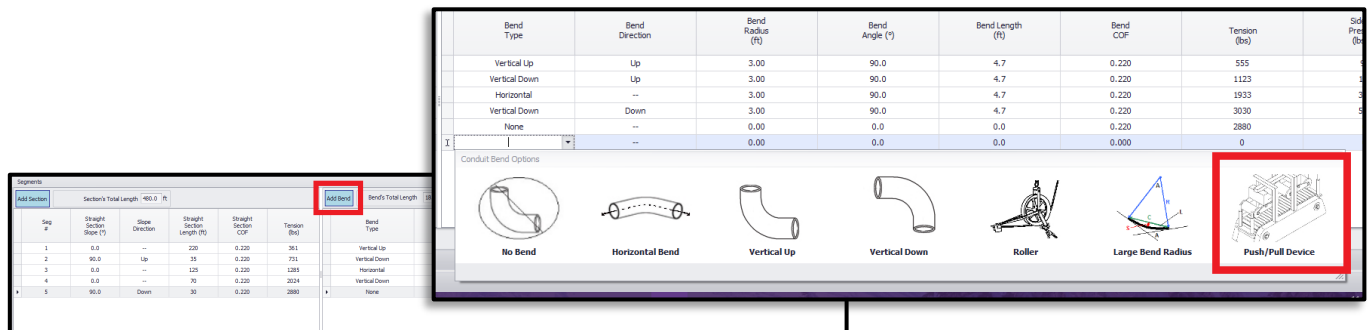
The roller increases tension as a direct addition of the Roller Add tension. Rollers will impact the sidewall tension for that section of the pull. The roller radius is used to calculate sidewall pressure so that a small-radius roller may result in a large sidewall pressure.

## Push/Pull Devices

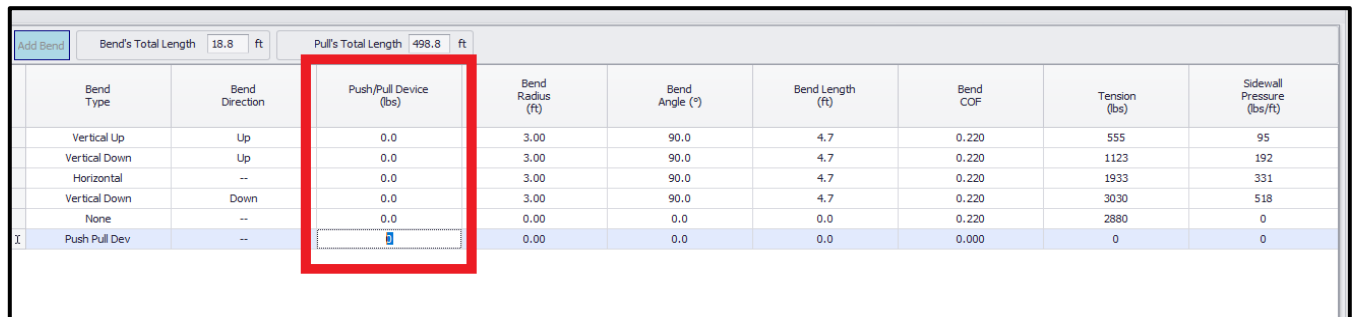
### Inserting the push/pull device

Push/Pull Devices advance the cable by mechanically grabbing the cable jacket. The imparted force can lower the pulling force required at the end of the run. The Pull-Planner 4.0 inserts a Push/Pull Device as a separate segment in the pull, and the initial input is the location of the device.

To insert a Push/Pull Device, start by clicking the Add Bend button and then choosing the Push/Pull Device option.



This brings up the Push/Pull Device column:



Add the tension the device imparts in the Push/Pull Device column. This is the only entry active for this add-on. The added pushing tension will be subtracted from the incoming tension of the segment.

Tension entered for the Push/Pull Device can be edited by double-clicking the cell.

### Guidance on the use of push/pull devices

The software treats the pushing force as a “negative tension” and it is carried forward as negative tension. Typically, these negative numbers approach zero and eventually go positive as you get farther in the pull. A negative tension at the end of a segment indicates that the cable is still advancing from the pushing force and pull is not yet required.

The effect of friction reduction is just as significant on a cable that is pushed as one that is pulled.

Pull-Planner 4.0 makes no judgments on the “ability” to actually push a cable with the input force. Flexible cables just tend to bunch up in the conduit and cannot be pushed.

### Reversing a pull with a push/pull device

When a Push/Pull Device is added to the raceway design, the Reverse Pull is deactivated and this option is unavailable. It is possible to remove the Push/Pull Device and reverse the pull. Once the pull is reversed, it can be moved to the Segment Input/Edit working tab so that the data can be edited. First, save the pull from the Reverse Segment tab using the Save As icon on the top ribbon. The pull will be saved with the existing file name appended with "-Reverse". The saved reverse pull can then be imported into the software by using the top screen Open icon. Once imported, file name and/or any other data can be changed. In this case, the Push/Pull Device can be reinserted into the pull.

### Using a push/pull device to preserve negative tension

Negative tensions from each full segment are reset to zero incoming tension ( $T_{in}$ ) for the next segment calculation. For example, in the raceway below, inputs are a cable weight of 46 lbs/ft and a coefficient of friction value of 0.15. The first segment includes a downward bend so that the  $T_{out}$  is -175 lbf. The second segment is a straight section, but does not include this incoming negative tension:

$$T_{out} = T_{in} + \mu WL = 0 + (0.15)(46 \times 240) = 1656$$

In this case the  $T_{in}$  is 0.

The screenshot shows the software interface for a pull calculation. At the top, the 'PPD Preserves Negative Tension' is selected. The Conduit Inner Diameter is 16.00 in, CCF is 0.15, and Back Tension is 0 lbs. The Cables table shows 1 cable with a weight of 46.000 lbs/ft. The Segments table shows 5 segments with their respective lengths, slopes, and tensions. The Tension values are 172, 1656, 8665, 18904, and 20620 lbs. The Bend table shows a downward bend at 45 degrees with a tension of -175 lbs.

Seg #	Straight Section Slope (°)	Slope Direction	Straight Section Length (ft)	Straight Section CCF	Tension (lbs)
1	0.0	--	25.0	0.15	172
2	0.0	--	240.0	0.15	1656
3	0.4	Up	1200.0	0.15	8665
4	12.0	Up	80.0	0.15	18904
5	0.0	--	25.0	0.15	20620

Bend Type	Bend Direction	Bend Radius (ft)	Bend Angle (°)	Bend Length (ft)	Bend CCF	Tension (lbs)	Sidual Pressure (lbs/ft)
Vertical Down	Down	40.00	45.0	31.4	0.15	-175	0
Vertical Up	Down	800.00	45.0	628.3	0.15	-5165	0
Vertical Up	Up	800.00	30.0	418.9	0.15	17599	22
Vertical Down	Up	100.00	20.0	34.9	0.15	20448	204
None	--	0.00	0.0	0.0	0.15	20620	0

A Push/Pull Device (PPD) can be entered with zero force. This preserves the negative tension as a negative  $T_{in}$  for the all the segments following the PPD.



<b>Add Bend</b>	Bend's Total Length	1113.5 ft	Pull's Total Length	2683.5 ft
Bend Type	Bend Direction	Push/Pull Device (lbs)	Bend Radius (ft)	
Push Pull Dev	--	0	0.00	
Vertical Down	Down	ft	40.00	

Using the same example raceway as before with the addition of the PPD, the second (now third) segment includes the negative incoming tension:

$$T_{out} = T_{in} + \mu WL = -175 + (0.15)(46 * 240) = 1481$$

PPD Preserves Negative Tension

Conduit Inner Diameter: 16.00 in    COF: 0.15    Back Tension: 0 lbs

Cable Type	Cable Outer Diameter (in)	Number of Cables	Cable Weight (lbs/ft)
1	6.770	1	46.000

Information

Pull Description : PPD Preserves Negative Tension  
Pull File Name : HelpExamplePPD.xpl

Conduit ID : 16.00 Inch(es)    Conduit Fill : 17.9%

Total of 1 cable(s) of 1 different type(s) being pulled.

Type # | Cables | Cable OD (in) | Cable Weight (lbs/ft)  
1 | 1 | 6.770 | 46.000

Total cable weight : 46.000 lbs/ft  
Weight correction factor set to: 1  
Configuration : Single Cable

Jam/Clearance Analysis : Jamming Not Possible

Seg #	Straight Section Slope (°)	Slope Direction	Straight Section Length (ft)	Straight Section COF	Tension (lbs)	Bend Type	Bend Direction	Push/Pull Device (lbs)	Bend Radius (ft)	Bend Angle (°)	Bend Length (ft)	Bend COF	Tension (lbs)	Sidewall Pressure (lbs/ft)
1	0.0	--	0.0	0.15	0	Push Pull Dev	--	0	0.00	0.0	0.0	0.15	0	0
2	0.0	--	25.0	0.15	172	Vertical Down	Down	0	40.00	45.0	31.4	0.15	-175	0
3	0.0	--	240.0	0.15	1481	Vertical Up	Down	0	800.00	45.0	628.3	0.15	-5318	0
4	0.4	Up	1200.0	0.15	3347	Vertical Up	Up	0	800.00	30.0	418.9	0.15	11847	15
5	12.0	Up	80.0	0.15	13152	Vertical Down	Up	0	100.00	20.0	34.9	0.15	14387	144
6	0.0	--	25.0	0.15	14560	None	--	0	0.00	0.0	0.0	0.15	14560	0

## Organizing data for segment entry

A worksheet is available to help organize the cable, conduit, and raceway data to enter the pull. See link below

[Pull Planner Worksheet Entry Form](#)

## Tension Calculations

### Additive nature of tension

Tension builds in cable pulls. In straight sections it is added from one section to the next. In bends, incoming tension is a multiplier. The tension calculated at the end of a segment depends on the tension developed in previous segments. Generally, the highest tension on the cable is after the final segment (the end of the pull). However, this may not be true if there is a significant "downhill" gravitational component or a Push/Pull Device somewhere in the pull.

The maximum estimated tension on a cable can be determined by looking for the highest tension reported at the end of each segment (second from right Tension column). If there is no bend in a segment, the tension from the previous straight section is carried forward to the second from right Tension column.

### Maximum tension determination

Excessive pulling tension will damage the cable. It may cause voids or other physical damage that will become focal points for corona deterioration and other electrical degradation.

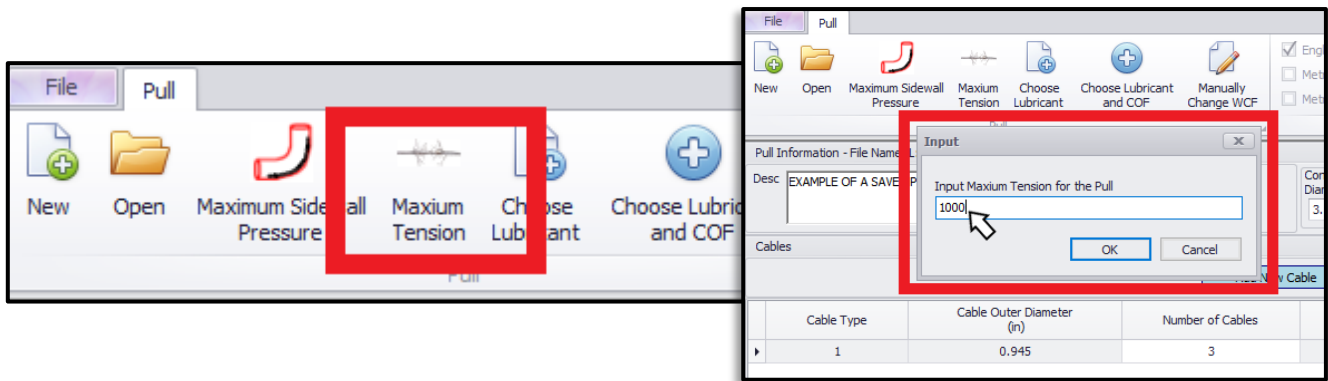
Cable manufacturers and other equipment suppliers have set guidelines for maximum cable tension. This is typically based on the following:

- Allowable tension on the cable gripping device
- Allowable tension on conductor (by conductor material)
- Allowable sidewall bearing pressure

Adhere to any limits established by the gripping device manufacturer. It is generally best to grip the cable by the conductor so that cable pulling force is focused on the conductor. Maximum allowable conductor tension will depend on the conductor material (copper or aluminum), the temper, and the size. Sidewall tension maximums will depend on the cable type, shielding, and whether the cable is armored.

### Flagging maximum tension

To flag maximum cable tension, click the Maximum Tension icon. An input box will open. Type in the value and click okay:



When the estimated tension exceeds this value, it will be highlighted with a dark grey.

Tension (lbs)	Bend Type	Bend Direction	Bend Radius (ft)	Bend Angle (°)	Bend Length (ft)	Bend COF	Tension (lbs)
283	Vertical Up	Up	3.00	90.0	4.7	0.160	394
570	Vertical Down	Up	3.00	90.0	4.7	0.160	788
906	Horizontal	--	3.00	90.0	4.7	0.160	1218
1285	Vertical Down	Down	3.00	90.0	4.7	0.160	1715
1565	None	--	0.00	0.0	0.0	0.160	1565

Denotes Tension or Sidewall Pressure exceeded

The flagging feature serves as a convenient reminder when tension or sidewall pressure is above an established maximum. It will not stop the calculations.

To remove the tension and/or sidewall pressure maximums, use the Flag Maximum For Cable Tension / Sidewall Pressure option again and set all maximums to zero.

### Maximum tension for multiple cables

If there are multiple cables, the literature suggests using 50% to 80% of the added maximum tension total for all cables. If pulling three cables, the most common recommendation is that two of the three cables bear the load. The tension on any single cable is assumed to be the total bundle tension divided by two. In this case, the total tension for the bundle will be 66% of the totaled maximum tension for the three cables. The max tension factor does not impact the tension calculation itself.

Example: If you had 3 identical cables pulled as a bundle and each cable has a maximum tension limit of 1,000 lbs. you would set the Maximum Tension as 2,000 lbs., which is 66% of the totaled maximum tension.

## Sidewall tension calculation

Sidewall pressure (or sidewall bearing pressure, SWBP) is a measure of the normal force pushing a cable against the conduit wall as it is pulled around a bend. Excessive sidewall force can crush a cable and is one of the most restrictive factors in installations with bends. It is directly proportional to the tension coming out of the bend and the radius of the bend. The following equations are used to calculate sidewall pressure:

$$1 \text{ Cable} \quad SP = \frac{T_{out}}{R}$$

$$2 \text{ Cables} \quad SP = \left(\frac{w}{2}\right) \frac{T_{out}}{R}$$

$$3 \text{ Cables (Cradled)} \quad SP = \left(\frac{3w-2}{3}\right) \frac{T_{out}}{R}$$

$$3 \text{ Cables (Triangular)} \quad SP = \left(\frac{w}{2}\right) \frac{T_{out}}{R}$$

$$4 \text{ or more Cables} \quad SP = \left(\frac{w}{2}\right) \frac{T_{out}}{R}$$

Where  $SP$  = Sidewall Pressure

$T_{out}$  = Tension coming out of the bend (Lb<sub>f</sub>, Kg<sub>f</sub>, KN)

$R$  = Bend Section Radius (feet, meters)

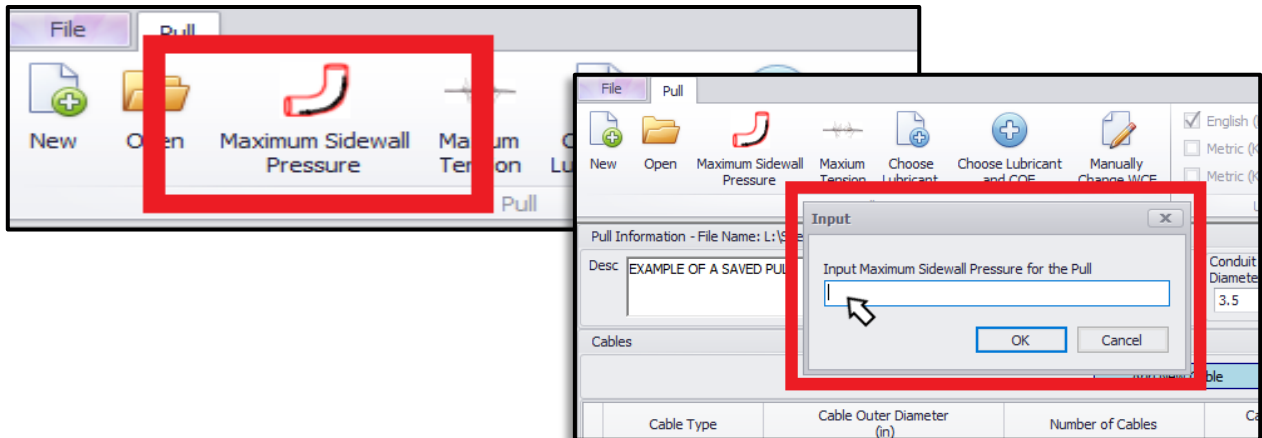
$w$  = Weight correction factor (dimensionless)

Sidewall pressure is specific to each bend. If there is no bend, there is no sidewall pressure. The highest sidewall pressure is not necessarily at the end of the pull. Sidewall pressure can be lowered by increasing the radius of the bend.

The maximum sidewall pressure on a cable can be determined by looking for the highest sidewall pressure reported at the end of each bend segment (far right Sidewall Pressure column).

## Flagging maximum sidewall tension

To flag maximum sidewall tension, click the Maximum Sidewall Pressure icon. An input box will open. Type in the value and click OK:



When the estimated sidewall pressure exceeds this value, it will be highlighted with a dark grey.

Tension (lbs)	Sidewall Pressure (lbs/ft)
394	67
788	135
1218	208
1715	293
1565	0

Since the maximum sidewall pressure depends on the tension coming out of the bend and the radius of the bend, the sidewall tensions can vary significantly by segment. Increasing the bend radius, along with any tension reduction, will lower sidewall pressure.

The flagging feature serves as a convenient reminder when tension or sidewall pressure is above an established maximum. It will not stop the calculations.

### Sidewall Tension Guidance

Sidewall tension guidance is offered by the cable manufacturer. See below for general guidance.

#### For Power Cables:

Cable Type	Maximum sidewall pressure	
	Lb <sub>r</sub> /ft	N/m
600 V multi-conductor (non-shielded)	500	7300
600 V and 1 kV single conductor	----	----
Size 8 and smaller	300	4380
Size 6 and larger	500	7300
5 to 15 kV power cable (shielded)	500	7300
25 to 35 kV power cable (shielded)	300	4380
Interlocked armored cable (all voltage classes)	300	4380
Instrumentation cable – single pair (shielded)	300	4380
Instrumentation cable – multi-pair (shielded)	500	7300

IEEE 1185-2019, “Recommended Practice for Cable Installation in Generating Stations and Industrial Facilities”, Table 7

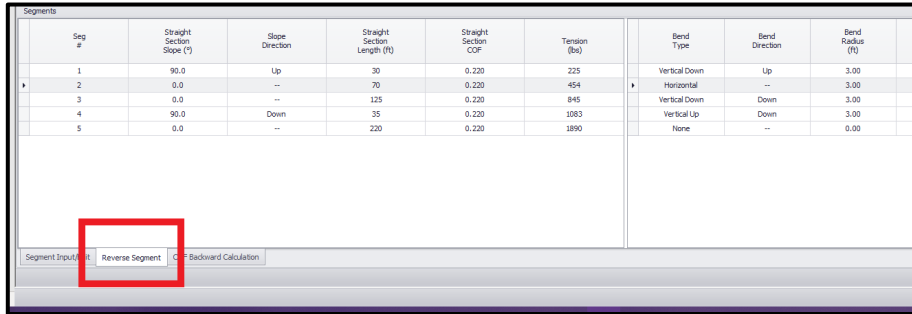
Since sidewall pressure limits may vary based on the type of cable armor employed, it is recommended to consult with the cable manufacturer to determine the maximum allowable sidewall pressure for the cable used in the installation.

#### For Communication Cables:

Fiber optic cables may meet crush strength requirements found in Telcordia GR-20-CORE 1,500 lbs./ft (21890 N/m). Recommended guidance for maximum sidewall tension is 50% of that value or 750 lbs./ft (10945 N/m). IEC 60794 1-2 Method E3 and TIA/EIA-455-41A both describe crush test methods.

## Reversing the Pull

The direction of pull is reversed by clicking on the Reverse Segment tab. This is usually done to determine if there are theoretical differences in pulling tension based on cable feed direction. Data cannot be entered or changed on the Reverse Segment tab.



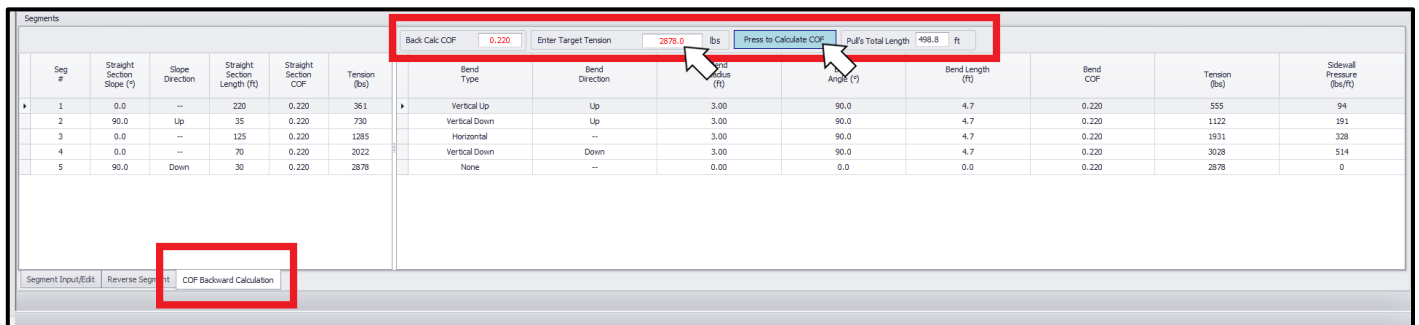
Seg #	Straight Section Slope (°)	Slope Direction	Straight Section Length (ft)	Straight Section COF	Tension (lbs)	Bend Type	Bend Direction	Bend Radius (ft)
1	90.0	Up	30	0.220	225	Vertical Down	Up	3.00
2	0.0	--	70	0.220	454	Horizontal	--	3.00
3	0.0	--	125	0.220	845	Vertical Down	Down	3.00
4	90.0	Down	35	0.220	1083	Vertical Up	Down	3.00
5	0.0	--	220	0.220	1890	None	--	0.00

To move reverse direction details to the Segment Input/Edit working tab so that the data can be edited, the pull must first be saved from the Reverse Segment tab using the Save As icon on the top ribbon. The pull will be saved with the existing file name appended with "-Reverse". The saved reverse pull can then be imported into the software by using the top screen Open icon. Once imported, file name and/or any other data can be changed.

When using a Push/Pull Device the Reverse Segment tab will be disabled. The Push/Pull Device must be removed to reenable the Reverse Segment tab.

## Back-calculating Effective Coefficient of Friction

The Pull-Planner 4.0 will calculate an "effective coefficient of friction" based on actual pull tension data. Go to the COF Backward Calculation tab and enter the target pull tension, or the pull tension measured after the cable installation. Press to calculate the COF.



Seg #	Straight Section Slope (°)	Slope Direction	Straight Section Length (ft)	Straight Section COF	Tension (lbs)	Bend Type	Bend Direction	Bend Radius (ft)	Angle (°)	Bend Length (ft)	Bend COF	Tension (lbs)	Sidewall Pressure (lbs/ft)
1	0.0	--	220	0.220	361	Vertical Up	Up	3.00	90.0	4.7	0.220	555	94
2	90.0	Up	35	0.220	730	Vertical Down	Up	3.00	90.0	4.7	0.220	1122	191
3	0.0	--	125	0.220	1285	Horizontal	--	3.00	90.0	4.7	0.220	1931	328
4	0.0	--	70	0.220	2022	Vertical Down	Down	3.00	90.0	4.7	0.220	3028	514
5	90.0	Down	30	0.220	2878	None	--	0.00	0.0	0.0	0.220	2878	0

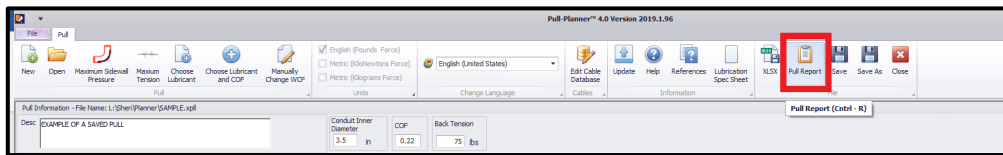
The Back Calc COF (red) value in the red box is calculated using the pull segment data and the target tension entered by the user in the Target Tension box. The calculated COF produces the closest tension within the variance and significant figures of the variable inputs.

The Backward Calculation feature can be quite useful in accessing pulling operations or actual field conditions. While the back-calculated COF is given to three decimal places, this is for calculational accuracy. The Pull-Planner 4.0 will only allow a user to input COF to two decimal places.

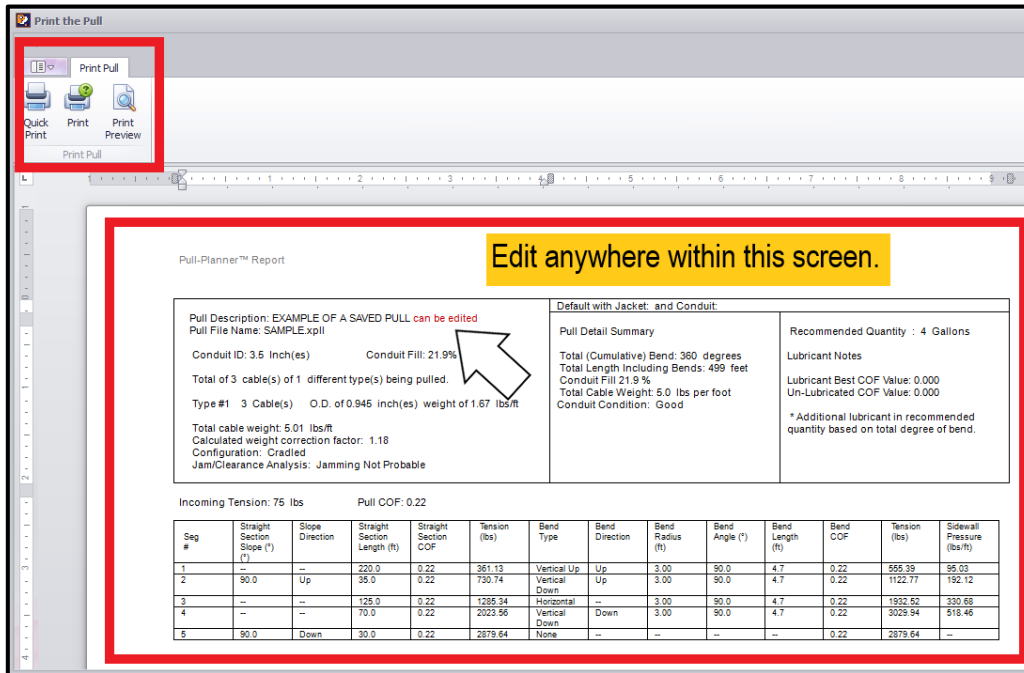
## Pull Report

### How to download, edit, and print the pull report

To download the Pull Report, start by clicking the Pull Report icon on the top bar:



This will bring the details of the current pull into a report form. The report can be edited as desired, and then printed.



The Print button will bring you to your standard print dialogue screen.

## Cable Tray

Cable installed into tray is subject to many of the same considerations as cable being installed in conduit systems. Multiple sources offer guidance [Reference 8 and 17] and suggest that lubrication will lower overall tension. The following support roller spacing is suggested:

$$S = \sqrt{\frac{8HT}{W}}$$

Where:  $S$  = Distance between rollers in feet (meters)

$H$  = Height of top of rollers above tray surface in feet (meters)

$T$  = Tension in pounds (kilograms)

$W$  = Weight of cable per length, lbs/ft (kg/m)

This spacing keeps the cable taut to reduce sag and drag. It also allows for relatively straight runs, bend to bend. If rollers or sheaves are free-turning, well designed and lubricated, and in good operating condition, a suggested coefficient of friction (COF) factor of 0.15 may be used to calculate the straight section tension. This COF factor may be varied based on field experience.

Tension is not multiplied when the cable is pulled around the bend through free-turning sheaves or rollers. The coefficient of a well-lubricated sheave approaches zero so that the tension add-on is used to account for the force required to bend the cable around the sheave. This value can be determined through experience and will depend on the weight and flexibility of the cable. Literature references indicate a 100- to 150-pound add-on for a 3/C 15 kV 500 kcmil copper conductor with metallic sheath.

The Pull-Planner Software can assist in planning this type of installation. Tension is calculated by adding the values section to section:

- For the straight sections through horizontal support rollers, treat as a straight section with 0° slope. Use a starting COF of 0.15 for the multiplier. Straight sections running up or down use the gravitational effect of the cable weight (length of run times the cable weight per length). Use a slope of 90° up or down. COF is not a factor in this scenario.
- Where the tray comes to a bend, use the Pull-Planner 4.0 roller function for the sheaves used.

## Appendix A – Equations

Below are the equations used in this program.

### HORIZONTAL STRAIGHT SECTION

$$T_{out} = w\mu WL + T_{in}$$

### INCLINED STRAIGHT SECTION

Pulling Up:  $T_{out} = T_{in} + WL [\sin(\varphi) + w\mu \cos(\varphi)]$

Pulling Down:  $T_{out} = T_{in} - WL [\sin(\varphi) - w\mu \cos(\varphi)]$

### HORIZONTAL BEND SECTION

$$T_{out} = T_{in} \cosh(w\mu\theta) + \left( \sinh(w\mu\theta) \sqrt{T_{in}^2 + (WR)^2} \right)$$

### VERTICAL CONCAVE UP BEND

Pulling Up:  $T_{out} = T_{in} e^{w\mu\theta} - \left( \frac{WR}{(1+(w\mu)^2)} \right) [(2w\mu \sin(\theta)) - (1 - (w\mu)^2)(e^{w\mu\theta} - \cos(\theta))]$

Pulling Down:  $T_{out} = T_{in} e^{w\mu\theta} - \left( \frac{WR}{(1+(w\mu)^2)} \right) [(2w\mu e^{w\mu\theta} \sin(\theta)) + (1 - (w\mu)^2)(1 - e^{w\mu\theta} \cos(\theta))]$

### VERTICAL CONCAVE DOWN BEND

Pulling Up:  $T_{out} = T_{in} e^{w\mu\theta} + \left( \frac{WR}{(1+(w\mu)^2)} \right) [(2w\mu e^{w\mu\theta} \sin(\theta)) + (1 - (w\mu)^2)(1 - e^{w\mu\theta} \cos(\theta))]$

Pulling Down:  $T_{out} = T_{in} e^{w\mu\theta} + \left( \frac{WR}{(1+(w\mu)^2)} \right) [(2w\mu \sin(\theta)) - (1 - (w\mu)^2)(e^{w\mu\theta} - \cos(\theta))]$

### LARGE RADIUS BEND

Where  $T_{in} < WR$ , and  $0^\circ \leq \theta < 90^\circ$

Pulling Up:  $T_{out} = (T_{in} + T_{slope}) * \cosh(w\theta\mu) + \sinh(w\theta\mu) * \sqrt{(T_{in} + T_{slope})^2 + (WR')^2} + T_{slope}$   
 Where  $T_{slope} = \frac{WR\theta}{2} \left( \sin\left(\frac{\theta}{2}\right) + w\mu \left( \cos\left(\frac{\theta}{2}\right) \right) \right)$

Pulling Down:  $T_{out} = (T_{in} - T_{slope}) * \cosh(w\theta\mu) + \sinh(w\theta\mu) * \sqrt{(T_{in} - T_{slope})^2 + (WR')^2} - T_{slope}$   
 Where  $T_{slope} = \frac{WR\theta}{2} \left( \sin\left(\frac{\theta}{2}\right) - w\mu \left( \cos\left(\frac{\theta}{2}\right) \right) \right)$

Where:

$T_{in}$  = Tension into Section

$T_{out}$  = Tension out of Section

$w$  = Weight Correction Factor (dimensionless)

$\mu$  = Coefficient of Friction (dimensionless)

$W$  = Total Cable Assembly Weight per Unit of Length (Lbs/Ft or Kg/m)

$L$  = Straight Section Length (feet, meters)

$\varphi$  = Straight Section Angle from Horizontal (degrees)

$\theta$  = Bend Section Angle (radians natural log, or degrees), *entry is in degrees*

$R$  = Bend Section Radius (feet, meters)

$R'$  = 1 (foot, meter)



## Appendix B – Bibliography and references

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3. J. M. Fee, “A Pulling Tension Calculation Program that Allows Coefficient of Friction to Vary Continuously with Cable Sidewall Pressure,” Presented at IEEE/PES Transmission and Distribution Conference, May 1994.
4. R. C. Rifenburg, “Pipe-Line Design for Pipe-Type Feeders,” Presented at AIEE Power Apparatus & Systems Conference, December 1953
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# Appendix C – Pull-Planner™ Cable Tension Calculator Data Form

## Pull Identification

**Pull Name and Identification:** \_\_\_\_\_  
 \_\_\_\_\_

## Conduit and Cable Data

**Conduit Inner Diameter (in, mm):** \_\_\_\_\_

**Cable Information:**

	Type 1	Type 2	Type 3
Cable outside diameter (in, mm):	_____	_____	_____
Cable weight (lbs/ft, kg/m):	_____	_____	_____
Number of cables	_____	_____	_____

*Note: add additional cable type(s) if necessary.*

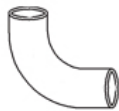
Cable jacket and conduit type: \_\_\_\_\_  
 (This will help determine COF)

## Raceway Bend Information

**Types of Bends**



Horizontal Bend

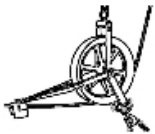


Vertical Concave Up

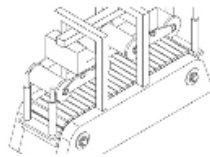


Vertical Concave Down

**Other Bend Inserts**

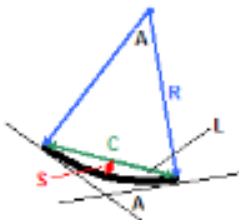


Roller



Push/Pull Device

**Large Radius Bends**



- L, Bend Length (ft, m) \_\_\_\_\_
- R, Bend Radius (ft, m) \_\_\_\_\_
- A, Bend Angle (degrees) \_\_\_\_\_
- C, Bend Chord (ft, m) \_\_\_\_\_
- S, Bend Sagitta (ft, m) \_\_\_\_\_

*Only two of the five variables are required.*

## Raceway Entry

### Segment 1

Straight Section

Straight Section Slope ( $\theta$  degrees) \_\_\_\_\_

Slope Direction (up/down) \_\_\_\_\_

Straight Section Length (ft, m) \_\_\_\_\_

Bend Section

Bend Type \_\_\_\_\_

Bend Direction (up/down) \_\_\_\_\_

Bend Radius (ft, m) \_\_\_\_\_

Bend Angle ( $\theta$  degrees) \_\_\_\_\_

### Segment 2

Straight Section

Straight Section Slope ( $\theta$  degrees) \_\_\_\_\_

Slope Direction (up/down) \_\_\_\_\_

Straight Section Length (ft, m) \_\_\_\_\_

Bend Section

Bend Type \_\_\_\_\_

Bend Direction (up/down) \_\_\_\_\_

Bend Radius (ft, m) \_\_\_\_\_

Bend Angle ( $\theta$  degrees) \_\_\_\_\_

### Segment 3

Straight Section

Straight Section Slope ( $\theta$  degrees) \_\_\_\_\_

Slope Direction (up/down) \_\_\_\_\_

Straight Section Length (ft, m) \_\_\_\_\_

Bend Section

Bend Type \_\_\_\_\_

Bend Direction (up/down) \_\_\_\_\_

Bend Radius (ft, m) \_\_\_\_\_

Bend Angle ( $\theta$  degrees) \_\_\_\_\_

### Segment 4

Straight Section

Straight Section Slope ( $\theta$  degrees) \_\_\_\_\_

Slope Direction (up/down) \_\_\_\_\_

Straight Section Length (ft, m) \_\_\_\_\_

Bend Section

Bend Type \_\_\_\_\_

Bend Direction (up/down) \_\_\_\_\_

Bend Radius (ft, m) \_\_\_\_\_

Bend Angle ( $\theta$  degrees) \_\_\_\_\_

### Segment 5

Straight Section

Straight Section Slope ( $\theta$  degrees) \_\_\_\_\_

Slope Direction (up/down) \_\_\_\_\_

Straight Section Length (ft, m) \_\_\_\_\_

Bend Section

Bend Type \_\_\_\_\_

Bend Direction (up/down) \_\_\_\_\_

Bend Radius (ft, m) \_\_\_\_\_

Bend Angle ( $\theta$  degrees) \_\_\_\_\_

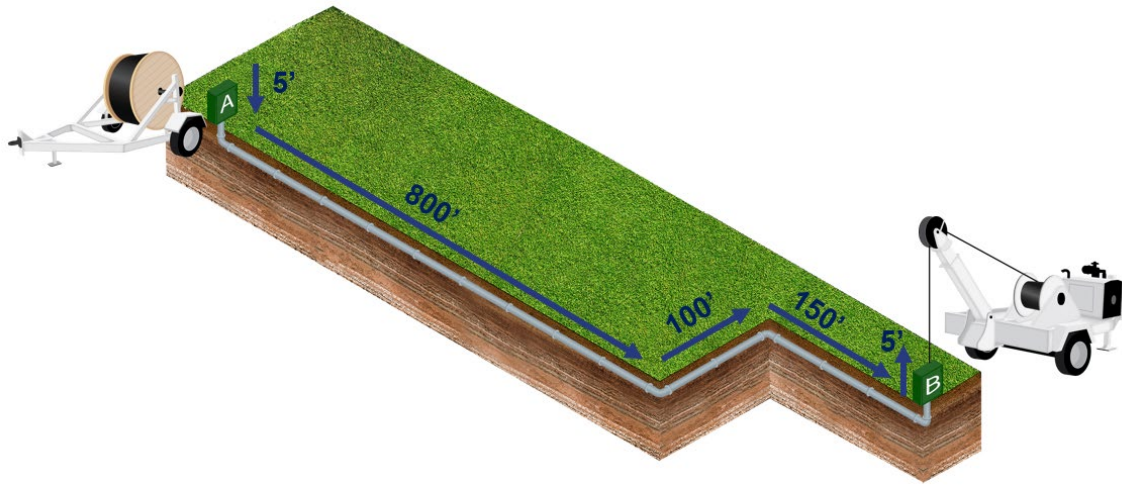
*Add additional segments as necessary.*

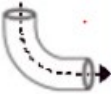

*Pull-Planner Software uses tension estimation equations common in technical studies and industry standards. For further information reference the Pull-Planner 4.0 Help Menu.*

## Appendix D – Example Entries

### Basic Pull -- Example 1

In this scenario, the raceway drops down with a 90 degree turn to make an underground, horizontal run with a couple of bends before turning back above ground. The raceway entry is broken into a series of straight and bend segments.



1. First segment is the run straight down underground with the 90 vertical up bend.
  - a. In this case, the pull direction is down: 
2. The second segment is a straight run (800 feet) ending with a horizontal bend. The third segment is a shorter straight run (100 feet) ending with a horizontal bend.
3. Segment four is a straight run (150 feet) and ends with a vertical up bend, the pull direction is up: 
4. The final segment ends with a straight, 5-foot section pulling up. The raceway ends with this straight section so there is no final bend section.

Below is the appearance in the Pull-Planner segment screen.

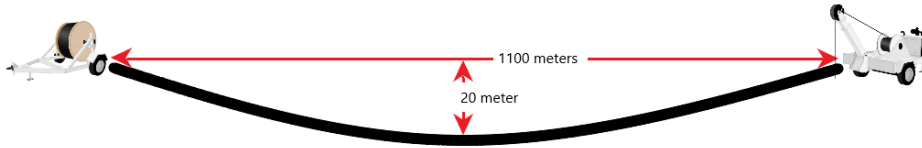
Add Section							Add Bend						
Section's Total Length 1060.0 ft							Bend's Total Length 25.1 ft		Pull's Total Length 1085.1 ft				
Seg #	Straight Section Slope (°)	Slope Direction	Straight Section Length (ft)	Straight Section COF	Tension (lbs)	Bend Type	Bend Direction	Bend Radius (ft)	Bend Angle (°)	Bend Length (ft)	Bend COF	Tension (lbs)	Sidewall Pressure (lbs/ft)
1	90.0	Down	5.0	0.11	170	Vertical Up	Down	4.00	90.0	6.3	0.11	178	23
2	0.0	--	800.0	0.11	797	Horizontal	--	4.00	90.0	6.3	0.11	977	125
3	0.0	--	100.0	0.11	1054	Horizontal	--	4.00	90.0	6.3	0.11	1293	166
4	0.0	--	150.0	0.11	1409	Vertical Up	Up	4.00	90.0	6.3	0.11	1750	225
5	90.0	Up	5.0	0.11	1780	None	--	0.00	0.0	0.0	0.11	1780	0

Once the data is entered, it is possible to change the COF, cable, or conduit information.

The tabs below the Segment Input/Edit screen can be toggled so that you can see the effect of reversing the pull. It is also possible to use the field measured tension to back-calculate the actual COF factor once the pull is completed.

## Large Radius Bend – Example 2

The large radius bend calculator can be used for a long, bend typical of horizontal directional drilling (HDD). In this example, there are actually two bends – in the first part the cable is pulled down into a vertical up bend and in the second part, the cable is pulled up into a vertical up bend.

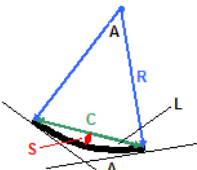


In this case you know the bend chord length (1100 m) and the sagitta length (20 m). In terms of segment entry, this is two bends. The first is a vertical up bend, pulling down and the second is a vertical up bend pulling up. In this case, you can split the two bends right down the middle.

Use the Large Radius Bend Calculator to determine the radius and arc length. To do this, start to enter a Large Radius Bend for the first segment to open the Large Radius Bend Calculator. Fill in the two variables that you know. (It doesn't matter which type of bend or gravitational direction at this point.) In this example:

**Large Radius Bend Calculator**

Any two variables below can be used to determine the angle and radius of the bend required for software input. Please fill in two of the input boxes and calculations are automatic.



L = Bend Length (meters)	1101
R = Bend Radius (meters)	7572.5
A = Bend Angle (degrees)	8.3
C = Bend Chord (meters)	1100
S = Bend Sagitta (meters)	20

You do not want to keep this bend segment. This exercise is to get the values for the Radius, 7572.5 meters and the Bend Angle, 8.3 degrees. To split into the two bends, the Radius would remain the same. Unfortunately, it exceeds the Pull-Planner entry limit. The Pull-Planner can still calculate this Large Radius Bend, but you will have to enter the Bend Length and the Bend Angle. These values must be divided by 2. Since the program rounds Bend Angle to the nearest 1/10<sup>th</sup>, use the slightly higher value in the Pull Up. This is the most conservative case. The pull is split into two segments:

1. Vertical Up Bend, Pulling Down with a Bend Length of 550.5 meters and a Bend Angle of 4.1 degrees.
2. Vertical Up Bend, Pulling Up with a Bend Length 550.5 meters and a Bend Angle of 4.2 degrees.

This preserves the correct cable length this design. The entry looks like this:

<input type="button" value="Add Bend"/>	Bend's Total Length 1101.0 m	Pull's Total Length 1101.0 m					
Bend Type	Bend Direction	Bend Radius (m)	Bend Angle (°)	Bend Length (m)	Bend COF	Tension (kN)	
Vertical Up	Down	7693.01	4.1	550.5	0.15	11.37	
Vertical Up	Up	7509.85	4.2	550.5	0.15	13.56	

These large radius bends do not generate high tension values and act very similar to gentle slopes.

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## CONTACT US

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