Water Distribution System Risk Tool for Investment Planning

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Water Distribution System Risk Tool for Investment Planning
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Water Distribution System Risk Tool for Investment Planning

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FOREWORD

The Water Research Foundation (WaterRF) is a nonprofit corporation dedicated to the development and implementation of scientifically sound research designed to help drinking water utilities respond to regulatory requirements and address high-priority concerns. WaterRF’s research agenda is developed through a process of consultation with WaterRF subscribers and other drinking water professionals. WaterRF’s Board of Trustees and other professional volunteers help prioritize and select research projects for funding based upon current and future industry needs, applicability, and past work. WaterRF sponsors research projects through the Focus Area, Emerging Opportunities, and Tailored Collaboration programs, as well as various joint research efforts with organizations such as the U.S. Environmental Protection Agency and the U.S. Bureau of Reclamation.

This publication is a result of a research project fully funded or funded in part by WaterRF subscribers. WaterRF’s subscription program provides a cost-effective and collaborative method for funding research in the public interest. The research investment that underpins this report will intrinsically increase in value as the findings are applied in communities throughout the world. WaterRF research projects are managed closely from their inception to the final report by the staff and a large cadre of volunteers who willingly contribute their time and expertise. WaterRF provides planning, management, and technical oversight and awards contracts to other institutions such as water utilities, universities, and engineering firms to conduct the research.

A broad spectrum of water supply issues is addressed by WaterRF’s research agenda, including resources, treatment and operations, distribution and storage, water quality and analysis, toxicology, economics, and management. The ultimate purpose of the coordinated effort is to assist water suppliers to provide a reliable supply of safe and affordable drinking water to consumers. The true benefits of WaterRF’s research are realized when the results are implemented at the utility level. WaterRF’s staff and Board of Trustees are pleased to offer this publication as a contribution toward that end.

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We would like to especially thank Mike Woodcock of the Washington Suburban Sanitary Commission who provided very valuable insight and suggestions about the theories and practical issues of this research. Mike helped the Principal Investigator back in 2002 to start a project on infrastructure integrity by providing data and tutoring and helping to organize a workshop at WSSC. His help has been invaluable over the years and he is recognized as a leading expert in pipe failure analysis and asset management.
EXECUTIVE SUMMARY

OBJECTIVE

The objective of the project is to help water utilities integrate the cost of failure into their decision making about asset management, and this report presents a tool to assess risk and organize data to aid in capital investment planning for pipelines. The tool is intended for use on water transmission and distribution pipes, and the data and the examples in the report focus on water supply pipelines.

This project was undertaken to support a cooperative agreement between USEPA, the Water Environment Research Foundation (WERF), and the Water Research Foundation (WaterRF). The report addresses the need expressed in USEPA’s plan about renewal (defined as major repair, rehabilitation, or replacement) of water transmission and distribution systems and decisions about rehabilitation versus replacement. It offers methods to assess whether and how to rehabilitate or replace a pipeline by integrating information about cost of failure into asset management decisions.

BACKGROUND

The U.S. Environmental Protection Agency (USEPA) estimated the total national infrastructure need for drinking water in the next 20 years, based on a 2007 survey, at $334.8 billion dollars. Of this total, $200.8 billion is specifically for transmission and distribution system projects (USEPA, 2009a). In a separate study the American Water Works Association (AWWA) recently estimated the investment needs for buried drinking water infrastructure at more than $1 trillion nationwide over the next 25 years, and in excess of $1.7 trillion of need through 2050. Of these totals, AWWA estimated 54% of the need is for replacement of existing infrastructure, and 46% of the need is attributable to population growth and migration (AWWA, 2012). While the specifics of these estimates vary, as did the methodologies by which they were developed, both of these recent reports indicate a large unmet need for re-investment in our infrastructure. Estimates of current investments in water infrastructure indicate that the backlog of deferred investments is increasing and renewal cycles are close to 200 years across the range of utility sizes. Resistance to rate increases combined with lack of appreciation of the buildup of renewal needs reinforces the need for effective business cases for pipe renewal. Based on these and other evaluations, it appears that a substantial gap exists between current expenditures on water main renewal and the investment levels needed to sustain system integrity. In most utilities, many deteriorating pipe segments are candidates for renewal and they should be prioritized to make valid business cases for funding through capital improvement programs. To prioritize the renewal projects requires a large amount of information to deal with the complexity of a multi-purpose program based on effective risk analysis that ultimately aims to improve the physical, hydraulic and water quality integrity of the systems. Access to this large amount of information requires data systems that support the utility decision processes, and the products of this work are intended to help provide those data systems and support informed decision-making at utilities. The results of this project are more suited to use and application by small and medium-sized systems.

This work is specific to potable water systems. The reason for this specificity is that while there are many common concerns and issues between potable water (water) and
wastewater systems, there are also some significant differences. In the area of infrastructure renewal, the commonalities include: the majority of both asset bases being buried, the need for a greater degree of investment, and an increasing number of tools to help understand and address this need for greater investment. One of the key tools in addressing these needs includes improved understanding and application of risk assessment and risk management procedures to pipe renewal decisions. However, there are differences between water and wastewater utilities that result in significant differences in applying the risk assessment and management principles to these two sets of assets. These differences include water systems operating as a closed and pressurized system, while most wastewater systems are open to the atmosphere and flowing by gravity (non-pressurized flow). Similarly, for a given flow, the size of water pipes is typically smaller than the size of wastewater pipes.

Most technologies for condition assessment of large quantities of an existing buried pipeline involve placing some type of device within the pipe. Given the two considerations of pressurized flow and typically smaller size, access to the interior of water pipes for condition assessment is generally much more difficult than access to the interior of wastewater pipes. Further, for wastewater pipelines the application of closed circuit television (CCTV) evaluation of the pipe, a type of condition assessment, has been commonly practiced for over two decades, and has been found to be extremely valuable in pipe condition assessment of wastewater systems. In fact, for wastewater systems a commonly accepted set of criteria has been developed for assessing the severity of defects noted in CCTV inspection of a wastewater line. On the other hand, CCTV evaluation of water pipelines has had only limited application, and the industry generally feels that CCTV evaluation of water pipelines has relatively little value in assessing the condition and expected remaining longevity of these pipelines. Also, there is no commonly accepted set of criteria to assess defects and their expected impact on longevity associated with water pipelines. The results of these differences in condition assessment of water and wastewater systems is that the ability to accurately and consistently predict the probability of failure is greater in wastewater systems than in water systems. Thus, in total, more condition assessment has been done on wastewater systems, primarily by CCTV, than has been done on water systems, so there are more uncertainties and unknowns in predicting the possibility of failure (or the remaining expected lifespan) of a water pipeline than a similar wastewater pipeline.

The objective of this project was to help water utilities integrate cost of failure considerations into their decision-making and to advance the general understanding of issues related to the cost of failure. The generally accepted risk equation is:

\[
\text{Risk} = \text{Probability (of Failure)} \times \text{Consequences (of Failure)}.
\]

Quite a bit of work has been done on the “probability of failure” since infrastructure failures are the visible symptom of deteriorating and failing infrastructure. Many people have worked on different approaches and tools that should help predict when a failure might occur, including statistical approaches applied to failure data, and condition assessment technologies and techniques. Despite more interest and literature on the probability of failure, our ability to predict failures is still poor. However, much less has been written about the "consequences of failure," and our understanding of it is generally very poorly developed, despite this term being one-half of the Risk Equation. While it is difficult to do so, if the consequences of failure are all monetized, then the “cost of failure” is an estimate of their total. During this project the
adequacy of existing databases on events and losses was evaluated to determine whether ongoing data collection efforts are sufficient to enable a more explicit consideration of consequences of failure in risk decisions. Finding limited literature and understanding of this topic, the research team created a tool to aid utility decision-making on pipe renewal risk decisions. Utility involvement in this work was arranged by organizing a Technical Advisory Panel from eleven utilities with experience in planning for failures of mains and other infrastructure components. A staff member at each utility was identified and asked to assist the research team in collecting and analyzing costs of failures. They were also asked to review, critique, and help improve the spreadsheet-based software that is explained in this report.

Risk management protocols were adapted to the range of risks in pipeline systems to demonstrate how they apply to decisions and asset management systems across the range of utility sizes. The research team developed the spreadsheet-based tool to organize the risk management protocol and data into a management tool. The tool was tested through expert opinion from utility managers and experts both by interviews and at the project workshop. Additional utility experts were consulted by email and at the workshop. After the workshop, the tool was tested by obtaining data from two of the utilities. In both cases the data was adequate to use the tool at a basic level, and using the tool offered the possibility of improving utility data management procedures.

RESULTS/CONCLUSIONS

This report presents the risk screening tool developed in this work to aid utility decision-making on pipe renewal decisions. The risk screening tool aids utility consideration of risk by helping to identify pipe segments from the database, their associated likelihoods and consequences of failure, and to compute risk costs on the basis of either numeric scores or monetary values. The monetary values cannot be considered as reliable projected risk costs because of uncertainties in the data of both likelihood and consequences of failure. Nevertheless, they represent orders-of-magnitude of risk costs that improve the information given to decision makers about the need for pipeline renewal.

APPLICATIONS/RECOMMENDATIONS

The report offers resources and methods for application by utilities to improve the asset management decision process by using the risk screening tool to prioritize pipelines for action. While probability (likelihood) of failure is difficult to assess, it can be ranked on a relative basis using influence factors such as traffic load, soils, and pipeline age, and can be helpful in differentiating amongst otherwise similar pipes for renewal. However, typically data are too sparse to differentiate such pipes in terms of probability of failure and so this initial work may result in too much pipe inventory under consideration for renewal (or increased scrutiny). Consequences considerations can then also be used to further differentiate otherwise similar piping and identify those segments worthy of increased consideration due to higher risk cost. Similarly, some consideration should be given to identifying “critical pipes” in the system and ensuring they are specifically considered in terms of renewal needs. These “critical pipes” might be important to serving particularly important areas or customers for which there is no redundancy, or which are critically important to continued system operation simply due to their size and large volumes of water conveyed, or for other considerations defined by the utility. The
primary criterion in identifying “critical pipes” is that they are pipes with which the utility would like to have a minimized possibility of failure. Sometimes consequences of failure considerations as discussed in this report can be used to identify “critical pipes” but in general, they are known to the utility due to knowledge of system operations. Since the probability of failure can never be driven to zero, the “critical pipes” can best be accommodated in these risk considerations through an evaluation of risk cost. Through these considerations pipes can be segregated into groups according to similar risk cost, as determined by likelihood and consequences of failure, and more informed decisions can be made regarding which pipes to address in what manner.

Research needs identified in the course of completing this work include: improved tools and techniques to predict pipe failure, data on the frequency of failures by severity, and statistics of the frequency of breaks by different types of severity. A study of asset data management with a focus on pipeline renewal could provide a protocol to collect and analyze the data and demonstrate its usefulness in improving decisions. Similarly, follow-up on key asset data should result in more standardization in terminology and definitions.
CHAPTER 1
RISK TOOL TO PLAN RENEWAL INVESTMENTS FOR WATER DISTRIBUTION SYSTEMS

This report presents a tool for the use of risk management to plan investments for renewal of water transmission and distribution system assets. It incorporates information about the cost of failure and the likelihood of failure to assess risk and aid utilities to make rational decisions about allocation of investment capital.

The focus of the report is on water transmission and distribution pipes, which comprise the major asset values in most water supply utilities. Much of the information also applies to other pipeline applications such as wastewater force mains and other industrial or oil and gas pipelines, but the examples and illustrations apply specifically to water supply pipelines. Decisions about source of supply, treatment facilities, collection systems, buildings and major equipment are not addressed in the report.

In the report, the term renewal is taken to mean major repair, rehabilitation or replacement (3Rs) that require capital expenditures. It does not include routine repairs, which are considered to be part of maintenance and to be financed from the operations budget and not require capital programming and budgeting.

The tool is a software-based screening aid to identify and rank candidate pipes for actions that range from active monitoring (including condition assessment) to replacement. It is intended for use by technical staff members who prepare and manage lists of pipelines that are candidates for renewal.

SUMMARY OF THE PIPE RENEWAL PLANNING AND DECISION PROCESS

Pipe renewal planning takes place within a utility’s asset management program, and might involve different forms of capital improvement planning and financing. Risk assessment is needed to identify the renewal projects that are most urgent so that priorities can be set and resources wisely allocated.

The goal of pipe renewal programs is to assure hydraulic, physical and water quality integrity, which measure the readiness-to-serve of pipes in these categories. Hydraulic integrity means there is enough capacity, physical integrity means the pipe is unlikely to fail, and water quality integrity measures water safety. These goals are at the heart of utility operations, which aim to provide safe, reliable and affordable water supplies to their customers.

Options for pipe renewal are analyzed within the capital planning process by considering risk as a multi-faceted variable with economic, social and environmental aspects. Three stages of pipe renewal options can be proposed: watchful waiting, active condition assessment, and renewal projects (which might involve rehabilitation or replacement). The highest priority renewal projects are normally analyzed and proposed through a more detailed business case process that explains the costs and benefits of renewal.

The pipe renewal planning process is summarized by Figure 1-1. The utility identifies the pipes-at-risk from its inventory of all distribution and transmission pipes.
Then it may use the risk tool or any appropriate risk assessment procedures to help set priorities for renewal, including both critical and non-critical pipes through a consideration of risk cost. However, it should be understood that the purpose of this tool is to aid in evaluation of large quantities of pipe with much of this pipe having otherwise similar characteristics. This tool helps to identify similar types of pipes in terms of probability and consequences of failure, but the tool does not “decide.” The tool aids decisions by helping to associate various considerations and with various pipes in a rational and reproducible manner that should aid in making an overall evaluation of actions that can be taken by the utility. Following these evaluations, both critical and non-critical pipes are included in the renewal program plan, and the renewal program can begin to be implemented. As an Excel tool, this risk tool can also be easily modified, so that as additional considerations are identified upon which a utility desires to base decisions, or as further actions are taken on a pipeline, the tool can be modified to continue to aid in managing the pipe inventory of a given utility.

![Figure 1-1. Overview of pipe renewal planning process](image)

**Figure 1-1. Overview of pipe renewal planning process**
CHAPTER 2
THE PIPE RISK SCREENING TOOL

FUNCTIONS OF THE PIPE RISK SCREENING TOOL

The pipe risk screening tool (PRST) has two basic functions. First, you can use it to manage data on an inventory of pipes-at-risk or any group of pipes on which you would like to focus. Normally, this would be a subset of your pipe inventory as the tool is not intended to replace the software used to manage all pipeline assets. The second function is to prioritize pipes for renewal or analysis based on estimated indices of likelihood and consequences of failure. The indices of likelihood and the consequences of failure are relative scores and not true probabilities of failure or precise estimates of costs. Additional analysis can be performed, but the estimation of actual failure probabilities and costs depends on many factors, some of which are uncertain.

You can use the tool to prioritize your water distribution and transmission pipes for renewal on the basis of a risk index, which is computed as the product of the estimate of likelihood index of failure and the estimated consequences of failure. This prioritization will identify the set of pipes most at-risk of failure and/or with the greatest potential consequences of failure. For a pipe to be “high risk,” either the likelihood of failure factor must be high, or the consequences of failure must be high, or both factors must be at least somewhat elevated.

You can also estimate the risk in dollars by assigning estimates of costs to the values of the risk index. This requires you to either use default costs or assign your own costs to the values of risk indices. The dollar costs cannot be anticipated with precision in advance of a failure, so they are only another way to express and normalize risk as an index.

The tool uses either default input values of the indices of likelihood and consequences of failure or user-supplied values of these indices. It is designed so users can modify not only the value of the indices but also the method to estimate these indices. The tool can be used to prioritize all the pipe segments in the inventory or prioritize only subsets of the inventory with selected characteristics. After the pipe segments are prioritized, the user may perform a more detailed analysis on some pipelines using benefit-cost and/or triple bottom line (TBL) assessment procedures.

The tool enables the user to get a prioritized list of pipes by the computed values of the risk index. Its use is similar to that intended for the National Mains Failure Database or NMFD. The NMFD is a developing tool managed by UK Water Research (UKWIR) and currently being tested for possible use in the United States. It has more capability to provide reports and perform data management and failure analysis functions than the PRST, but it is more complex and not yet in use in the U.S. on a widespread basis. The tool provided here is limited to using likelihood and consequence indices developed for your own system to create a table of ranked pipes-at-risk.

This chapter explains the functions of the screening tool and the sources of default and user-supplied data. A user manual is supplied within the spreadsheet software.
PREPROCESSING OF DATA

The spreadsheet tool can be applied in situations where pipe segment inventories are in the range of hundreds to thousands of segments. While EXCEL version 2007 and later versions allow spreadsheet pages with more than a million rows and a large number of calculations can be made, it would be difficult for a utility to analyze such a large table of results within a spreadsheet tool. Since the number of pipe segments on a watch list for increased scrutiny or renewal will be only part of the overall inventory and the number of actual renewals will be a smaller part of that, a larger utility may wish to focus the use of this tool on those pipe segments most at risk.

The tool requires that you select data records from your pipe asset records and enter them into the spreadsheet. Utilities manage their pipe asset data in different formats and must extract the data on pipe segments of interest to enter into the tool by copying them into the Excel spreadsheet. Because the tool is spreadsheet-based, data can be imported from a variety of file types supported by database or GIS software. Likewise, data from the spreadsheet could be augmented with spatial location information and imported into GIS software to display a map showing the computed values of the risk index.

The data needed in the tool are shown in Table 2.1:

<table>
<thead>
<tr>
<th>Table 2.1</th>
<th>Pipe data needed in the screening tool</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Asset Data</strong></td>
<td></td>
</tr>
<tr>
<td>Pipe ID</td>
<td>Required</td>
</tr>
<tr>
<td>Alt ID / Street Name</td>
<td>Optional</td>
</tr>
<tr>
<td>Length (ft)</td>
<td>Required</td>
</tr>
<tr>
<td>Material</td>
<td>Required</td>
</tr>
<tr>
<td>Installation (year)</td>
<td>Required</td>
</tr>
<tr>
<td>Diameter (in)</td>
<td>Required</td>
</tr>
<tr>
<td><strong>Maintenance Data</strong></td>
<td></td>
</tr>
<tr>
<td>No. Breaks</td>
<td>Required</td>
</tr>
<tr>
<td>Breaking Status Factor</td>
<td>Required</td>
</tr>
<tr>
<td>Service Factor</td>
<td>Required</td>
</tr>
<tr>
<td><strong>Consequence Drivers</strong></td>
<td></td>
</tr>
<tr>
<td>Location Factor</td>
<td>Required</td>
</tr>
<tr>
<td>Repair Difficulty Factor</td>
<td>Required</td>
</tr>
<tr>
<td><strong>Other Considerations</strong></td>
<td></td>
</tr>
<tr>
<td>Priority</td>
<td>Optional</td>
</tr>
<tr>
<td>Zone</td>
<td>Optional</td>
</tr>
</tbody>
</table>
The data will be used to help select subsets of pipe segments to screen or to calculate the likelihood and consequences indices. Data shown as Required in Table 2.1 are used in the calculations and should be provided. If these data are left blank, then the tool will return a failure likelihood index of 0 for that pipe segment which will result in a risk index of 0. Therefore, it will always be better to estimate unknown data elements than to leave values as blank. Utilities might choose to use a regression analysis on available data in order to estimate unknown data. Optional data is not used in the calculation of likelihood and consequences indices; however, it may be used in selecting pipe segments to analyze.

Both the Required and Optional data can be used for screening and defining subsets of pipe segments to analyze. Providing the Optional data will allow for greater flexibility in screening pipe segments of interest.

The tool will allow the utility to analyze all the pipe segments; however, the utility might want to analyze all pipes of a particular category, such as large high-risk pipes or smaller pipes with lower consequences, or it might want to analyze pipes in groups. Therefore, you can enter data on individual segments or you can aggregate segments into renewal projects. You can enter data on cohorts of similar pipe, such as large at-risk pipes located in high-consequence areas or smaller lower-risk pipes located in residential areas. Every utility might want to consider different factors in defining cohorts of pipe segments and the tool was designed to provide that flexibility.

On the basis of the risk index, it might be better to analyze pipes of similar characteristics; such as size, age, location or pipe material. This is easily done using the filtering capabilities of the tool. Otherwise, the prioritized pipes-at-risk list will likely show the largest and most critical pipes at the top. This is because the risk index is the product of the likelihood of failure index multiplied by the consequences index. Therefore the larger and more critical pipes will have the largest potential consequences. You might also want to prioritize the smaller lower consequence pipes and you can do this by segregating them in their own separate analysis.

You can also decide whether to aggregate data into a single instance of the tool or to maintain different copies of the tool for different cohorts of similar pipe segments. If all the data are included in a single instance of the tool, different cohorts of similar pipe segments can be identified using the settings in the Filter tool. Additionally the tool provides the capability to save the results of an analysis so that the results for different cohorts of pipe segments can be compared.

The tool is designed for up to 500 pipe segments, but this number can be increased. The tool was successfully tested with 3000 pipe segments.

GUIDELINES FOR SELECTING PIPES-AT-RISK

The selection of pipes-at-risk for analysis is determined by the utility and is normally to be coordinated with the capital improvement program. If a utility maintains a 10-year capital program, for example, it might choose to manage data on the number of pipes that might be renewed in that planning period or perhaps more pipes in order to keep a list that can change over time.
Utilities use different methods to identify pipe segments in their asset databases and should package the segments to fit their capital planning process. A utility might identify pipe segments by block lengths between intersections. In this case segments lengths might average 200 - 500 feet each, and there would be from 10 to 25 segments per mile. For a utility serving a population of 250,000, there might be nearly 1,000 miles of pipe, or some 10,000 – 25,000 segments in the database. Some utilities have many more segments in their databases.

If pipe segments are too long, it is difficult to compute likelihood and cost of failure as too many factors are involved. If pipe segments are too short, it makes the data management more complex because more data must be collected and entered to address the entire system.

In packaging pipe segments for use in the tool, the utility might decide that renewal projects should be in the range of, for example, $100,000 - 300,000. If renewal is to be by replacement and average costs are $500 per foot, then the segment lengths would be on the order of 200 to 600 feet for inclusion in the dataset of pipes-at-risk. These are examples only and each utility will decide on its own approach.

The Appendix contains an example of a data layout for preprocessing.

**SELECTION OF POINT OR DOLLAR SYSTEM AS INDICATORS FOR RATING**

In most cases you cannot estimate the total cost of a pipe failure before it happens because you do not know where or when the failure will occur or how severe it will be. It is possible to make an estimate of a failure after-the-fact, so the utility can compile experience factors on its costs of past failure. There might be, however, situations where you can estimate the cost of failure in advance, as for example a failure of a critical pipe at a fixed location, such as crossing a major highway. Associating dollar values to possible consequences of a failure can be more understandable than risk-point systems. Also, monetizing a possible failure is a good way to allow for comparison of possible consequences of failure for pipes of different sizes, types, and cohorts which might not otherwise be compared. Cases like that will normally be handled on an individual basis, rather than through the pipe screening tool.

The difficulty in estimating the cost of failure before the event means that you cannot assign a benefit of loss avoidance to a proposed renewal project because you do not know the loss. To get around that dilemma, most decision models use point systems that rely on indices that assign relative costs and benefits. This is the basic approach of the pipe risk screening tool, but you can use dollars as indices as well as points.

If you assign dollar values to consequences, you must realize that the dollar values are indices rather than valid estimates of the dollar costs of pipe failures. The benefit of using dollar values is that they may communicate to stakeholders better than a point system. If you use the dollar index method, you must explain to stakeholders that these are typical levels of costs and are not valid cost estimates because you lack advance knowledge of the cost factors. However, the ranges of cost levels are based on historical failure data.
ESTIMATION OF FAILURE LIKELIHOOD INDEX

To compute values to screen pipe segments by risk, the tool must estimate a failure likelihood index and a failure consequences index for each pipe segment. It estimates these indices by using a combination of a point system and relationships defined by the user. The spreadsheet can also be modified to incorporate user-defined calculations for failure likelihood or consequences. Information on modifying the tool is provided in the Appendix.

Much research has been conducted on pipe failure likelihood, but no consensus method has been developed for computing it. The tool is designed to use research-based concepts to estimate it from data you can normally obtain. The tool enables you to estimate likelihood of failure (meaning estimated likelihood of failure in the next few years) based on threat factors such as age, soils, traffic load and other causes of deterioration. The tool has a built-in method to estimate an approximate overall likelihood index based on parameters that are surrogates for threat factors (pipe age, number of previous breaks and service conditions).

Pipe age is a measure of years in service. Although we know that pipes do not fail due to age alone, the reasoning is that pipes are in general more likely to fail as they age. The age likelihood index can also be modified depending on what type of material the pipe is.

Number of previous breaks means the number of failures or maintenance events on that pipe segment. This measures the history of breaks, which is an indicator of a pipe that may fail again. You can also modify the parameter if breaks have been occurring more frequently.

Service conditions is an indicator variable to measure threats such as traffic load, high pressure zones, corrosive soils and other conditions that might cause the pipe to fail more quickly than the average. They are rated a 1, 2 or 3, corresponding to light, medium and heavy service threats.

Based upon its experience, the utility provides the input for a table of values to relate the values of the parameters to an estimate of the overall likelihood index (see the Appendix). The table may have between 2 and 9 values.

The overall likelihood estimate is called an index because it is not an empirical observation of an actual likelihood but is an estimate based on a calculation. Following probability principles, the lower bound of the likelihood index is zero because a pipe segment might not fail in many years. The upper bound of likelihood is 1 because there cannot be more than a 100 percent chance of failure. It should be noted that the time frame associated with the likelihood of failure is one year for the tool, which is a simplification useful in this evaluation. Due to the inability to predict failure of buried water pipeline, typically the best that can be done is understanding that a pipe is in a “distressed state” meaning very deteriorated, or at a high likelihood of failure in the next couple of years. We have no predictive tool that can accurately assess exactly when a water pipe will fail, only that there are indications that it is very distressed, thus the likelihood index is estimating the likelihood that a pipe will fail within the coming year.

Each of the threat factors (age, breaks, and service conditions) has an input table. For pipe age, an input such as illustrated in Table 2.2 must be specified. In this example, age is specified between 0 and 200 years. At 200 years (or greater), and lacking other
data, the likelihood of a pipe break in the coming year is set equal to 1. Since this is an index, it does not mean that this pipe segment is guaranteed to break in the coming year, but rather that the likelihood of a break is very high. If the user is uncomfortable with setting an upper limit of the likelihood index equal to 1, then they can choose an upper limit that they are comfortable with such as 0.95. The set of likelihood index values in this example shows increasing likelihood of breaks for pipes older than 50 years (see Figure 2.1). For pipe ages between the values in the table, linear interpolation is used. The increments of pipe age do not have to be the same, and should be selected to define the shape of the relationship curve of likelihood index as a function of pipe age. The advantage of having a user-defined likelihood function like this is that it can represent a variety of shapes of likelihood curves. For example, a “bathtub” relationship can be created by increasing the likelihood index estimate for recently installed pipe segments and then decreasing it as the pipe works through the break-in period.

Table 2.2
Pipe age and likelihood index estimates

<table>
<thead>
<tr>
<th>Age (yrs)</th>
<th>LI</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>0.1</td>
</tr>
<tr>
<td>40</td>
<td>0.25</td>
</tr>
<tr>
<td>60</td>
<td>0.4</td>
</tr>
<tr>
<td>80</td>
<td>0.6</td>
</tr>
<tr>
<td>100</td>
<td>0.8</td>
</tr>
<tr>
<td>200</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 2.1 Example likelihood index curve as a function of pipe age

Service conditions are suggested to be rated a 1, 2 or 3, corresponding to light, medium and heavy service threats. Similar to pipe age, an input table must be provided with the service levels and corresponding estimates of the likelihood indices. For example, a service level of 1 might have an estimated likelihood index equal to 0.1, a service level of 2 might have an estimated likelihood index equal to 0.25 and a service level of 3 might have an estimated likelihood index equal to 0.5. You would estimate...
these values based on your judgment as to whether a pipe segment is exposed to any of a range of threats that include heavy traffic, hot soils, high pressures and water hammer, among others. Note that if a utility wants to have more service conditions than the three suggested, they can enter those into the input table (up to a maximum of nine values).

The likelihood index calculation for the number of pipe breaks is based on national statistics of average conditions that show about 0.3 breaks per mile per year. For example, a pipe segment of 660 feet (1/8 mile) would have an average annual likelihood of failure of 0.3/8 = .0375. During a 50 year period, that pipe segment might experience 1.9 breaks (on average), which is computed as 50*0.0375 = 1.9.

The pipe data input contains the length of the pipe segment, the year of installation and the number of breaks experienced. The tool uses this information to compute the expected number of pipe breaks for a pipe segment. The actual number of pipe breaks observed for that segment is used to compute a “break ratio” that is defined as the actual number of breaks divided by the number of expected breaks, based on the national average and the age of the pipe. This break ratio normalizes the pipe break information for different ages and lengths of pipe segment so that the utility can provide a single table to relate the break ratio to the estimated likelihood index for breaks.

An example is shown in Table 2.3 and a graph of the relationship is shown in Figure 2.2.

Table 2.3

<table>
<thead>
<tr>
<th>Break Ratio</th>
<th>LI</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.25</td>
<td>0.15</td>
</tr>
<tr>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>0.75</td>
<td>0.4</td>
</tr>
<tr>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>1.25</td>
<td>0.6</td>
</tr>
<tr>
<td>1.5</td>
<td>0.7</td>
</tr>
<tr>
<td>1.75</td>
<td>0.85</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>
Figure 2.2 Example of a break ratio and likelihood index relationship

Note that in the above example, the upper limit of the normalized break ratio was defined by the user as 2. This implies that if a pipe segment is experiencing pipe breaks at twice the expected rate, the likelihood index for pipe breaks is equal to 1. This means the utility expects the pipe segment to break again in the coming year if only the break record is considered. This upper limit on the normalized break ratio and its associated likelihood index are defined by the utility and can be adjusted as appropriate. See the Appendix for further detail.

Based upon the information in the pipe segment inventory provided by the user, the tool computes the estimated likelihood indices based on pipe age, pipe breaks, and service level. These indices of likelihood that are then combined to give an overall likelihood index of failure using this basic relationship:

\[
\text{Overall likelihood index of failure} = f(\text{age}, \text{breaks}, \text{service}) \tag{1}
\]

To compute the overall likelihood index, the tool uses a weighted average combination of the likelihood indices for age, breaks and service:

\[
\text{Overall likelihood index of failure} = w_1 \times \text{Likelihood (age)} + w_2 \times \text{Likelihood (breaks)} + w_3 \times \text{Likelihood (service)} \tag{2}
\]

The tool allows the user to specify the relative importance of the indices, and the weights \((w_1, w_2, w_3)\) are computed from this user input. Table 2.4 shows the table of relative importance factors that are specified by the user.

Table 2.4
Example of relative importance factors

<table>
<thead>
<tr>
<th>Levels</th>
<th>Relative Importance Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Age</td>
</tr>
<tr>
<td>Level 1</td>
<td>1</td>
</tr>
<tr>
<td>Level 2</td>
<td>1</td>
</tr>
<tr>
<td>Level 3</td>
<td>1</td>
</tr>
</tbody>
</table>
The user can select from one of three different options to compute an overall likelihood index by choosing combinations of age, breaks and service conditions. The three methods are defined here upon the relative importance factors shown in Table 2.4:

- **Level 1**—based 100% on age (w1 = 1.0)
- **Level 2**—based 50% on age and 50% on breaks (w1 = 0.5 and w2 = 0.5)
- **Level 3**—based 25% on age, 50% on breaks and 25% on service condition (w1 = 0.25; w2 = 0.5; w3 = 0.25).

Note that the user can specify the relative importance factors which are used to calculate w1, w2 and w3. Providing three methods to estimate the overall likelihood index allows the user to try combinations of factors and then select the best method for their organization. Once the method has been selected, the tool can compute the overall likelihood index for each pipe segment.

**ESTIMATION OF CONSEQUENCE OF FAILURE**

The risk equation also requires an estimate of the consequences of failure to prioritize pipe segments on the basis of likely cost levels. As explained earlier, you can use either a point system or assign dollar values based on default values or the experience in your utility. The consequence model is based on the assumption that three parameters have the greatest influence on cost of failure: location, pipe size, and cost of repair. The variable location measures exposure due to proximity to congested or important facilities, such as highway crossings, downtown locations, and locations where the failure is likely to cause more damage and traffic congestion than in other locations. Cost of repair will depend on a number of factors, including location, accessibility, size and number of facilities affected. Pipe size is a measure of potential flooding and the water lost if a pipe breaks. Taken together, these variables explain a significant part of the cost drivers.

The point system allows you to select a consequence score from 1 to 3 for location, repair difficulty and size (Table 2.5).
Table 2.5
Consequence scores

<table>
<thead>
<tr>
<th>Consequence Driver Factors</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Repair Difficulty</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Location</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Size</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Small &lt; 16 in</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Med 16-24 in</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Large &gt; 24 in</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

The overall consequences score is computed as a weighted sum of these scores for each driver:

\[
\text{Overall consequence score} = \text{wt1*Consequence (repair difficulty)} + \text{wt2*Consequence (location)} + \text{wt3* Consequence (size)} \quad (3)
\]

The weights are specified by the user and must sum to 1. Therefore, the highest overall consequence score will equal 3 and the lowest score will equal 1.

Figure 2.3 illustrates the procedure of estimating the consequence index.

Figure 2.3 Estimation of consequence index
If you choose the dollar-based system, you can map costs to these points, but be sure to understand that these costs are still indices and are not actual costs. Since every failure event is unique, this will always be the case, but we expect that more understanding of costs and consequences of failures will be developed as further research work is done and as more risk assessment and management work is done in North America. Meanwhile, if a utility analyzes its own cost histories, these cost estimates may improve. A utility can estimate a range of costs associated with a failure based on its past experience, using an estimator for future costs (typically a mean or median). Since this past experience will include local and regional factors that drive costs, this range of costs should be more accurate and narrower for the given utility than a national estimate. For larger pipes, or those laid in more densely populated urban or commercial areas, or in sensitive areas, the range of costs may still be quite large and subject to considerable uncertainty. Barring specific local data, at this time, the cost indices should only be considered order-of-magnitude estimates in almost all cases.

An example of a user generated table to map costs to these points is shown in Table 2.6. The tool allows the user an option of displaying these dollar estimates as part of the risk-based ranking. In this case, the analyst assigns a low cost of $5,000 to a consequence rating of 1 (remote location, easy repair, small pipe) and a cost of $5,000,000 for failure of a large pipe in a highly congested area, near buildings, that is very difficult to repair.

Table 2.6
Mapping consequence score to estimated costs

<table>
<thead>
<tr>
<th>Conseq Index</th>
<th>Est Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>$5,000</td>
</tr>
<tr>
<td>0.4</td>
<td>$200,000</td>
</tr>
<tr>
<td>0.5</td>
<td>$300,000</td>
</tr>
<tr>
<td>0.6</td>
<td>$400,000</td>
</tr>
<tr>
<td>0.7</td>
<td>$500,000</td>
</tr>
<tr>
<td>0.75</td>
<td>$750,000</td>
</tr>
<tr>
<td>0.8</td>
<td>$1,000,000</td>
</tr>
<tr>
<td>0.9</td>
<td>$2,000,000</td>
</tr>
<tr>
<td>1</td>
<td>$5,000,000</td>
</tr>
</tbody>
</table>

With the overall likelihood index and the overall consequences score for each pipe segment computed, the overall risk is computed as the product of these two numbers. Since the overall likelihood index and the consequences score are both on scales of 0 to 1, the overall risk is likewise on a scale of 0 to 1.

To develop a risk based ranking of a pipe segments, the user first filters the data to create a subset of pipe segments that they would like to consider. For example, they may filter (or select) only specific types of pipe materials, or certain diameters, or certain service levels, or certain zones in the city. The tool will then copy this subset of pipe segments to a page where the overall likelihood index, consequences score, overall risk
and dollar estimate (if selected) will be displayed. A macro is provided to allow the user to sort the selected subset or pipe segments in terms of overall risk (from highest to lowest). Actually, the user can manually use the spreadsheet’s Filter tool to sort the table of selected pipe segments according to any of the columns in the table if so desired.

The user has the option to save these results to a separate Results page in the tool. Then can then create a new subset of pipes and save these results. This allows a variety of scenarios to be saved and compared. A simple example of how a risk based ranking of pipe segments might be approached is provided in the Appendix.
CHAPTER 3
CASE STUDIES OF UTILITY PRACTICES

INTRODUCTION

During the project, the team studied data availability and practices at a number of utilities. This included discussions and exchange of information with a number of utilities, reviews of the literature about utility data management, study of data management requirements for the National Mains Failure Database (NMFD), and interviews with data managers. In addition, the team utilized actual data from one utility to demonstrate the Pipe Risk Tool, and another utility took the tool and demonstrated how it would be used on its data. From these inquiries a common pattern of data availability for use with the tool can be seen. This chapter explains the results of our inquiries with the utilities, our analysis of data management based on experiences with the NMFD, and experiences by two utilities in using the pipe risk tool with their data. It presents a discussion of current data management practices by utilities and how the tool can be applied as demonstrated by applications at two of the participating utilities.

RANGE OF UTILITY DATA PRACTICES

We contacted water supply utilities about the status of their inventories of pipeline assets, how they collect and organize data on main failures and how they use the information to prepare plans for renewal. Practices among very large cities, medium cities and small towns were of interest. As expected, the level of technology application varies widely across the utilities. Most small utilities are still struggling to organize their information from paper to digital format. Limited financial and human resources capabilities restrict them from adopting the full use of digital data organizing and retrieving technologies.

At larger utilities, more sophisticated information technology methods to manage pipeline inventory and operations are used or being implemented. Financial and human resources capacity, along with availability of historical data have helped the large utilities convert from paper records to a new era of digital in-house databases and use of commercially available software like GIS. Some are able to run sophisticated hydraulic models and/or use pipeline main break information to plan for pipeline renewal. Medium to large utilities are using GIS to store, organize, and present their asset data. Some are using GIS to store inventory information and use a separate in-house database to store pipeline condition and repair history.

As an example, the water asset database of a large Canadian city evolved from paper format to CAD files and is now in a fully implemented GIS system which includes data management for its historical pipeline inventory data. The GIS system is connected to other in-house databases with information on main break failures, their causes, the degree of damage, and the method used for repair and location of the main break. The GIS system provides mapping, data management and addition of new field data. The
software creates maps of types of pipeline materials and associated data such as main breaks, age, date of break, areas with new pipeline, areas with multiple breaks, and areas with high risk of corrosion. Queries can be run to highlight areas with multiple main failures and to plan for pipeline renewal. The GIS system also allows the city to study different factors that are causes of pipeline failure. For example, the city conducted a study to determine hot soils and relate them with pipeline failures. They also studied the correlation between failures over time, between failure and pipeline material, and failure and pipeline diameter, among others. The in-house database serves maintenance functions with the work order number, the time of failure, the asset type, the asset ID, pipeline structural condition at the repair site (poor, fair, or good), corrosion condition (slightly, moderate, or heavy), type of failure (fitting, leaking, hole, fracture, pipeline settling, etc.), and cause of the failure (corrosion, frozen, construction damage, traffic loading, etc.). The data base includes additional detail on mechanics of failure, repair action, site description, nature of the failure, and the consequences of the failure (road closure, business affected, homes out of service for 5 hours, water collecting on the streets and freezing and effects on traffic and pedestrian movement, as well flooding of nearby structures). The PRST developed under this project would not be of much use to a utility with such sophisticated capabilities.

A large western U.S. city has an extensive system with the oldest pipelines predating the 1900’s. The utility has had a GIS system with pipe inventory and pipeline main break data for 20 years. It records main break characteristics on work orders which indicate the type of break as full circle break, corrosion caused, longitudinal break, etc. The utility may decide to conduct additional investigations to establish the root causes of the failure. The additional investigations may include assessing the possibility of water hammer, corrosion issues, initial construction issues and others. Currently the city is organizing its asset management databases for the water distribution system and the plan is to have it in place by the end of 2011. The city is planning to assess the correlation between the collected pipeline condition and failure data with soil type. It believes that the GIS system with the asset management databases will help it to conduct studies on factors that contribute to main failures. They intend to develop a corrosion potential map based on soil condition and corrosion break data. Currently the city prioritizes its annual water line replacement program based on data available. It does not use specific software to decide about main renewal as the data are not yet organized in one place. This utility might use the PRST as a way to collect and organize information on critical pipelines.

A large eastern U.S. city has provided water services for over 200 years. It used cast iron until 1967 when they switched to ductile iron. The main break renewal program has been in place for over 20 years and the current level is 230 breaks per 1,000 miles per year. On average the city replaces pipeline at about the national average of 0.7 percent per year on the basis of mileage. In 2009 the city completed a city-wide GIS system to document the water main inventory. It plans to display its infrastructure and link it to operation, maintenance and construction data using this system. This will enable it to convert existing paper maps and specifications into an electronic information system to provide quick access to data, to increase productivity, to reduce risk and to enable timely management decisions. The city also intends to develop a GIS database to allow preparation of work orders and to track field operation and maintenance. Main failures are included on the GIS map layer but this layer does not currently include the
cause of the break or the damage. Transmission main breaks are analyzed more thoroughly but the analysis results are not stored in a digital format. The city uses its hydraulic model to make decisions about main replacement. Also, the city replaces mains when breaks occur that damage pipelines beyond repair. The process of linking the GIS and other software and geo-databases is in progress. When this is completed the city intends to use the GIS tools and other tools such as hydraulic models for main replacement prioritization. This utility might also use the PRST as a way to collect and organize information on critical pipelines.

A large Midwestern city is now served by a private water company that also serves a regional system. The company is working with the city and they have developed a database with the pipeline asset inventory. When main breaks occur, a report is prepared and if the failure is due to hydraulic causes, an investigation is conducted. The company has a GIS system with a database linked to it to provide maintenance and inventory information. To prioritize main replacements, the company conducts hydraulic model studies and decisions are made based on the results and other factors including leakage and breaks, as well as consequence information such as the proximity of the main to high traffic roads, the number of affected customers, etc.

Regarding medium utilities, an eastern private water company provides water to a number of people distributed across small cities. An increase in rates helped to accelerate the replacement of pipelines, hydrants, valves, and meters. The company bases its decisions on the age and condition of the pipelines, frequency of main breaks, leakage and loss of water and history of water quality complaints. The company does not yet have a well-developed database for its pipeline assets but it has initiated a GIS system to record water main attributes. Due to historical reasons, records have gaps and it uses the best available information. Main breaks are recorded on paper forms and the information is transferred to a database. The company plans to expand its efforts and implement a GIS system in the future.

A medium sized West Coast city has an old system and now is embarking on an active capital improvement plan for the next ten years. The city has detailed records of its pipeline asset inventory and records main failures, data on why the break occurred and the damage caused. It has a GIS system that includes a database of failure information that enables studies on how to prioritize for pipeline replacement. The city reported that the most difficult task is to set priorities for competing projects and to refine its priorities for individual projects. For this purpose it used a new prioritization model that requires further improvement.

A medium city in the Rocky Mountains has a distribution system that suffers from excessive failure rate due to corrosive soils and pipeline aging. The failure rate exceeds three times the national and regional average and repair and replacement costs the utility about one seventh of their annual budget. The city does not have a complete asset inventory database but it is in the process of identifying its assets. The city records main breaks by paper format, but the cause of damage is not recorded. The city’s historical information is not yet organized in a digital format. The city implements main replacements based on failure rate.

As a result of these cases and observations from other utilities we have visited or worked with, we believe that the following trends are evident in the databases that are needed to integrate cost of failure into asset management:
● Collection of pipeline asset data is a work in progress and utilities range from excellent to just-beginning stages. However, most utilities are aware of the need for the databases, even if they are not yet fully committed to implementing them.

● The GIS system is the best practice for data management and, when full capabilities are implemented, all necessary data management processes from inventory through analysis can be conducted. Although many utilities express desires and even plans to obtain GIS, many remain works in progress and it is not clear when they will achieve full operational status.

● Although maintenance databases are common, along with work order and scheduling systems, the integration of these maintenance data with GIS and with renewal decision making is a work in progress in most places.

● While these data systems continue to be developed, it is apparent that utilities need a common set of data and analysis capabilities that include: basic asset inventories, condition data, main break records, and analysis of causes and consequences of failures.

CASE EXPERIENCES WITH PARTICIPATING UTILITIES

We worked with two of the participating utilities to test the pipe risk tool with their data. The experiences showed that the utilities were able to use the tool with their existing data management systems.

The small utility provided a .csv (comma separated) format data file with 2812 records of pipe segments. Their data file contained the following fields of information; ObjectID (or a PipeID), the type of pipe material, main type (all of their entries were “Pressurized”), pressure zones (their data had eight different pressure zones), water type (this was either Potable or Non-Potable), two fields named “Enabled and Retired” which showed pipe segments that were no longer in use, pipe diameter in inches, and Shape_Len which was the length of the pipe in feet. An example of the data file in shown in Figure 3.1 below. The installation year and break history were not part of the provided records. The data were copied from the .csv file and pasted as values into the spreadsheet tool.
Figure 3.1 Data file provided by the small utility

This data set was very useful in testing the ease of expansion of the size of the spreadsheet, the issues the spreadsheet would encounter when dealing with missing data (for example, not all of the pipe materials were known), and the use of the pressure zone and water type data as additional screening factors. To modify this data set so that it could be tested in the spreadsheet tool, modifications were made to the data set. These included putting an “Unspecified” value in the Material field for all pipe segments that did not have a material provide, eliminating all retired pipe segments, and rounding the pipe lengths to the nearest foot. To provide an example installation year, random years between 1900 and 2010 were generated. To provide example break information, random numbers of breaks between 0 and 4 were generated. To include the information on pressure zones and water type, the “Other Considerations” portion of the Database page in the spreadsheet tool was modified to include the pressure zones and water type. Finally, the size of the spreadsheet tool was expanded to include 3000 pipe segments and then the spreadsheet tool was thoroughly tested to make sure it performed all the calculations correctly. An example of the Database page for the tool with the data from the small utility is illustrated in Figure 3.2 below:
The data from the larger utility was put directly into the pilot version of the spreadsheet tool by the utility. It included 19 records. There were very minimal issues with this provided data set. Some of the installation years were unknown and some of the pipe segments very listed as “new” instead of providing the year. There were some missing values for repair difficulty and the breaking status was not provided. This missing information was randomly generated and then this data set was thoroughly tested in the tool. Figure 3.3 shows this dataset within the spreadsheet tool.

Both of these datasets helped to identify changes needed in the spreadsheet tool to handle missing data, as well as improvements in the user manual to help users understand the importance of checking the datasets to make sure missing data is addressed and also to make sure pipe materials are entered consistently. The effort required to enter these example datasets into the tool was minimal.
APPENDIX A
USER MANUAL FOR RISK TOOL

OVERVIEW OF THE PIPE RISK SCREENING TOOL SPREADSHEET DESIGN

The primary design objectives for the spreadsheet tool were to design a tool that was easy to use and highly customizable: The tool was designed to have the following characteristics:

- Be easy to use
- Have maximum flexibility / customization potential
- Use a modular design – each major task is on an individual work page
- Have main features of a primary data set, a subset of selected data, likelihood and consequences calculations
- Use a minimal number of macros and simple macros wherever possible
- Have the ability to save priority ranked subsets of data
- Use features available in versions of EXCEL from 2007 – 2010

The spreadsheet uses the Filter tool and EXCEL 2007 – 2010 versions expanded the functionality of this tool from earlier versions. The spreadsheet tool will work in EXCEL 2003; however, the ease of using the Filter tool is much less than in the later versions.

The spreadsheet tool has eight pages (work pages). Users enter data and information on only two of these pages. The names of these pages and the function of each page are described in Table A.1.

Table A-1
Spreadsheet pages and purpose

<table>
<thead>
<tr>
<th>PAGE NAME</th>
<th>PURPOSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTRODUCTION</td>
<td>Describes the purpose of the tool, contains contact information and a link to a tutorial video. Gives a brief overview of the use of the tool in a series of steps.</td>
</tr>
<tr>
<td>DATABASE</td>
<td>This is a user data-entry page. It contains the pipe-segment inventory entered by the user. The version is currently designed for 500 records; however, the number of records is expandable. This page is where the user will use the filter tool to select subsets of data for analysis. Icons are provided to run macros to turn the filter on or off and to copy a desired subset of pipe segments to the RISKCALC page.</td>
</tr>
<tr>
<td>DATAENTRY</td>
<td>This is a user data-entry page. It contains the user defined tables that provide the relationships between the likelihood index values and the values of the pipe failure influence factors, and</td>
</tr>
</tbody>
</table>
The consequence ratings or scores and the values of the pipe failure influence factors. The user defines the weighting factors for the overall likelihood index and the overall consequences rating or score.

**RISKCALC**
This page shows the information for the subset of pipe segments defined by the user on the database page. When the user clicks the icon to copy a subset of records to the RISKCALC page, the macro not only copies the subset of records, but also queries the LI_INDEX_CALCS and CONSEQ_MODEL pages to get the likelihood index of failure and consequences score for each record in the subset of pipe segments. The macro also computes and displays the risk of each record (likelihood index * consequences score). Icons are provided to sort the subset of pipe segments from the highest to lowest risk and also to copy the information on this page to the results page.

**RESULTS**
This page is designed to store the information displayed on the RISKCALC page. The user might define a subset of pipe segment, calculate the risks and store this subset of pipe segments. They might then repeat the process with a different subset of pipe segments. Whenever a new subset of records is stored on the results page, it is stored below the previously stored values. An icon is provided to run a macro to clear all previously stored values from the results page.

**LI_INDEX_CALCS**
This page computes the likelihood index of failure for every pipe segment defined on the DATABASE page. The calculations are done in cell formulas that relate the pipe inventory information on the database page and the likelihood table values on the DATAENTRY page. If the user wishes to create their own formulas to compute a likelihood index of failure, they would do so on this page.

**CONSEQ_MODEL**
This page computes the consequence score for every pipe segment defined on the DATABASE page. The calculations are done in cell formulas that relate the pipe inventory information on the database page and the consequences table values on the DATAENTRY page. If the user wishes to create their own formulas to compute a consequence score, they would do so on this page.

**USER MANUAL**
This page contains the text of the user manual for the tool.

**THE DATABASE PAGE**

The tool requires that you enter data from your pipe segment records. The tool is setup to handle 500 pipe segments; however, this can be expanded as described in the Expanding the Size of the Tool section of this manual. Data can be entered manually or copied and pasted in from other files or applications. To preserve formatting it is highly recommended to use Paste Special Values, when pasting information into the page. A
A sample set of data is provided in the spreadsheet as a guide to the desired information. Because the tool is a spreadsheet-based tool, data can be imported from a variety of file types supported by database or GIS software. It is recommended that information from database or GIS software be first imported into an intermediate EXCEL spreadsheet and then copied and pasted into the DATABASE page of the tool. This process will minimize any potential formatting issues (for example, numbers being displayed as text values). Table A-2 shows the pipe inventory data required by the tool:

<table>
<thead>
<tr>
<th>Table A-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe Inventory Data</td>
</tr>
<tr>
<td><strong>Asset Data</strong></td>
</tr>
<tr>
<td>Pipe ID</td>
</tr>
<tr>
<td>Alt ID / Street Name</td>
</tr>
<tr>
<td>Length (ft)</td>
</tr>
<tr>
<td>Material</td>
</tr>
<tr>
<td>Installation (year)</td>
</tr>
<tr>
<td>Diameter (in)</td>
</tr>
<tr>
<td><strong>Maintenance Data</strong></td>
</tr>
<tr>
<td>No. Breaks</td>
</tr>
<tr>
<td>Breaking Status Factor</td>
</tr>
<tr>
<td>Service Factor</td>
</tr>
<tr>
<td><strong>Consequence Drivers</strong></td>
</tr>
<tr>
<td>Location Factor</td>
</tr>
<tr>
<td>Repair Difficulty Factor</td>
</tr>
<tr>
<td><strong>Other Considerations</strong></td>
</tr>
<tr>
<td>Priority</td>
</tr>
<tr>
<td>Zone</td>
</tr>
</tbody>
</table>

**PipeID** is a unique identifier given to each pipe segment in the data base. The PipeID is used as the primary identifier of each record and must be provided. If a utility does not have a unique identifier they might use a set of sequential numbers to serve as the PipeID. The PipeID can be letters, numeric or alphanumerical.

**Alt ID / Street Name** is an optional input. Various utilities suggested that they use street names or an alternative identifier system to allow them to select subset of pipes in common locations. This can provide for a more detailed level of filtering subsets of pipe segments. This field can be left blank if desired.

**Length (ft)** is required for each pipe segment in feet. It is used in the calculation of the expected number of pipe breaks for the age of the pipe.

**Material** is required for each pipe segment. This may be entered as a name (cast iron pipe) or as initials (CIP); however the entries for the material must be consistent.
throughout the database and should correspond to the material names provided in the *Modification Factors* table on the DataEntry worksheet. This will allow the user to filter subsets of pipe segments based upon the type of material the pipe is constructed of. If the pipe material is unknown, a name of “Unknown” might be used so that those pipes can be filtered into subsets as desired.

**Installation (year)** is required for each pipe segment. This is used in the calculation of pipe age (current year – installation year). If the installation year is not known, it might be approximated by the installation years for other pipe segments in the same area.

**Diameter (in)** is required for each pipe segment. This is used in the calculation of the consequences score. It is also useful for filtering subsets of pipes.

**No. Breaks** is required for each pipe segment. This is the number of breaks a pipe segment has experienced and it is used in the calculation of the normalized break ratio, that is, the ratio of the actual number of pipe breaks divided by the expected number of pipe breaks. If a pipe segment has had no breaks then a 0 should be entered.

**Breaking Status Factor** is required for each pipe segment. The value of this factor would typically be set to a value of 1. However, if a pipe segment has experienced more than 1 break in a short period of time (for example, within the past 5 years) this might be an indication that the likelihood of breaks is increasing for this pipe segment. The likelihood index computed for the number of pipe breaks based upon age and pipe segment length is multiplied by the breaking status factor. For example, if the utility estimates that a pipe segment is breaking at twice the expected rate, then the breaking status factor should be set equal to 2.

**Service Factor** is required for each pipe segment. Service factors will have values of 1, 2 or 3, corresponding to a word scale of light, medium and heavy. This is an indicator variable that measures threats such as traffic load, high pressure zone, corrosive soils and any other service condition that might cause the pipe to fail more quickly than expected.

**Location Factor** is required for each pipe segment. Location factors will have values of 1, 2 or 3, corresponding to a word scale of remote, average and difficult. For example a remote location (factor = 1) would be used where a location is easy to get to and less likely to cause collateral damage. By contrast a difficult location (factor = 3) would be used where a location is hard to get to and more likely to cause collateral damage and liability payments.

**Repair Difficulty Factor** is required for each pipe segment. Repair difficulty factors will have values of 1, 2 or 3, corresponding to a word scale of easy, medium and difficult. For example an easy repair (factor = 1) would be used where the access, depth of the pipe segment, and other aspects of the site are amenable to an easy repair. A difficult repair (factor = 3) would be used where access, depth of the pipe segment, unique conditions such as a stream crossing, or a combination of issues would create a difficult repair situation.

**Priority** is an optional input. This input was suggested to allow users to identify pipe segments with priority for repair or renewal. An example might be pipe segments under a roadway that is scheduled to be rebuilt. This input is used only as a means to filter subsets of pipes. Priorities can be identified using either numbers of an appropriate word scale. This field can be left blank if desired.
Zone is an optional input. This input was suggested to allow users to identify zones as another means to filter subsets of pipe segments. An example might be to identify pipes in pressure zones. Zones can be identified using either numbers of an appropriate word scale. This field can be left blank if desired.

The provided data will be used to either help select subsets of pipe segments to screen or the data will directly be used in the calculations of the likelihood and consequences indices. Data shown as Required in Table A.1 is used in the calculations and should be provided. If these data are left blank, then the tool will return a failure likelihood index of 0 for that pipe segment which will result in a risk index of 0. It will therefore always be better to approximate unknown data as opposed to leaving the value as a blank. Both the Required and Optional data can be used for screening and defining subsets of pipe segments to analyze. Providing the Optional data will allow for greater flexibility in screening pipe segments of interest, as illustrated in Figure A.1.

**Figure A-1 Example pipe segment records**

**THE DATAENTRY PAGE**

The DataEntry page is where the user inputs basic data to create the likelihood and consequences indices. All cells that are color coded are cells that contain user input. The following cells require user input:

- Current year – Cell C3.
- Pipe Age likelihood index (LI) table – Cells B18:C27 and Modification table – Cells E18:F25. An example of input into these tables is shown in Figure G.2.
Figure G-2 Pipe age likelihood index input

The example shows an input function for age and LI that ranges from 0 to 200 years. This represents a situation where the likelihood index of having a pipe break increases over time and increases more rapidly after the pipe age is 70 years. The user can enter a table with between 2 and 9 values. The likelihood index should be in the range of 0 to 1 and based upon the best estimate of the utility. The values should be entered as a contiguous block as shown in Figure A.2. The spacing of the values does not have to be uniform. If a pipe segment has an age greater than the largest value of age in the table, the likelihood index value for the largest age in the table will be assigned.

The Modification table will typically have these factors set to a value of 1. If a utility knows that a certain type of pipe material is breaking more often than the other types of material, they can assign a factor greater than 1. The likelihood index computed for the pipe segment age is multiplied by the modification factor. For example, if the utility estimates that a certain pipe material is breaking at 50% more than the expected rate, then the modification factor for that pipe material should be set equal to 1.5. It is very important that the pipe material specified on the DataBase page match exactly (the same spelling) with the material specified in the modification factors table.

Service Condition likelihood index table – Cells B34:C43. An example of the input for this table is shown in Figure A.3.
**Figure A.3 Service likelihood index input**

If the user wishes to use the LI based on three service levels, then they only need to enter their estimates for the likelihood index as illustrated in Figure G.3. Their estimates of the LI should be based upon their experience.

Pipe Breaks likelihood index table – Cells B51:C60. An example of the input for this table is shown in Figure A.4.

<table>
<thead>
<tr>
<th>Brk Ratio</th>
<th>LI</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.25</td>
<td>0.15</td>
</tr>
<tr>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>0.75</td>
<td>0.4</td>
</tr>
<tr>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>1.25</td>
<td>0.6</td>
</tr>
<tr>
<td>1.5</td>
<td>0.7</td>
</tr>
<tr>
<td>1.75</td>
<td>0.85</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

**Figure A-4 Pipe Breaks likelihood index input**

For this table the utility must enter their best estimate of the LI as a function of the normalized break ratio. Note that a value of break ratio less than 1 corresponds to a pipe segment that is experiencing fewer breaks than expected and a value greater than 1 corresponds to a pipe segment that is experiencing more breaks than expected. In Figure A.4, the maximum break ratio specified is 2 (twice the expected rate); however, this can be changed as desired. The values shown in the example of Figure A.4 show a case where the LI increases as the break ratio approaches a value of 2. For pipe segments with a number of recent breaks, the Breaking Status factor will be multiplied by the break ratio LI thereby increasing the effective LI used in the analysis.

Based upon the information in the pipe segment inventory and the likelihood index tables provided by the user, the spreadsheet has the information required to compute the estimated likelihood indices based on pipe age, pipe breaks, and service level. These indices of likelihood are then combined to give an overall likelihood index of failure,

\[
\text{Overall likelihood index of failure} = f \left( \text{age, breaks, service} \right)
\]

To compute the overall likelihood index, the tool uses a weighted average combination of the likelihood indices for age, breaks and service:

\[
\text{Overall likelihood index of failure} = w_1 \times \text{LI (age)} + w_2 \times \text{LI (breaks)} + w_3 \times \text{LI (service)}
\]
The tool allows the user to specify the relative importance of the indices which in turn are used to compute the normalized weights \((w_1, w_2, w_3)\). The normalized weights are computed by dividing the individual relative importance values by the sum of all the relative importance values. Figure A.5 shows an example of the table of relative importance factors that are specified by the user (Cells B70:D73). For example, the relative importance factors for Level 3 (1,2,1) will produce normalized weights of 0.25, 0.5, and 0.25.

<table>
<thead>
<tr>
<th>Levels</th>
<th>Relative Importance Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Age</td>
</tr>
<tr>
<td>Level 1</td>
<td>1</td>
</tr>
<tr>
<td>Level 2</td>
<td>1</td>
</tr>
<tr>
<td>Level 3</td>
<td>1</td>
</tr>
</tbody>
</table>

**Figure A.5 Relative importance factors**

The tool provides three options or levels to compute an overall likelihood index, using combinations of age, breaks and service conditions. The three different methods of overall likelihood index computation provided are defined below based upon the relative importance factors shown in Figure A.5:

- **Level 1**—based 100% on age \((w_1 = 1.0)\)
- **Level 2**—based 50% on age and 50% on breaks \((w_1 = 0.5\) and \(w_2 = 0.5\))
- **Level 3**—based 25% on age, 50% on breaks and 25% on service condition \((w_1 = 0.25; w_2 = 0.5; w_3 = 0.25)\).

The user selects the desired Level using the drop down menu in Cell F71.

Estimated Consequences Rating Table – Cells B98:D85. The information in this table contains the default values for a 1 to 3 point or rating system used to estimate a consequence of failure index. This table has three main factors of repair difficulty, location and pipe size. The user does not change any values in this table; however, they do provide the relative importance values for these factors in Cells B88:D89 as shown in Figure A.6.

<table>
<thead>
<tr>
<th>Relative Importance Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repair</td>
</tr>
<tr>
<td>1</td>
</tr>
</tbody>
</table>

**Figure A.6 Relative importance factors for the consequences score**

Figure A.6 shows an example where the location factor is twice as important as the repair difficulty or size factors.
The user has the option of providing an estimate of costs that are linked to the consequence of failure score. This estimate is provided in the estimated costs table. Optional Consequences Rating related to Estimated Costs Table – Cells B94:C103. This table is illustrated in Figure A.7.

<table>
<thead>
<tr>
<th>Conseq Index</th>
<th>Est Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>$5,000</td>
</tr>
<tr>
<td>0.4</td>
<td>$200,000</td>
</tr>
<tr>
<td>0.5</td>
<td>$300,000</td>
</tr>
<tr>
<td>0.6</td>
<td>$400,000</td>
</tr>
<tr>
<td>0.7</td>
<td>$500,000</td>
</tr>
<tr>
<td>0.75</td>
<td>$750,000</td>
</tr>
<tr>
<td>0.8</td>
<td>$1,000,000</td>
</tr>
<tr>
<td>0.9</td>
<td>$2,000,000</td>
</tr>
<tr>
<td>1</td>
<td>$5,000,000</td>
</tr>
</tbody>
</table>

Figure A.7 Estimated costs and consequence rating

If the user wishes to include the estimated costs in their analysis, they must check the box in Cell F92. If the cell is unchecked the estimated costs will not be included. Note that the consequence rating in the table is a combination of scores based upon repair difficulty, location and pipe size. For example, a rating = 1 is for an easy repair in an easy to get to location for a small pipe, while a rating = 3 is for a difficult repair in a difficult location for a large pipe.

USING THE TOOL

Once the pipe inventory information and the user information to define the likelihood and consequences indices have been entered the tool can be used to evaluate subsets of pipe segments. A simple example of how the tool is used on a subset of pipes are shown below.

The following simple example will show how the spreadsheet tool can be used and how the user can customize the analysis to suit the specific requirements of a utility. It is assumed that the reader is already familiar with the model and knows how to filter, copy, paste, etc.

Say for instance a utility wants to start the screening process by evaluating all the pipes in the database. The results showing the top-ranked pipes are shown below.
When this list of pipes-at-risk is examined then it can be seen that the pipes with the greatest risk are a mixture between large pipes (≥ 36”) and small pipes (≤ 24”). Some of the pipes might not even have a significant likelihood index, but because their consequences index is high they will rank among the higher risk pipes.

Many utilities might not necessarily just focus on the highest risk pipes within the network but will select a subset of pipes and focus on the highest risk pipes within the subset. A utility might have made the decision to focus on smaller pipes because of a number of reasons, such that the prices of smaller pipes are low at the moment, thus decreasing the capital cost required to renew the pipes. Likewise the price of a certain pipe material type might influence the utility’s decision to focus on a particular subset of pipes.

Focusing on the smaller pipes will yield the following output from the screening tool:

<table>
<thead>
<tr>
<th>Pipe ID</th>
<th>All ID / Street Name</th>
<th>Length (ft)</th>
<th>Material</th>
<th>Installation</th>
<th>Diameter</th>
<th>No. of Breaks</th>
<th>Breaking Status</th>
<th>Service</th>
<th>Location</th>
<th>Repair Difficulty</th>
<th>Priority</th>
<th>Zone</th>
<th>Likelihood Index</th>
<th>Consequence Index</th>
<th>Risk</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>RISK2A</td>
<td>NHG</td>
<td>30</td>
<td>DIP</td>
<td>1950</td>
<td>36</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.80</td>
<td>0.67</td>
<td>0.91</td>
<td>0.05</td>
<td>0.99</td>
<td>5000000</td>
<td></td>
</tr>
<tr>
<td>RISK54</td>
<td>MOO</td>
<td>40</td>
<td>DIP</td>
<td>1950</td>
<td>38</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>2.1</td>
<td>0.80</td>
<td>0.67</td>
<td>0.94</td>
<td>0.96</td>
<td>466667</td>
<td></td>
</tr>
<tr>
<td>RISK11</td>
<td>UIC</td>
<td>40</td>
<td>PVC</td>
<td>1975</td>
<td>36</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>0.63</td>
<td>0.75</td>
<td>0.44</td>
<td>0.05</td>
<td>0.99</td>
<td>5000000</td>
<td></td>
</tr>
<tr>
<td>RISK21</td>
<td>SNH</td>
<td>40</td>
<td>PVC</td>
<td>1950</td>
<td>34</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>0.59</td>
<td>0.63</td>
<td>0.44</td>
<td>0.05</td>
<td>0.99</td>
<td>5000000</td>
<td></td>
</tr>
<tr>
<td>RISK10</td>
<td>FJF</td>
<td>40</td>
<td>PVC</td>
<td>1950</td>
<td>34</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>0.59</td>
<td>0.63</td>
<td>0.44</td>
<td>0.05</td>
<td>0.99</td>
<td>5000000</td>
<td></td>
</tr>
<tr>
<td>RISK14</td>
<td>TDI</td>
<td>17</td>
<td>CIP</td>
<td>1950</td>
<td>34</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.80</td>
<td>0.67</td>
<td>0.91</td>
<td>0.05</td>
<td>0.99</td>
<td>5000000</td>
<td></td>
</tr>
<tr>
<td>RISK13</td>
<td>LIL</td>
<td>40</td>
<td>PVC</td>
<td>1975</td>
<td>36</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>0.80</td>
<td>0.67</td>
<td>0.91</td>
<td>0.05</td>
<td>0.99</td>
<td>5000000</td>
<td></td>
</tr>
<tr>
<td>RISK56</td>
<td>KLO</td>
<td>40</td>
<td>PVC</td>
<td>1950</td>
<td>36</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>0.80</td>
<td>0.67</td>
<td>0.91</td>
<td>0.05</td>
<td>0.99</td>
<td>5000000</td>
<td></td>
</tr>
<tr>
<td>RISK58</td>
<td>DIO</td>
<td>40</td>
<td>PVC</td>
<td>1950</td>
<td>36</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>0.80</td>
<td>0.67</td>
<td>0.91</td>
<td>0.05</td>
<td>0.99</td>
<td>5000000</td>
<td></td>
</tr>
<tr>
<td>RISK51</td>
<td>NIK</td>
<td>40</td>
<td>PVC</td>
<td>1975</td>
<td>36</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>0.80</td>
<td>0.67</td>
<td>0.91</td>
<td>0.05</td>
<td>0.99</td>
<td>5000000</td>
<td></td>
</tr>
<tr>
<td>RISK17</td>
<td>NHI</td>
<td>40</td>
<td>PVC</td>
<td>1980</td>
<td>36</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>0.80</td>
<td>0.67</td>
<td>0.91</td>
<td>0.05</td>
<td>0.99</td>
<td>5000000</td>
<td></td>
</tr>
<tr>
<td>RISK49</td>
<td>RSI</td>
<td>40</td>
<td>PVC</td>
<td>1960</td>
<td>36</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>0.80</td>
<td>0.67</td>
<td>0.91</td>
<td>0.05</td>
<td>0.99</td>
<td>5000000</td>
<td></td>
</tr>
<tr>
<td>RISK48</td>
<td>PHR</td>
<td>40</td>
<td>PVC</td>
<td>1950</td>
<td>36</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>0.80</td>
<td>0.67</td>
<td>0.91</td>
<td>0.05</td>
<td>0.99</td>
<td>5000000</td>
<td></td>
</tr>
</tbody>
</table>

Depending on the utility’s specific needs and requirements, the tool can be used in numerous ways to evaluate the pipes based on size, age, material, zone, priority and length.

**EXPANDING THE SIZE OF THE SPREADSHEET**

The spreadsheet is designed to handle 500 pipe segments. To expand the spreadsheet to handle a larger data set, the DataBase, LI_Index_Calcs, and Conseq_Model pages must be modified and some of the macros will need to be modified. The modification process should be done as follows:

Determine the number of additional pipe segments that must be considered.
On the DataBase page, copy the range A515:M515 and paste the range downward for the desired additional number of rows. For example, pasting the range down to A1015 will add an additional 500 records.

On the LI_Index_Calcs page, copy the range A515:U515 and paste the range downward for the desired additional number of rows.

On the Conseq_Model page, copy the range A515:G515 and paste the range downward for the desired additional number of rows.

The following macros will also have to be modified:

Sub RiskCostPipes() in Module 1. Change the highlighted numbers in the following three lines of code to reflect the new row of the last record:

\[
\begin{align*}
\text{Likeli\_Val} &= \text{Application.WorksheetFunction.VLookup(PipeID, Sheets("Li\_Index\_Calcs").Range("A11:B515"), 2, False)} \\
\text{Conseq\_Val} &= \text{Application.WorksheetFunction.VLookup(PipeID, Sheets("Conseq\_Model").Range("A11:G515"), 6, False)} \\
\text{EstCost\_Val} &= \text{Application.WorksheetFunction.VLookup(PipeID, Sheets("Conseq\_Model").Range("A11:G515"), 7, False)}
\end{align*}
\]

Sub Sort_Results() in Module 3. Change the highlighted numbers in the following three lines of code to reflect the new row of the last record:

\[
\begin{align*}
\text{xlSortNormal With ActiveWorkbook.Worksheets("RiskCalc").Sort .SetRange Range("A13:Q515")}
\end{align*}
\]

**USING THE SPREADSHEET TOOL**

The user should begin on the DataBase page. Clicking the icon toggles the Filter on and off. The user should turn the Filter on and then define their subset of pipe segments by selecting the characteristics they want using the drop down menus. Consider the situation shown in Figure A.8. This shows the filter settings on Material, Diameter and Service.
Once the subset of pipe segments is defined, the user clicks the copy icon to make a copy of the filtered records and put them on the RiskCalc page. The macro

Figure A.8 Example filtered subset of pipe segments
that copies the subset also looks up the likelihood index and consequences rating of each pipe in the subset and adds these values to the RiskCalc page.

Figure A.9 shows the RiskCalc page after the subset of pipe segments has been copied to it.

![Figure A.9 Example of the RiskCalc page](image)

The Risk column (column P) was computed by multiplying the likelihood index * consequences score. Clicking the icon will sort the records by the Risk column from the largest value to the smallest. If the user has selected the option to show the estimated consequences costs on the DataEntry page, these costs will be shown in the Est. Costs column (column Q), otherwise this column will be blank.

To save a copy of the information on the RiskCalc page to compare with another subset of pipe segments, the user clicks the icon. They are then prompted to enter a name for the scenario to be saved. A copy of the information on the RiskCalc page will be saved to the Results page. Every time a new set of results is saved to the Results page, it will be saved below the previous saved sets of results. All saved results can be saved by clicking the icon.
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ABBREVIATIONS

AWWA  American Water Works Association
NMFD  National Mains Failure Database (A database developed by the United Kingdom Water Industry Research [UKWIR] group to track failures of water and wastewater pipelines and meaningful data related to those failures. The Water Research Foundation and Colorado State University have attempted to modify and adapt this database for use with North American water utilities.)
PRST  Pipe risk screening tool
TBL   Triple Bottom Line
USEPA U.S. Environmental Protection Agency
WaterRF Water Research Foundation
WERF  Water Environment Research Foundation