WEB-BASED AND GEOSPATIALLY ENABLED TOOL FOR WATER AND WASTEWATER PIPELINE INFRASTRUCTURE RISK MANAGEMENT

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ABSTRACT

Advanced pipeline risk management is contingent on accurately locating the buried pipelines, the milieu, and also the physical condition of the pipelines. The web-based and geospatially enabled tool presented in this thesis provides an improved way to assess the risks associated with the failure of water and wastewater pipelines. This thesis focuses on the development of a web-based and geospatially enabled tool and a network level risk model for the quantitative risk assessment of water and wastewater pipelines by taking into account the likelihood and consequence of pipeline failure. The parameters used in the risk model are evaluated by water and wastewater utility asset managers in the United States, and derived by GIS using advanced geospatial tools. A web-based and geospatially enabled proof of concept is developed as a tool for utilities to access the risk model results for the water and wastewater pipelines. An exclusive working environment will be provided for each utility with access to their respective data and risk model results. Also, this is a risk model for strategic infrastructure risk management, and it is to be used for asset allocation, financial planning, and determining condition assessment methods on a network level.

I dedicate this thesis to my dad Dr. P. Sekar and mom Meena Sekar.

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1. INTRODUCTION

"The costs associated with maintaining old and deteriorating infrastructure systems, as well as expanding new systems, are staggering" [1]

The Congressional Budget Office (CBO) has concluded in 2003 that current funding from all levels of government and current revenues generated from ratepayers will not be sufficient to meet the nation's future demand for infrastructure [2]. America's drinking water systems face an annual shortfall of at least $11 billion to replace aging facilities that are near the end of their useful lives and to comply with existing and future federal water regulations [3].

"*The utility is faced with an aging stock which is losing its capital value and deteriorating in performance*" [4]

Billions of gallons of untreated water is discharged into the US Surface waters each year and the United States Environmental Protection Agency (US EPA) estimates that the nation must invest $390 billion over the next 20 years to update or replace existing systems and build new ones to meet increasing demand [3]. The projected shortfall in funding for water and wastewater infrastructure projects in the next five years has been estimated to be $108.6 billion by the American Society of Civil Engineers (ASCE) [3].

The economic and social costs of pipe failures in water and wastewater systems are increasing, putting pressure on utility managers to develop annual replacement plans that balance investments with expected benefits in a risk-based management context. In addition, analysts and water system managers need reliable and robust models for assessing water and wastewater pipeline network performance [5]. Integrated municipal risk management which prioritizes the underground water and wastewater pipelines based on location, condition, need for repair, and risk will aid decision makers in allocating funding for pipeline condition assessment, renewal or replacement in times of funding crunch.

The Australian/New Zealand Risk Management standard [6] defines risk as "The chance of something happening that will have an impact upon objectives, and is measured in terms of a combination of the likelihood and consequences of events."

This research defines risk as a measure of the likelihood of failure of water and wastewater pipelines and the consequence of its failure. Also, the risk model developed in this research is a network level risk model. This model will be used by the utilities to know the risk of their system on a network level, and thus plan for strategic infrastructure risk management.

"Geographical information systems (GIS) are powerful tools for handling spatial data, performing spatial analysis and manipulating spatial outputs. A GIS also provides a consistent visualization environment for displaying the input data and results of a model. This ability of GIS is very useful in a decision- making process. The integration of GIS and external models enables the utilization of the advantages of both" [7-15]. Halfawy et al. 2005 [16] reviewed the commercial municipal asset management systems and found that GIS is an integral component of all municipal information systems, and also various municipalities have started moving to software with GIS functionality. Halfawy and Figueroa, 2006 [17] determined that integrated GIS-based asset data repositories can lead to a cost-effective and more efficient operational and strategic decisions.

Based on the feedback from major water and wastewater utility managers across the United States, it is understood that a GIS integrated system to visualize, query and determine the risk associated with the failure of water or wastewater pipeline is not yet available to many and would be highly beneficial. The trustworthiness of the available risk models with the utilities is minimal, and many utilities tend to measure the risk of a pipe based on age and location. Asset allocation is based on simple data, and many utilities face budget shortfalls as they did not predict the system risk in an accurate way. This research aims to address these issues by developing a web-based and geospatially enabled proof of concept risk management tool to aid the asset managers of water and wastewater utilities for water and wastewater pipeline infrastructure risk management.

1.1 RESEARCH OVERVIEW

The key objectives of this research include:

i. The development of a risk model for water and wastewater pipelines
ii. The development of a web-based and geospatially enabled proof of concept for risk management of water and wastewater pipelines

The various components that went into the research and the steps undertaken to accomplish the research objectives include:

For Risk Model:

i. Various types of risk models were studied and the indexing model was determined to be used in this research.
ii. The parameters and their ranges that determine the risk of water and wastewater pipelines were identified from the literature.
iii. A utility feedback form was prepared and mailed to utility managers to get their feedback on the selection of parameters used for the risk model and to determine the parameter weights.
iv. The quantitative equation for risk and risk scale was developed using the methodology for the indexing model and based on the literature.
v. The risk model was then evaluated for a section of water and wastewater pipeline.

For Web-based and geospatially enabled proof of concept:

i. The literature and the utility current practice with respect to web-based and geospatially enabled applications for water and wastewater pipeline infrastructure risk management was reviewed.
ii. The available utility GIS data was migrated to a multi-user Oracle database and the data was published using ArcGIS Server Manager along with the model results.
iii. A web-based and geospatially enabled proof of concept was developed using ESRI's and Adobe Flex's resources using Adobe Flash Builder.
iv. The files for the proof of concept were then transferred and hosted on Virginia Tech's web server.
v. The web-based and geospatially enabled proof of concept was then demonstrated to utility managers.

1.2 THESIS STRUCTURE

This thesis is divided into five chapters and formatted using the manuscript format.

i. Chapter 1 provides an introduction to the thesis by highlighting the condition of infrastructure and infrastructure funding in the United States, as well as the need and the overall scope of this research.
ii. Chapter 2 reviews the literature and analyzes the current practice in the development of risk models and GIS applications for water and wastewater pipeline infrastructure.
iii. Chapter 3 is a manuscript focusing on the development of the risk model for water and wastewater pipelines. This manuscript discusses the methods used to determine and rank the parameters used in the model. Model implementation and a pilot study of the model with WSSC's water and wastewater pipeline data is also discussed in this manuscript.
iv. Chapter 4 is a manuscript focusing on the development of the web-based and geospatially enabled proof of concept using Adobe Flex. This manuscript also discusses the ArcGIS Server architecture, Adobe Flex architecture, the programming methods used to develop the web application, and the case study with utilities.
v. Chapter 5 concludes this thesis by providing an overview of the research accomplishments, importance and future work to be carried out.
vi. Appendix A contains the utility feedback form template with the responses received.
vii. Appendix B provides details about the GIS data upload and publishing it as a web service.
viii. Appendix C provides the code for the web-based tool to be used in Adobe Flash Builder

2. LITERATURE REVIEW

2.1 RISK MODEL FOR WATER AND WASTEWATER PIPELINES

Many research efforts have been undertaken to predict the likelihood and consequence of failure of water and wastewater pipelines. As a result, different models using various methodologies and parameters have surfaced. Rajani and Kleiner, 2001 [18] have done a comprehensive review and critiqued the deterministic and stochastic based physical and mechanical models for water pipeline failures. Also, most of the models developed are not realistic to the actual field results and thus not widely used by the water and wastewater utilities.

Most of the models found in the literature and in current practice deal with the likelihood of failure of water and wastewater pipelines. The development of the consequence of failure models is still burgeoning. Different water main deterioration models have been developed to facilitate the prediction of asset condition and the possibility of failure [19]. Sadiq et al., 2004 [20] developed a methodology to evaluate the time dependent reliability of underground grey cast iron water mains and to identify the factors that contribute to the water main failures.

Also for wastewater pipelines, J.P. Davies et al., 2001 [21] have reviewed various factors that have been recognized as influencing the structural stability of wastewater pipes. The authors have also described the general process of wastewater pipe deterioration and failure by categorizing the factors into three main groups: construction features, local external factors and other factors. Kleiner et al., 2004 [22] developed a fuzzy rule based, non-homogeneous Markov process to model the deterioration of buried pipes. Also, a methodology to assess the pipeline condition rating using multi-criteria decision making (MCDM) was proposed by Yan and Vairavamoorthy, 2003 [7].

Significant models to determine the failure risk of water and wastewater pipelines have also been developed, but these models rely on very few parameters. Based on the feedback from utilities, the trustworthiness of the models is minimal. Rogers, 2006 [23] developed a model to assess water main failure risk using the weighted average method which is based on the Power Law form of a Non-Homogeneous Poisson Process (NHPP) and Multi-Criteria Decision Analysis (MCDA). A fuzzy logic based methodology to evaluate pipeline failure risk was developed by Kleiner et al., (2006) [24], but the practicality of this model is not yet evident.

MWH, a consulting company in the wet infrastructure area, has developed a software "MWH Soft's CapPlan Sewer" [25], which takes into consideration of the likelihood and consequence of failure for wastewater pipelines to calculate risk. Based on limited parameters to determine risk, the software uses a simple method and a matrix method to determine the risk associated with the failure of wastewater pipelines. Australian and New Zealand Standard [6] for Risk Management has determined a five-step standard risk management process, which is a. Establish the context, b. Identify Risks, c. Analyze the Risks, d. Evaluate the risks, and e. Treat the risks.

Salem et al., 2003 [26] developed a network level risk-based model for highway infrastructure to estimate life-cycle costs for evaluating infrastructure rehabilitation and construction alternatives. Zayed et al., 2008 [27] proposed a network level risk model tool for highway infrastructure to evaluate sources of risk and uncertainty to prioritize highway construction projects. This research identified sources of risk and uncertainty for highway projects and developed the risk-based model tool using analytical hierarchy process.

The risk model used by Washington Suburban Sanitary Commission (WSSC), an eighth largest utility in the United States, for their water and wastewater pipelines considered the following parameters to determine the risk [28] : a. Land Use Factors (LF), b. Repair History (RH), c. Operational Needs (ON), d. Known Manufacturing Defects (KD), e. Last Inspected (LI), and f. Diameter (DI). The model then uses a simple mathematical formula: Risk = (RH+DI+KD) * (ON*4+LI) * (LF). The major limitations of this model are that the environmental factors, financial impact, and social issues in the event of a pipe failure are not taken into consideration. Another major risk model reviewed was from the Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia. Their risk model took into consideration of the following parameters to determine the risk associated with water and wastewater pipelines: a. Climate, b. Demographics, c. Natural Influences, d. Malicious Activity, e. Existing Operational Environment, f. Societal Influences, and g. Financial Impact. The major limitations of this model were that it was a qualitative model to define risks in a system rather than to determine risk.

2.2 WEB-BASED AND GEOSPATIALLY ENABLED TOOL FOR WATER AND WASTEWATER PIPELINE INFRASTRUCTURE

Of all the commercial systems that can be used to display and share data, ArcGIS Server systems complements the experiences and lessons learned by other groups [29]. The functions provided by

ArcGIS Server includes geodatabase management, GIS web services and web mapping applications [30]. Menon, 2009 [31] illustrated the capabilities of ArcGIS Server which included its ability to compile, manage and disseminate geographic information over the web. The ArcGIS Server's geospatial web services support visualization, analysis, data access, and replication along with key GIS services which includes Mapping, Query, Location, Network Analysis, Editing, and Geoprocessing.

Li et al., 2011 [29] have developed a prototype to visualize Sea Ice Information and Ice Service Archive using web-based geospatial tools. ArcGIS Server was used as the base platform, and Adobe Flex Technology was used to develop the web applications. This is one of the most comprehensive research works to use the Adobe Flex technology and ArcGIS Server for data visualization and sharing.

Yan et al., 2009 [32] recommended that for enterprise level management, GIS for water pipeline infrastructure should have functions to (a) manage all information including information of the network such as pipelines and valves, and information of the urban terrain, streets, residential areas, divisions, (b) be able to browse, zoom, roam, query by conditions, and query by regions. In the same research, Yan et al., 2009 [32] used commercial software SuperMap to develop the methods for GIS Data Management. However, a web-based tool for visualizing and querying pipeline infrastructure to aid for asset management is not presented in this research.

Western Virginia Water Authority (WVWA), Roanoke, VA [33] has developed a web-based visualization and query tool for its underground water and wastewater infrastructure. The WVWA's web-based geospatial system (Figure 1) can be accessed by the public from their website. The data that can be accessed in this system include: water and wastewater pipelines with locations, valves, hydrants, meters, manholes, and also several base layers such as roads, railways and soil. This is a basic web-based geospatial system and cannot be used as a comprehensive tool for asset management as it has no provisions to determine the risk of their water and wastewater pipelines.

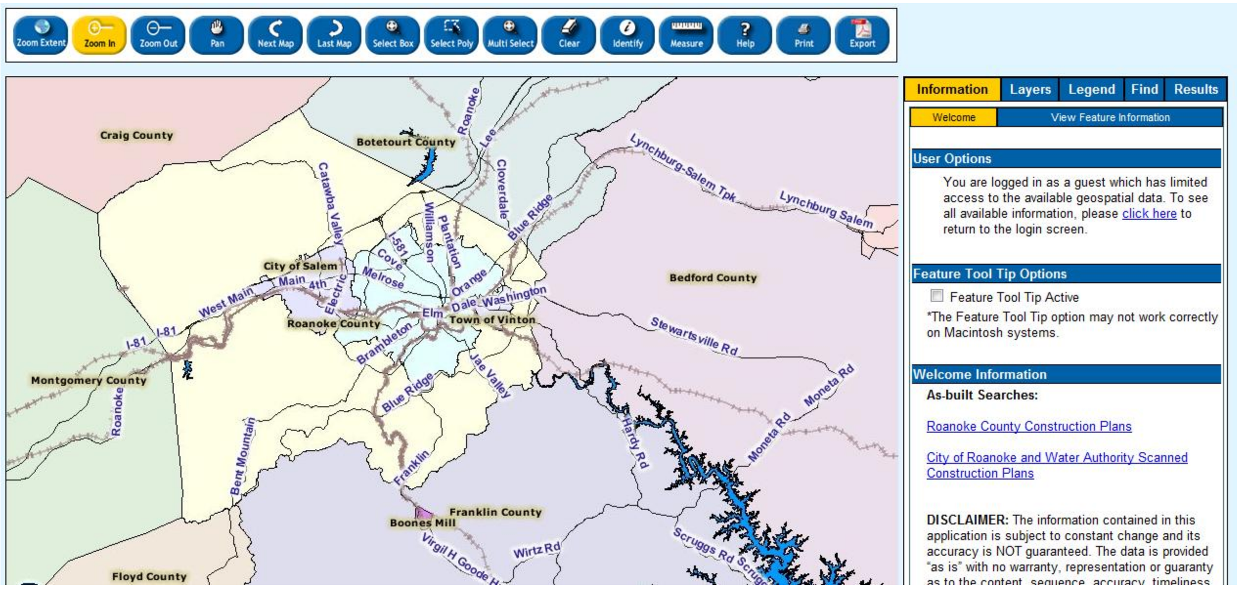

Figure 1 WVWA's web-based geospatial tool [WVWA GIS. 2001 (cited 2011 August 18); Available from: http://wvwagis.westernvawater.org/wvwaims/gis.aspx.]

Rahul, 2010 [28] developed a standard data model for water and wastewater utilities based on 100 parameters determined by researchers at Virginia Tech. The GIS data received from utilities and associated pipeline data from several databases related to soil, land use, etc. is then converted into the standard data model using a developed Geospatial ETL (Extract, Transform and Load) based tool in ArcMap. This data was stored as a single user MS Access database for each utility [28]. This MS Access database is used as the source GIS data for this research.

2.3 KEY FINDINGS OF LITERATURE REVIEW

The key findings of this literature review and thus the basis for this research include:

i. Previous research has determined and evaluated the parameters to be used in the risk models for water and wastewater pipeline infrastructure.
ii. From the review of the models used in the current practice of utilities, it is found that most of the risk models had limitations including limited parameters and are qualitative models to define risks in a system rather than to determine risk.
iii. ArcGIS Server's ability to share data among the web and for data management is highly appraised. Adobe Flex based web applications to distribute GIS information using ArcGIS Server's services have been tested and proven to be efficient.
iv. ArcGIS Server's abilities can be leveraged to develop a proof of concept for water and wastewater pipeline infrastructure risk management.

v. A desktop based database containing the utility GIS data and associated information in a standard data model has been developed by Virginia Tech. Also, a Geospatial ETL based tool in ArcMap has been developed by Virginia Tech which can be used to transform new GIS data into a standard data model.

3. NETWORK LEVEL MODEL FOR WATER AND WASTEWATER PIPELINE INFRASTRUCTURE RISK MANAGEMENT

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3.1 ABSTRACT

This manuscript focuses on the development of a model for the quantitative risk assessment for water and wastewater pipelines by taking into account the likelihood and the consequence of failure of the pipelines. This is a network level risk model, and it is to be used to determine the risk of the pipelines on a network level. This model is not to be used for classifying each pipeline for condition assessment, repair or renewal. Physical, operational and environmental parameters are used to determine the likelihood of failure of a pipe, and societal, environmental, operational and renewal complexity parameters are used to determine the consequence of failure of a pipe. These parameters are determined through literature and based on utility experience, and ranked based on their significance by major water and wastewater utility asset managers across the United States. The model results are then linked to each pipeline GIS data and color coded based on Very High Risk (Dark Red) to Very Low Risk (Light Green). The model results can be visualized and queried using a web-based geospatial tool.

Keywords: Risk Management, Water Pipeline, Wastewater Pipeline

3.2 INTRODUCTION

Previous studies involving utilities in North America and the United Kingdom have shown that only 30% of the utilities laid trust in models available in literature and used it for their operations [18]. Many water and wastewater utility asset managers in the United States feel that the various models currently available for pipelines are only for research purposes and do not feel confident in implementing the model results in their asset management plan. Still, conventional methods, like planning for condition assessment, repair, and renewal based on the pipe age, are followed in many utilities across the United States. Particularly in times of low infrastructure funding, utility asset managers require a model they can trust in performing strategic risk management. This research aims to gather trust of utility asset managers in the model by making them an active participant in the model development process.

InfraGuide, 2006 [34] defines risk as the probability and consequence of a particular event or combination that will adversely affect the ability of a municipality to meet its objectives. In this research, risk is defined as:

Risk = Likelihood of failure of pipeline * Consequence of failure of pipeline

Likelihood of Failure: The most common type of pipeline failure which results in a pipe break and causes a major release of water [35], sewage or combined sewage is the definition of likelihood of failure pipelines in this research. The calculated likelihood of failure may not be used to point to a pipe with high chances of failing, but to identify miles of water and wastewater pipelines with various levels of likelihood of failure in a network. The likelihood of failure risks are calculated based on three global parameters: physical deterioration, environmental, and operational.

Consequence of Failure: The consequence of failure determines the impact due to the failure of a water or wastewater pipeline. The consequence of a pipeline failure may lead to loss and the loss can be quantified into direct or indirect costs and also other environmental, societal impacts.

The three general types of models for risk assessment from simplest to complex include matrix, probabilistic, and indexing models [36]. The three types of models for risk assessment are discussed below:

Matrix Models: The simplest risk assessment model is the decision analysis matrix which ranks pipeline risks based on the likelihood and consequence of failure on a simple scale like high, medium, low or on a numerical scale from 1 to 5. Each cell in the matrix is assigned a threat, and this approach may also use expert opinion or quantitative information to rank risks associated with pipelines. The Australian and New Zealand standard [6] for matrix based risk assessment in which the likelihood of failure (LoF) values and the consequence of failure (CoF) values are converted to a 1 to 5 score and multiplied is adapted and discussed in the table below. The score values from 1 to 5 is a measure of risk level from Very High to Very Low.

Table 1 Matrix Method of Risk Assessment adapted for this research [6]

		Consequence of Failure				
		1	2	3	4	5
Likelihood of failure	1	Very Low	Very Low	Very Low	Very Low	Low
	2	Very Low	Very Low	Low	Low	Medium
	3	Very Low	Low	Low	Medium	High
	4	Very Low	Low	Medium	High	Very High
	5	Low	Medium	High	Very High	Very High

Probabilistic Models: Probabilistic risk assessment (PRA) which is also sometimes referred as quantitative risk assessment (QRA) or numerical risk assessment (NRA) is a rigorous technique that relies on historical failure data and event/fault-tree analysis. PRA is a data intensive technique, and it yields an absolute risk assessment of all possible failure events. Also, PRA techniques are used when estimates of absolute risk value, as expressed in property damages due to pipeline failures per time period is required [36].

Indexing Models: Index Model is the most popular risk assessment technique in which numerical scores are assigned to important conditions and activities that contribute to a pipe failure, and it may include risk increasing and risk reducing factors. Each factor is assigned a weight and the relative weight indicates the importance of the factor in the risk assessment. The weight is determined using engineering judgment and statistics, and each pipe section is scored based on all of its attributes. The main advantages of this method include [36]:

i. Immediate risk assessment results.
ii. An intuitive approach using available information.
iii. A comprehensive method that allows for incomplete knowledge which is easily modified as new information becomes available.

In this research, the indexing method is used to determine the risk associated with the failure of water and wastewater pipelines. Apart from the advantages of the index method, the other reasons for choosing this method include [36]:

i. To gain confidence among the utility managers to use this model as they are made an integral part in the model development process. The parameters and weights used in the model is evaluated and determined by the utility managers.
ii. With limited information and data available for the risks associated due to failures, collecting data for probabilistic risk assessment is highly non-feasible.
iii. The matrix method of risk assessment is not undertaken in this research, as this method provides a risk value based on the matrix, and thus it cannot be easily quantified to display the results geospatially.

3.3 RISK MODEL DEVELOPMENT

Figure 2 shows the framework used to develop this risk model.

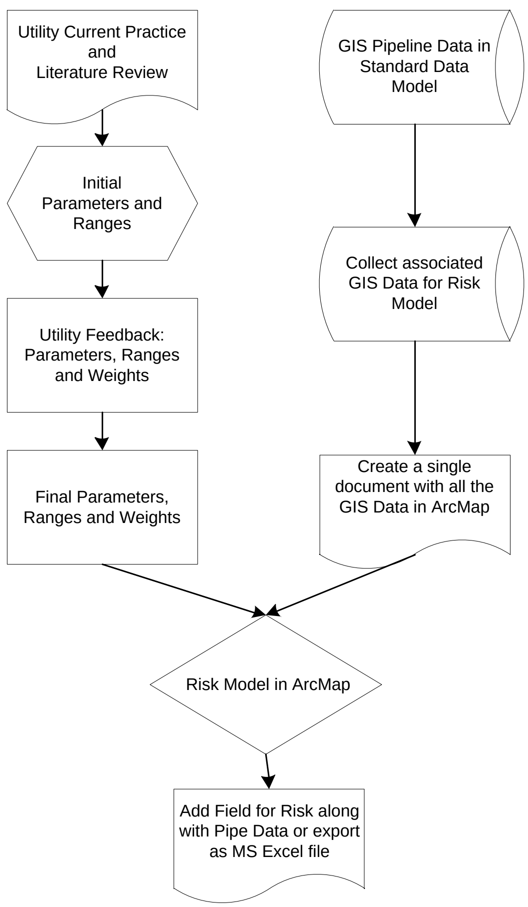

Figure 2 Process chart of the model development process

3.3.1 DATA FOR THE RISK MODEL

Rahul, 2010 [28] developed a standard data model for water and wastewater utilities based on 100 parameters determined by researchers at Virginia Tech. The GIS data received from utilities and associated pipeline data from several databases related to soil, land use, etc. is then converted into the standard data model using a developed Geospatial ETL (Extract, Transform and Load) tool in ArcMap. This data was stored as a single user MS Access database for each utility [28]. This MS Access database is used as the source GIS data for this research.

3.3.2 MODEL ASSUMPTIONS

i. This is a network level risk model only for water and wastewater pipelines.

ii. Based on the received GIS data of pipelines, the model would perform the analysis for each polyline in ArcMap. For example, if a utility stores pipeline data from node to node, then this model would perform analysis based on the data, i.e. node to node. Or, if a utility stores pipeline data based on length, then this model would perform the analysis for the length of the pipeline.

3.3.3 IDENTIFYING THE PARAMETERS

From literature [19, 37-40], the various parameters that contribute to the likelihood and consequence of failure of water and wastewater pipelines was identified. A document was prepared to get the feedback from utilities, and it was mailed to get the utility perspective on the parameters determined. The feedback form was sent to ten key asset managers in utilities across the United States. The reasons for small sampling in the survey were due to accessibility of the asset managers who could dedicate their voluntary time to respond to the survey. Due to limited time it was not possible to identify key people in all utilities across the United States who would respond to the survey. Also, the ten asset managers were identified based on their active participation in similar research work at Virginia Tech.

Responses were received from 50% i.e. five asset managers and those include asset managers from Washington Suburban Sanitary Commission (WSSC), Portland Water Bureau, Seattle Public Utilities and Town of Blacksburg (TOB). The responses cover utilities on the East Coast and West Coast of the United States. In the response form, the utilities were asked to add new parameters to the existing ones if they felt that it contributes to the risk. The parameters to be used in the model and the reason for selecting them are discussed in the following section.

Likelihood of Failure:

A. Physical

i. Pipe Material: Pipes made from different materials fail in different ways and vary in design life.
ii. Pipe Age: Effects of pipe degradation become more apparent over time.
iii. Pipe Diameter: Small diameter pipes are more susceptible to beam failure.
iv. Pipe Slope: More sloped pipes tend to have better hydraulic condition.
v. Pipe Lining and Coating: Lined and coated pipes are less susceptible to corrosion.

B. Environmental

i. Soil Type: Some soils are corrosive and experience significant volume changes in response to moisture changes, resulting in changes to pipe loading.
ii. Groundwater: Some groundwater is aggressive toward certain pipe materials.
iii. Traffic Loads: Pipe failure rate increases with traffic loads.

C. Operational

i. Maintenance Frequency : Poor practices can compromise structural integrity.
ii. Number of Breaks: Only for water pipelines; this is an indicator of the performance of the pipe.
iii. Hazen-William Coefficient (C): Only for water pipelines; low C factors indicate older pipes and poor internal conditions.
iv. CCTV Feedback: Only for wastewater pipelines; this provides information about pipe sections identified to be in poor condition based on CCTV videos.

Consequence of Failure:

A. Societal

i. Traffic Flow: Disruption to traffic due to water/wastewater flooding near or on the road.
ii. Type of Property nearby: Pipe break near a particular type of property has a direct relation to the consequence.
iii. Proximity to Areas of Interest: Failure near tourist destinations and other recreation centers would pose severe effects.
iv. Time Impact: Length of time out-of-service.
v. Financial Impact on Private Property: The third party damage costs that a utility may have to pay through insurances.

B. Environmental

i. Landslide Potential: Excessive water/wastewater flooding may potentially cause landslides.

ii. Proximity to Environmentally Sensitive Areas: Water flooding near environmentally sensitive areas is a serious consequence.

iii. Proximity to Surface water: Mixing of wastewater into nearby water bodies is disastrous and may be dangerous to aquatic life.

C. Operational

i. Pipe Diameter: Failure of large diameter pipes tends to have an adverse effect.

ii. Number of Customers Served: Water/Wastewater services cut to large number of customers are a serious consequence.

iii. Financial Impact: Carrying out the repair of pipe sections determined based on the previous utility experience.

D. Renewal Complexity

i. Access to Pipe: Access to utilities refers to the difficulty or ease of access to buried utilities that may be encountered.

ii. Utility Density: Density of utilities refers to the number of buried utilities that can be expected to be encountered.

iii. Availability of Repair materials: Existing Inventory of the available materials.

iv. Utility Pattern: Pattern of utilities refers to the configuration of buried utilities that may be encountered.

v. Type of Utility: Type of utilities refers to the various service types of buried utilities that can be expected to be encountered.

vi. Quality of Utility Record: Indicates the reliability of existing records on buried utilities.

3.3.4 PARAMETER WEIGHTS AND RANGES

The utility feedback form also consisted of a section where the utilities were asked to provide the significance value (Very High, High, Medium, Low, Very Low) for each parameter based on their experience for the likelihood and consequence of failure of water and wastewater pipes. The ranges for each parameter were determined through literature [19, 37-40], and the utilities were asked to determine if they were realistic. The following tables provide the final parameter ranges, attribute weights, parameter weight, and the standard deviation of the weights based on their feedback.

Table 2 Parameter weights and ranges for the likelihood of failure of water pipelines

Global Parameter	Parameter	Attributes	Attribute Weight (WLA_x)	Parameter Weight (WLP_y)	Standard Deviation (σ)
Physical	Pipe Material	PVC Pipes	1	4	1.22
		Concrete Pipes	2		
		Asbestos	3		
		Ductile Iron	4		
		Cast Iron	5		
	Pipe Age	<10 years	1	4	0.7
		10-24 years	2		
		25-49 years	3		
		50-75 years	4		
		>75 years	5		
	Pipe Diameter	>75 inches	1	2.8	0.44
		50- 75	2		
		24-49 inches	3		
		12-24 inches	4		
		<12inches	5		
	Pipe Slope	<2	1	3.33	1.52
		3-5	3		
		>5	5		
	Pipe Lining and Coating	Yes	1	3.2	1.3
		No	5		
Environmental	Soil Type	Moderate, pH 5-9	1	4.2	0.44
		Aggressive, pH >5 and pH <9	5		
	Traffic Loads	Low (≤ 1,500 ADT per lane)	1	3.2	1.09
		Moderate (> 1,500 and ≤ 6,000 ADT per lane)	3		
		High (> 6,000 ADT per lane)	5		
Operational	Maintenance Frequency	1-3 years	1	3.4	0.89
		4-8 years	3		
		>9	5		
	Number of Breaks	0-1	1	4.4	0.89
		2-3	3		
		4-5	5		
	Hazen-William Coefficient	<41 C factor	1	2	1
		40-100 C factor	3		
		>101 C factor	5		

Table 3 Parameter weights and ranges for the consequence of failure of water pipelines

Global Parameter	Parameter	Attributes	Attribute Weight (WCA_x)	Parameter Weight (WCP_y)	Standard Deviation (σ)
Societal	Traffic Flow	Low (≤ 1,500 ADT per lane)	1	4.2	0.44
		Moderate (> 1,500 and ≤ 6,000 ADT per lane)	3		
		High (> 6,000 ADT per lane)	5		
	Type of Property Nearby	Industrial	1	4.4	0.89
		Commercial	3		
		Residential	5		
	Proximity to Areas of Interest	>1000 feet	1	3.5	1.29
		100-1000 feet	3		
		<100 feet	5		
	Time Impact	<1hour	1	3.5	0.57
		1-65hours	3		
		>6hours	5		
	Financial Impact on Private Property	Low	1	3.25	0.5
		Medium	3		
		High	5		
Environmental	Landslide Potential	No	1	3.4	1.51
		Yes	5		
	Proximity to Environmentally Sensitive Areas	>1000 feet	1	2.8	1.3
		100-1000 feet	3		
		<100 feet	5		
Operational	Pipe Diameter	<18	1	3.8	1.09
		18-36	3		
		>36	5		
	Number of Customers Served	<10	1	4.6	0.55
		20-24	3		
		>25	5		
	Financial Impact	Low	1	3.75	1.25
		Medium	3		
		High	5		
Renewal Complexity	Access to Pipe	Access available	1	4.6	0.54
		Restricted access (under railway, bridge, building, river, etc)	5		
	Utility Density	Low (1 to 2 pipes in close proximity)	1	3.8	0.83
		Medium (3 to 5 pipes in close proximity)	3		
		High (more than 5 in close proximity)	5		

Table 3 Parameter weights and ranges for the consequence of failure of water pipelines (cont.)

Global Parameter	**Parameter**	**Attributes**	**Attribute Weight (WCA_x)**	**Parameter Weight (WCP_y)**	**Standard Deviation (σ)**
Renewal Complexity	Availability of Repair Materials	Yes	1	2.2	1.4
		No	5		
	Utility Pattern	Simple: One parallel and/or one crossing utility parallel and/or two crossing utilities	1	3	1.22
		Average: Two parallel and/or two crossing utilities	3		
		Complex: More than two parallel and/or crossing utilities	5		
	Type of Utility	Less-Critical: Water, sewer, storm water	1	2.4	0.54
		. Sub-Critical: Telephone, electric, television cable, etc.	3		
		Critical: Fiber-optic cable, gas, oil, high-voltage line, etc.	5		
	Quality of Utility Record	Good	1	2.75	0.95
		Fair	3		
		Bad	5		

Table 4 Parameter weights and ranges for the likelihood of failure of wastewater pipelines

Global Parameter	**Parameter**	**Attributes**	**Attribute Weight ($WWLA_x$)**	**Parameter Weight ($WWLP_y$)**	**Standard Deviation (σ)**
Physical	Pipe Material	PVC Pipes	1	4	0.81
		Concrete Pipes	2		
		Asbestos	3		
		Ductile Iron	4		
		Cast Iron	5		
	Pipe Age	<10 years	1	3.5	1.29
		10-24 years	2		
		25-49 years	3		
		50-75 years	4		
		>75 years	5		

Table 4 Parameter weights and ranges for the likelihood of failure of wastewater pipelines (contd.)

Global Parameter	Parameter	Attributes	Attribute Weight ($WWLA_x$)	Parameter Weight ($WWLP_y$)	Standard Deviation (σ)
Physical	Pipe Diameter	>75 inches	1	3	0
		50- 75	2		
		24-49 inches	3		
		12-24 inches	4		
		<12inches	5		
	Pipe Slope	<2	1	3.75	1.5
		3-5	3		
		>5	5		
	Pipe Lining and Coating	Yes	1	3.75	0.95
		No	5		
Environmental	Soil Type	Moderate, pH 5-9	1	4	0.81
		Aggressive, pH >5 and pH <9	5		
	Traffic Loads	Low (≤ 1,500 ADT per lane)	1	2.5	1.29
		Moderate (> 1,500 and ≤ 6,000 ADT per lane)	3		
		High (> 6,000 ADT per lane)	5		
Operational	Maintenance Frequency	1-3 years	1	4	0
		4-8 years	3		
		>9	5		
	CCTV Feedback	Excellent	1	4	0
		Average	3		
		Poor	5		

Table 5 Parameter weights and ranges for the consequence of failure of wastewater pipelines

Global Parameter	Parameter	Attributes	Attribute Weight ($WWCP_y$)	Parameter Weight ($WWCP_y$)	Standard Deviation (σ)
Societal	Traffic Flow	Low (≤ 1,500 ADT per lane)	1	4.25	0.95
		Moderate (> 1,500 and ≤ 6,000 ADT per lane)	3		
		High (> 6,000 ADT per lane)	5		
	Type of Property Nearby	Industrial	1	4	1.41
		Commercial	3		
		Residential	5		

Table 5 Parameter weights and ranges for the consequence of failure of wastewater pipelines (contd.)

Global Parameter	Parameter	Attributes	Attribute Weight ($WWCP_y$)	Parameter Weight ($WWCP_y$)	Standard Deviation (σ)
Societal	Proximity to Areas of Interest	>1000 feet	1	3	1.15
		100-1000 feet	3		
		<100 feet	5		
	Time Impact	<1hour	1	3.25	0.5
		1-65hours	3		
		>6hours	5		
	Financial Impact on Private Property	Low	1	3	0.5
		Medium	3		
		High	5		
Environmental	Landslide Potential	No	1	2.75	1.70
		Yes	5		
	Proximity to Surface water	>1000 feet	1	4.75	0.5
		100-1000 feet	3		
		<100 feet	5		
Operational	Pipe Diameter	<18	1	3.5	0.57
		18-36	3		
		>36	5		
	Number of Customers Served	<10	1	4.5	0.57
		20-24	3		
		>25	5		
	Financial Impact	Low	1	4	0.81
		Medium	3		
		High	5		
Renewal Complexity	Access to Pipe	Access available	1	4.5	1.0
		Restricted access (under railway, bridge, building, river, etc)	5		
	Utility Density	Low (1 to 2 pipes in close proximity)	1	3.5	1.0
		Medium (3 to 5 pipes in close proximity)	3		
		High (more than 5 in close proximity)	5		
	Availability of Repair Materials	Yes	1	2	1.41
		No	5		

Table 5 Parameter weights and ranges for the consequence of failure of wastewater pipelines (contd.)

Global Parameter	Parameter	Attributes	Attribute Weight ($WWCP_y$)	Parameter Weight ($WWCP_y$)	Standard Deviation (σ)
Renewal Complexity	Utility Pattern	Simple: One parallel and/or one crossing utility parallel and/or two crossing utilities	1	2.25	0.95
		Average: Two parallel and/or two crossing utilities	3		
		Complex: More than two parallel and/or crossing utilities	5		
	Type of Utility	Less-Critical: Water, sewer, storm water	1	2.5	1.29
		. Sub-Critical: Telephone, electric, television cable, etc.	3		
		Critical: Fiber-optic cable, gas, oil, high-voltage line, etc.	5		
	Quality of Utility Record	Good	1	2.5	1.29
		Fair	3		
		Bad	5		

The standard deviation provided the comparison of how varied the weights for each parameter were in the response received from utilities. The highest standard deviation is 1.7 for one parameter, and it is 0 for many parameters. Thus, the responses received were very much realistic and did not vary on a very high range.

Also, a comparative study based on the mean of the weights and standard deviation from the responses received from the east coast and west coast utilities did not show significant differences. Thus, it was decided to use the mean of all responses in determining the weights of the parameters. The parameter pipe length, which was part of the feedback form, was removed as pipe length received a weight = 1.6, and three experts marked it low, and two have marked it very low. Pipe bedding and joint type parameters were removed as many utilities did not collect the data for them. The ground water/depth of water table parameter was removed as the collected GIS data was available countywide.

3.3.5 QUANTITATIVE INDEX MODEL AND SCALE

The key step in the model development process is to determine the risk value for each pipeline on a range of 0-5 (Very Low to Very High). The following equations are used to determine the likelihood and consequence of failure of each pipeline and thus the risk.

<u>Water:-</u>

Risk = Likelihood of Failure * Consequence of Failure

$$\text{Thus, Risk} = [\{\sum (WLAx * WLPy)/ \sum(WLPy) \} * \{\sum (WCAx * WCPy)/ \sum(WCPy) \}] / 5$$

<u>Wastewater:-</u>

Risk = Likelihood of Failure * Consequence of Failure

$$\text{Thus, Risk} = [\{\sum (WWLAx * WWLPy)/ \sum(WWLPy) \} * \{\sum (WWCAx * WWCPy)/ \sum(WWCPy) \}] / 5$$

<u>Risk Scale</u>: The following risk scale adapted from Fares and Zayed, 2010 [41] is used to determine the necessary actions that needs to be undertaken based on the risk model results, which is on a range of 1-5 for sustainable infrastructure risk management. The risk scale, which ranges from 1 to 5, indicates the risk possessed by each water and wastewater pipeline with 1 being a very low risk to 5 being a very high risk. The proposed actions that need to be undertaken for each risk value are discussed in the following table.

Table 6 Risk Scale and Action

Risk Value	Linguistic Value	Action
0-0.99	Very Low	No Action Required
1-1.99	Low	Watch out Required
2-2.99	Medium	Mitigation action in Long Term
3-3.99	High	Mitigation action in Short Term
4-5.0	Very High	Immediate Mitigate Actions Required

3.3.6 GIS ANALYSIS

The GIS data received from utilities and collected from other national databases is analyzed in ArcMap. The analysis is done using the calculate field tool of ArcMap inside the attribute table of the water and wastewater pipeline GIS data. The steps taken to perform the GIS analysis and retrieve the model results are:

i. A separate geodatabase with the pipeline GIS data and the associated GIS data for risk model is created in ArcMap.
ii. Using various analysis tools in ArcMap, geospatial analysis is performed based on the pipeline GIS data. The analysis includes proximity to parks, roads etc., and separate fields are created along with the pipeline GIS data.
iii. Using the calculate field tool in ArcMap and based on the parameter ranges, weights, and the mathematical equation the risk is calculated, and added as a separate field along with the pipeline GIS data.
iv. The pipes are then color coded based on the risk, 1 (Light Green) to 5 (Dark Red).
v. Once the analysis is completed, the GIS data can be exported as a comma separated value (CSV) file, and the index model can also be executed in MS Excel.

3.3.7 DISPLAY RESULTS

An Adobe Flex-based geospatial tool developed as part of this research is used to visualize and query the model results. The development of the web-based geospatial tool is discussed in detail in the next manuscript.

A random risk model result generated for water pipelines and visualized in the web-based geospatial tool is shown in the following snapshot (Figure 3).

Figure 3 Sample Risk Model results visualized in the web-based geospatial tool

3.3.8 MODEL LIMITATIONS

i. This is a network level risk model and cannot be used to determine a pipe(s) that need(s) condition assessment, rehab, and replacement. However, it can be used only for strategic risk management to determine the risk of the pipelines in the network and plan for financial investments.

ii. This model is very subjective as the parameter weights are determined by limited utility asset managers based on their experience and data that is currently available.

iii. Not all small utilities have the required GIS data used in the model or can afford to collect them. However, many small utilities feel this model as a baseline to know what data needs to be collected for strategic risk management.

iv. Currently, this model requires a GIS Analyst or an in-house GIS expert to run and add the model results to the pipes.

3.4 CASE STUDY

The steps required by the utilities in order to get access to the risk model results are explained in the following flowchart (Figure 4):

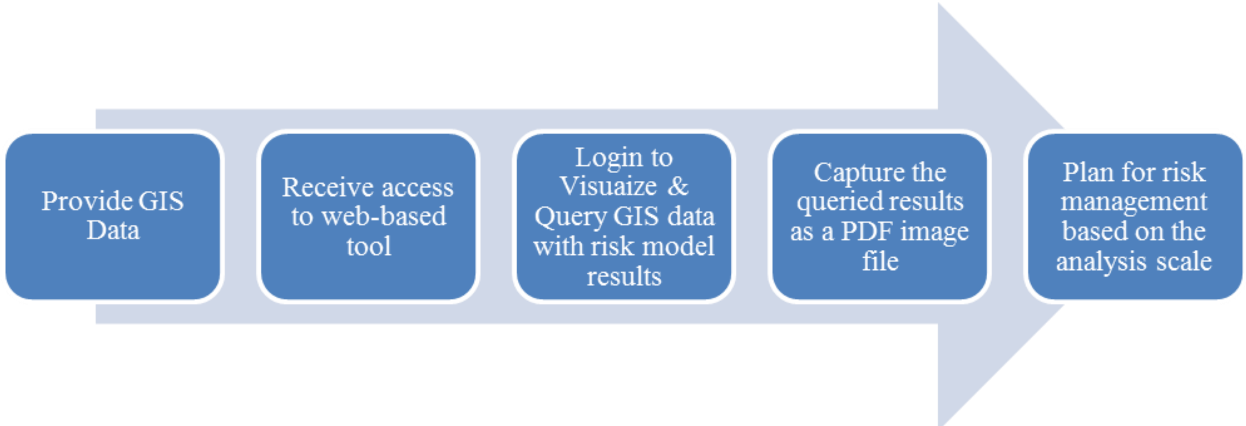

Figure 4 Steps required by utilities to get access to the risk model results

The Memorandum of Understanding between Virginia Tech and Utilities prohibits the discussion and publishing the geographic location and also the condition/risk possessed by the pipeline infrastructure. Thus, the results for a utility with name sanitized are presented in this research. The GIS data received from Utility A for water pipelines include age, diameter, material, lining type number of customer accounts, depth, slope, and Hazen William coefficient. The GIS data received from Utility A for wastewater pipelines include age, diameter, material, lining type, number of customer accounts, depth, and slope. The GIS data collected from other national databases for Utility A include parks, streets, environmentally sensitive areas, and types of structures nearby.

After assembling the necessary GIS data, a pipe segment in both water and wastewater pipelines was selected, and the following analysis was done in ArcMap and MS Excel. An analysis for two segments of water and wastewater pipelines and their risk values are discussed in this case study.

Table 7 Likelihood of failure calculation for a water pipeline

Likelihood of Failure					
		Value	Attribute Weight (WLA_x)	Parameter Weight (WP_y)	Total Weight (WLA_x * WPA_y)
Physical	Material	Cast Iron	5	4	20
	Age	64	4	4	16
	Diameter	16	4	2.8	11.2
	Slope	2	1	3.33	3.33
	Lining and Coating	Yes	1	3.2	3.2
Environmental	Soil Type	Moderate	3	4.2	12.6
	Traffic Loads	High	5	3.2	16
Operational	Maintenance Frequency	N/A	N/A	3.4	N/A
	Number of Breaks	N/A	N/A	4.4	N/A
	Hazen William Coefficient	N/A	N/A	1.2	N/A

Table 8 Consequence of failure calculation for a water pipeline

Consequence of Failure					
		Value	Attribute Weight (WCA_x)	Parameter Weight (WCP_y)	Total Weight (WCA_x * WCP_y)
Societal	Traffic Flow	High	5	4.2	21
	Type of Property Nearby	Residential	5	4.4	22
	Proximity to Areas of Interest	>1000feet	1	3.5	3.5
	Time Impact	N/A	N/A	0	N/A
	Financial Impact on Private Property	N/A	N/A	0	N/A
Environmental	Landslide Potential	No	1	3.4	3.4
	Proximity to Sensitive Areas	>1000	1	2.8	2.8
Operational	Pipe Diameter	16	1	3.8	3.8
	Number of Customers Served	9	1	4.6	4.6
	Financial Impact	N/A	N/A	3.75	N/A
Renewal Complexity	Access to Pipe	Restricted	5	4.6	23
	Utility Density	N/A	N/A	0	N/A
	Availability of Repair Materials	Yes	1	2.2	2.2
	Utility Pattern	Average	3	3	9
	Type of Utility	Less-Critical	1	2.4	2.4
	Quality of Utility Record	Good	1	2.75	2.75

$$Risk = [\{\sum (WLAx * WLPy)/ \sum(WLPy) \} * \{\sum (WCAx * WCPy)/ \sum(WCPy) \}] / 5$$

Thus, Risk = (3.33 * 2.21) /5 = 1.47

Based on the risk scale this pipeline would be color coded Dark Green, and the necessary action would be to watch out for this pipe segment.

Table 9 Likelihood of failure calculation for a wastewater pipeline

Likelihood of Failure					
		Value	Attribute Weight ($WWLA_x$)	Parameter Weight ($WWLP_y$)	Total Weight ($WWLA_x$ * $WWLP_y$)
Physical	Material	Concrete	2	4	8
	Age	41	3	3.5	10.5
	Diameter	8	5	3	15
	Slope	6	5	3.75	18.75
	Lining and Coating	No	5	3.75	18.75
Environmental	Soil Type	Moderate	3	4	12
	Traffic Loads	Low	1	2.5	2.5
Operational	Maintenance Frequency	X	0	0	0
	CCTV Feedback	X	0	0	0

Table 10 Consequence of failure calculation for a wastewater pipeline

Consequence of Failure					
		Value	Attribute ($WWCA_x$)	Parameter Weight ($WWLP_y$)	Total Weight ($WWCA_x$ * $WWCP_y$)
Societal	Traffic Flow	Moderate	3	4.25	12.75
	Type of Property Nearby	Commercial	3	4	12
	Proximity to Areas of Interest	<100feet	5	3	15
	Time Impact	X	0	0	0
	Financial Impact on Private Property	High	5	4	20
Environmental	Landslide Potential	no	1	2.75	2.75
	Proximity to surface water	<100feet	5	4.75	23.75
	Pipe Diameter	8	1	3.5	3.5
Operational	Number of Customers Served	N/A	0	0	0
	Financial Impact	High	5	4	20
Renewal Complexity	Access to Pipe	Restricted	5	4.5	22.5
	Utility Density	X	0	0	0
	Availability of Repair Materials	Yes	1	2	2
	Utility Pattern	Average	3	2.25	6.75
	Type of Utility	Less-Critical	1	2.5	2.5
	Quality of Utility Record	Good	1	2.5	2.5

$$Risk = [\{\sum (WWLAx * WWLPy)/ \sum(WWLPy) \} * \{\sum (WWCAx * WWCPy)/ \sum(WWCPy) \}] / 5$$

$$Risk = (3.49 * 3.32)/5 = 2.32$$

Based on the risk scale this pipeline would be color coded Yellow, and the necessary action would be to take action in long term for this pipe segment.

3.5 CONCLUSION

This manuscript presented the development and implementation of a network level risk model for water and wastewater pipelines. This is one of very few studies undertaken to develop a risk model for water and wastewater pipelines involving the water/wastewater utility asset managers from the development of the model to its implementation stage. A total of 10 factors were used to determine the likelihood of failure of water pipelines and 9 for wastewater pipelines, and 16 factors were used to determine the consequence of failure of water/wastewater pipelines. The weights and ranges of these parameters were evaluated and identified by the utility asset managers' feedback. Water and wastewater pipeline infrastructure asset managers can use this GIS integrated risk model to determine the risk of their water/wastewater pipeline infrastructure systems and plan for strategic risk management based on the risk scale described in this research. Thus, the main contributions of this research include:

i. Identification of parameters for a risk model for water and wastewater pipelines,
ii. Determination of ranges and weights for the parameters based on utility feedback, and
iii. Development of a GIS integrated quantitative index model for water and wastewater pipeline infrastructure.

The next manuscript discusses the development of the web-based geospatial tool used to visualize and query the model results in a web environment.

4. WEB-BASED AND GEOSPATIALLY ENABLED PROOF OF CONCEPT FOR WATER AND WASTEWATER PIPELINE INFRASTRUCTURE RISK MANAGEMENT

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4.1 ABSTRACT

Advanced pipeline risk management is contingent on accurately locating the buried pipelines, the milieu, and the physical condition of the pipelines. This web-based geospatial proof of concept provides a platform to visualize and query the risk associated with the failure of water and wastewater pipelines. This research focuses on the development of a web based tool enabling the utility managers to visualize and query water and wastewater pipeline information along with associated information provided by the utilities and information retrieved from other national databases. An exclusive working environment will be provided for each utility, which provides GIS data with access to their respective data, and to the risk model results for their water and wastewater pipelines. Advanced tools such as Adobe Flex and ArcGIS Server are used in this research to build this web based geospatial tool. Pilot studies and constructive feedback from utility asset managers has shown that this web-based geospatial proof of concept has important practical value and is of high benefit to the utilities.

Keywords: Web, Geospatial, ArcGIS Server, Water Pipeline, Wastewater Pipeline, Risk Management

4.2 INTRODUCTION

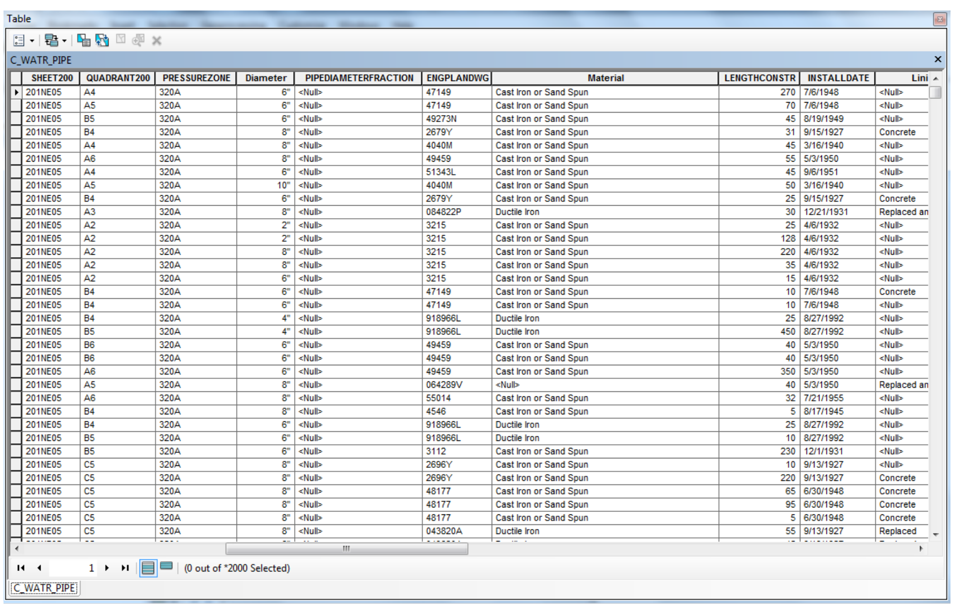
From literature review and from the current practice study of major water and wastewater utilities across the United States, it has been found that a web-based geospatial tool to visualize and query risk model results for strategic infrastructure risk management is not yet available. Also, many large utilities had the monetary benefits to hire consultants to provide them with simple GIS based tools for water and wastewater infrastructure visualization and querying. Basic GIS tools are also provided to the asset managers by in-house GIS specialists in many large utilities. However, most of the utilities in the United States have no access to necessary geospatial tools for strategic water and wastewater pipeline infrastructure risk management. Asset managers cannot afford time to master a GIS software and carry out functions in it. They prefer simple tools to visualize and query their pipeline infrastructure data, along with risk model results in a simple web page.

This research addresses these issues by developing a web-based and geospatially enabled proof of concept with intuitive applications making it highly useful for the utility managers to access risk models results, assess their pipeline infrastructure, and plan for strategic pipeline infrastructure risk management. Web-based geospatial tools provide an effective way to share GIS data and models developed at one location to utilities spread across the United States. This research leverages the provisions provided by commercial off-the-shelf software and integrating it with risk model results for access and use by utilities.

4.3 WEB-BASED AND GEOSPATIALLY ENABLED PROOF OF CONCEPT DEVELOPMENT

4.3.1 GIS DATA

Rahul, 2010 [28] developed a standard data model for water and wastewater utilities based on 100 parameters determined by researchers at Virginia Tech. The GIS data received from utilities and associated pipeline data from several databases related to soil, land use, etc. is then converted into the standard data model using the Geospatial ETL (Extract, Transform and Load) tool in ArcMap. This data was stored as a single user MS Access database for each utility [28]. This MS Access database is used as the source GIS data for this research.



Table

C_WATR_PIPE

SHEET200	QUADRANT200	PRESSUREZONE	Diameter	PIPEDIAMETERFRACTION	ENGPLANDWG	Material	LENGTHCONSTR	INSTALLDATE	Lini
201NE05	A4	320A	6"	<Null>	47149	Cast Iron or Sand Spun	270	7/6/1948	<Null>
201NE05	A5	320A	6"	<Null>	47149	Cast Iron or Sand Spun	70	7/6/1948	<Null>
201NE05	B5	320A	6"	<Null>	49273N	Cast Iron or Sand Spun	45	8/19/1949	<Null>
201NE05	B4	320A	8"	<Null>	2679Y	Cast Iron or Sand Spun	31	9/15/1927	Concrete
201NE05	A4	320A	8"	<Null>	4040M	Cast Iron or Sand Spun	45	3/16/1940	<Null>
201NE05	A6	320A	8"	<Null>	49459	Cast Iron or Sand Spun	55	5/3/1950	<Null>
201NE05	A4	320A	6"	<Null>	51343L	Cast Iron or Sand Spun	45	9/6/1951	<Null>
201NE05	A5	320A	10"	<Null>	4040M	Cast Iron or Sand Spun	50	3/16/1940	<Null>
201NE05	B4	320A	6"	<Null>	2679Y	Cast Iron or Sand Spun	25	9/15/1927	Concrete
201NE05	A3	320A	8"	<Null>	084822P	Ductile Iron	30	12/21/1931	Replaced an
201NE05	A2	320A	2"	<Null>	3215	Cast Iron or Sand Spun	25	4/6/1932	<Null>
201NE05	A2	320A	2"	<Null>	3215	Cast Iron or Sand Spun	128	4/6/1932	<Null>
201NE05	A2	320A	8"	<Null>	3215	Cast Iron or Sand Spun	220	4/6/1932	<Null>
201NE05	A2	320A	8"	<Null>	3215	Cast Iron or Sand Spun	35	4/6/1932	<Null>
201NE05	A2	320A	6"	<Null>	3215	Cast Iron or Sand Spun	15	4/6/1932	<Null>
201NE05	B4	320A	6"	<Null>	47149	Cast Iron or Sand Spun	10	7/6/1948	Concrete
201NE05	B4	320A	6"	<Null>	47149	Cast Iron or Sand Spun	10	7/6/1948	<Null>
201NE05	B4	320A	4"	<Null>	918966L	Ductile Iron	25	8/27/1992	<Null>
201NE05	B5	320A	4"	<Null>	918966L	Ductile Iron	450	8/27/1992	<Null>
201NE05	B6	320A	6"	<Null>	49459	Cast Iron or Sand Spun	40	5/3/1950	<Null>
201NE05	B6	320A	6"	<Null>	49459	Cast Iron or Sand Spun	40	5/3/1950	<Null>
201NE05	A6	320A	6"	<Null>	49459	Cast Iron or Sand Spun	350	5/3/1950	<Null>
201NE05	A5	320A	8"	<Null>	064289V	<Null>	40	5/3/1950	Replaced an
201NE05	A6	320A	8"	<Null>	55014	Cast Iron or Sand Spun	32	7/21/1955	<Null>
201NE05	B4	320A	8"	<Null>	4546	Cast Iron or Sand Spun	5	8/17/1945	<Null>
201NE05	B4	320A	6"	<Null>	918966L	Ductile Iron	25	8/27/1992	<Null>
201NE05	B5	320A	6"	<Null>	918966L	Ductile Iron	10	8/27/1992	<Null>
201NE05	B5	320A	6"	<Null>	3112	Cast Iron or Sand Spun	230	12/1/1931	<Null>
201NE05	C5	320A	8"	<Null>	2696Y	Cast Iron or Sand Spun	10	9/13/1927	<Null>
201NE05	C5	320A	8"	<Null>	2696Y	Cast Iron or Sand Spun	220	9/13/1927	Concrete
201NE05	C5	320A	8"	<Null>	48177	Cast Iron or Sand Spun	65	6/30/1948	Concrete
201NE05	C5	320A	8"	<Null>	48177	Cast Iron or Sand Spun	95	6/30/1948	Concrete
201NE05	C5	320A	8"	<Null>	48177	Cast Iron or Sand Spun	5	6/30/1948	Concrete
201NE05	C5	320A	8"	<Null>	043820A	Ductile Iron	55	9/13/1927	Replaced

1 (0 out of *2000 Selected)

C_WATR_PIPE

Figure 5 Utility GIS data in a standard data model

4.3.2 SERVER ARCHITECTURE

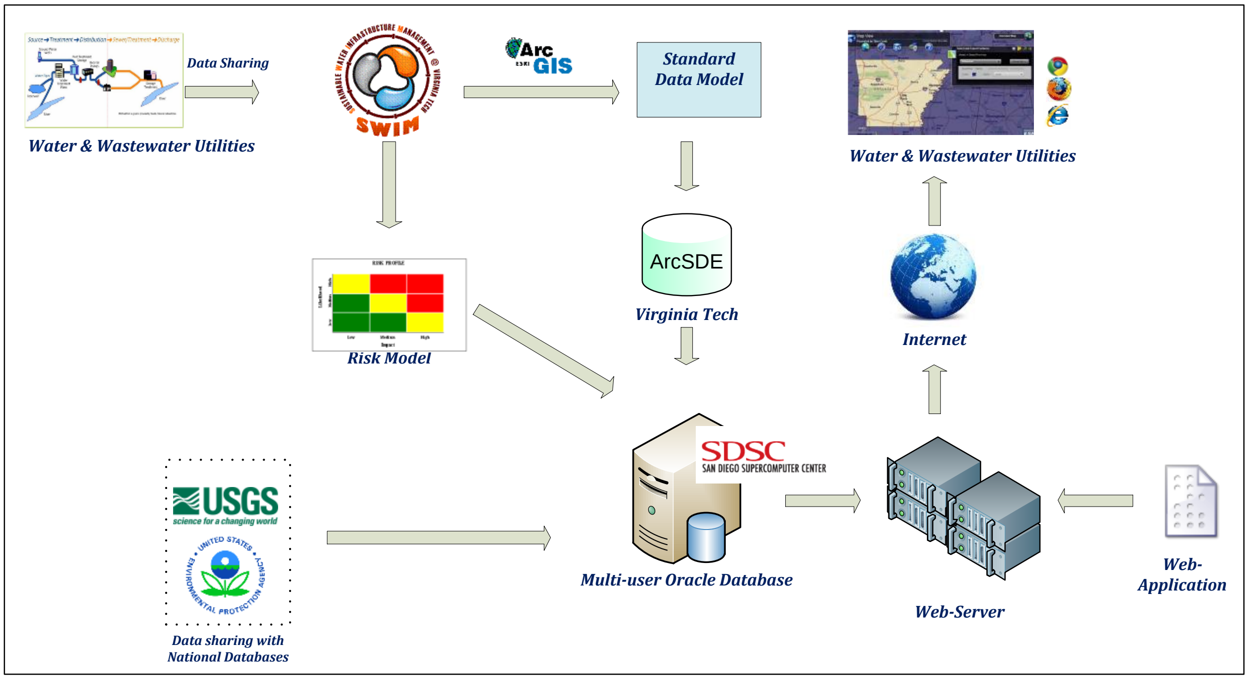


Figure 6 Entire process chart for the web-based geospatial proof of concept development

The utilities GIS data, when processed at Virginia Tech, is stored on an Oracle Real Applications Clusters server at the San Diego Supercomputing Center (SDSC). Virginia Tech and the San Diego Supercomputer Center has a dedicated point-to-point pathway fiber-Optic Communication Link. It is not part of the public Internet; however, it is a link in the National Lambda Rail research network that is only used by major universities and institutions. The data is owned by a single Oracle schema, and the only other user accounts that exist in this database instance are assigned to selected members at Virginia Tech. The utility GIS data are sensitive, and the primary goal of computer and network security activities at the San Diego Supercomputer Center is to protect the confidentiality, integrity, and availability of computing resources. The Data Intensive Computing Environments (DICE) group at the San Diego Supercomputer Center (SDSC) has implemented software to make use of a variety of authentication/data-security systems in the SDSC Storage Resource Broker (SRB) and other distributed applications [39].

ArcGIS Server allows sharing the processed utility GIS data across the web to the respective utilities. ArcGIS Server also allows managing the GIS data in a variety of database management systems. Data can be stored in a central database and support the concurrent multiuser editing necessary for many data management workflows. Also, ArcGIS Server provides the ability to create and load spatial data into geodatabases. The key functionalities of ArcGIS Server that is utilized in this research include: a. geodatabase management, b. GIS Web Services, c. web-mapping applications, and d. geoprocessing [30].

The web-based tool is client-side and it is built using Adobe Flex and using ArcGIS Server as the base platform. The web-based tool that is built is a rich internet application (RIA) that has an appearance and similar characteristics of desktop applications which are built on platforms such as Adobe Flash, Java and Microsoft Silverlight. The RIA technologies also support the idea of a rich client interface that is more robust, responsive and visually pleasing than a HTML-based interface [29, 42]. The web-based tools are stored in the web server provided by Virginia Tech. The utilities are then provided access to the web-based tool to query and visualize their respective GIS data.

The various steps required to publish the GIS data as a map service are: (Explained with screenshots in Appendix B)

i. Using a spatial database connection in ArcGIS Desktop, a connection is made to the Oracle Database in SDSC/VT using ArcSDE.

ii. Feature classes are created in the Oracle database, and the GIS data from the single user MS Access database is converted to feature classes in the multi-user Oracle database.

iii. An ArcGIS map document (*.mxd) is then created using the data on the Oracle database, and the document is stored on the server using a FTP connection.

iv. Using ArcGIS Server Manager, the map document is published as a web-service.

v. From the ArcGIS Services directory, the URL (Uniform Resource Locator) for the REST (Representational State Transfer) service is retrieved. The REST URL is embedded in the master code of the Flex Application to seek access to the GIS services on top of ArcGIS Server

4.3.3 ArcGIS API FOR FLEX AND FLEX FRAMEWORK

Flex applications are developed using the MXML (XML based user interface markup language) and ActionScript languages with the ActionScript class library, which contains components, manager classes, data service classes, and classes for all other features [43]. The Flex framework provides the declarative language, application services, components, and data connectivity that developers need to rapidly build applications for mobile, web, or desktop [44].

The main components of the Flex framework include [44]:

i. *Languages:* The behaviors of the Flex Application and the definition of the user interface layout and appearance are programmed using MXML language. ActionScript® 3.0 is the language used to build the client-side application logic and it is an object-oriented language.

ii. *Class library and application services:* A prebuilt class library and other application services to build RIAs using more than one hundred rich, prebuilt application components are already contained in Flex. Services such as data binding, drag-and-drop management, a display system that manages the interface layout, a style system that manages the look and feel of interface components, and effects and an animation system to manage motions and transitions are already included.

iii. *Components:* Flex 4 provides a component model that provides complete separation from appearance and functionality, enabling each to be changed independently without affecting each other.

Adobe Flash Builder 4, which is an Eclipse based development tool, is software that accelerates Flex application development. It enables intelligent coding, interactive step-through debugging, visual design of the user interface layout, appearance, and behavior of RIAs. Flash Builder 4 includes the complete Flex framework, including compilers, component library, and debuggers [44]. Adobe Flash Builder 4 is used extensively in this research to program the web-based geospatial tools. A snapshot of Adobe Flash Builder 4 used for programming is shown in Figure 7.

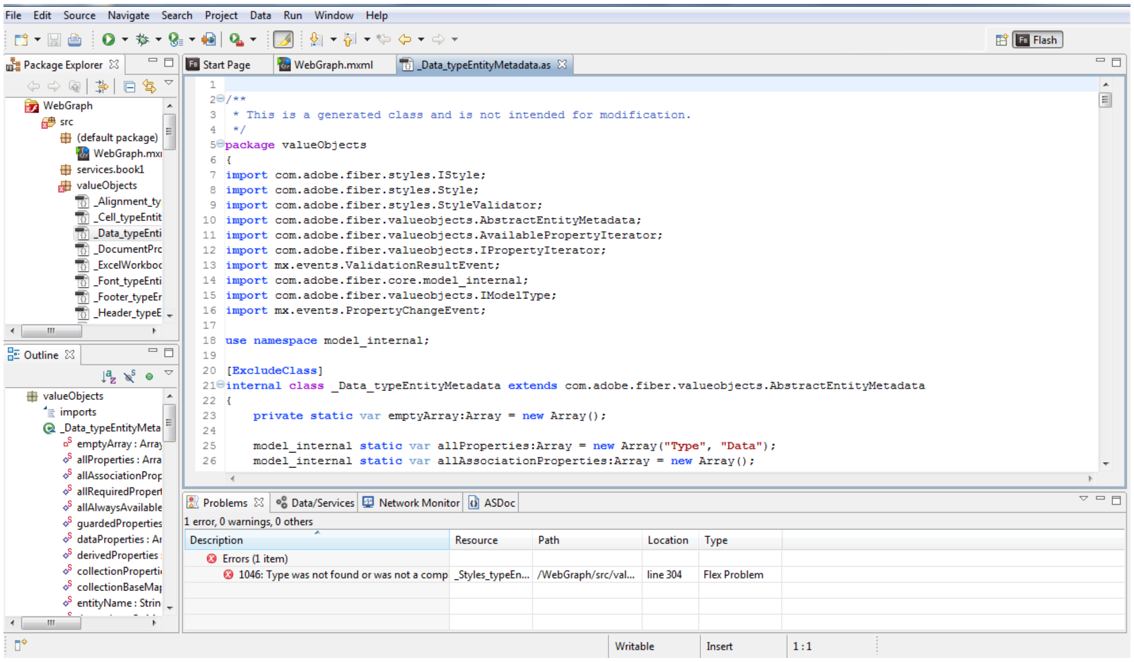


Figure 7 Adobe Flash Builder 4 interface used for programming the web-based geospatial tool

The ArcGIS API for Flex enables developers to create dynamic, interactive and expressive web applications leveraging ArcGIS Server resources—such as maps, locators, feature services and geoprocessing models—and Flex components—such as grids, trees and charts on top of ArcGIS Server [43].

The ArcGIS server REST (Representational State Transfer) API (Application Programming Interface), which provides an open web interface to services hosted by ArcGIS server, is used in this research. All resources and operations exposed by the REST API are accessible through a hierarchy of endpoints or URL for each GIS service published with ArcGIS Server. The core functions of GIS, to provide service mode scaling, roaming, spatial query and advanced analysis functions of map application, is provided by the ArcGIS Server REST [45]. The following code shows how the REST service from ArcGIS Server Manager is utilized in the Flex application.

```
<livemaps>
<mapservice label="Seattle Manholes" type="dynamic" visible="false"
alpha="1">http://maps.gis.vt.edu:8399/arcgis/rest/services/wiis/Nodes/MapServer</mapservice>
<mapservice label="Performance Index Blacksburg" type="dynamic" visible="false"
alpha="1">http://maps.gis.vt.edu:8399/arcgis/rest/services/wiis/BBMODEL/MapServer</mapservice>
```

The web-based proof of concept is built using ArcGIS API for Flex and ESRI's Sample Flex Viewer using the services provided by the ArcGIS Server. The complete code for the homepage of the web-based geospatial tool and the code to access the capabilities of the Sample Flex Viewer are provided in Appendix C.

4.3.4 WEB-BASED GEOSPATIAL TOOL

The developed web-based and geospatially enabled tool provides an intuitive method to visualize and query pipeline infrastructure data, view model results on web, and capture images for strategic infrastructure risk management. The following are the three key capabilities of the web-based tool:

1. *Visualization Tool*: Utilities, which have provided their GIS data and supplementary information, can login to the web-based tool with the access code provided. Once into the system, they can view their buried pipeline assets and their attributes on various themes and base maps. Data from other national databases, which includes US EPA and USGS, can be accessed from the tool.

2. *Query Tool:* Asset Managers who would like to retrieve data only for a particular geographical region, or search for pipeline data with certain attributes can do so by entering a simple query in the query tool or selecting by location.

3. *Risk Model*: The risk model results for both water and wastewater pipelines can be accessed for each pipeline from the online system.

Figure 8 shows a snapshot of the web based tool showing the various widgets along with a GIS layer of pipelines visualized on a satellite map.

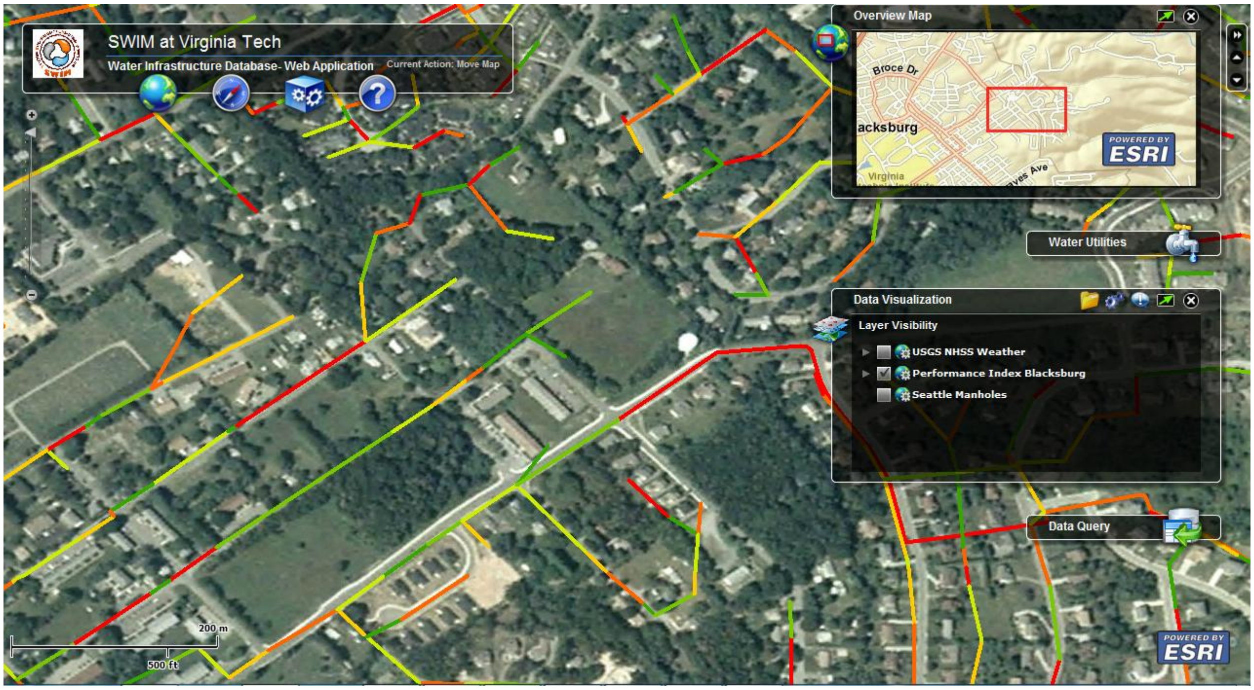


Figure 8 Visualization Tool in the web-based geospatial tool

Once the utility asset manager gets access to the web-based tool, they can see various icons in the upper left hand corner and in the right side of the screen. By clicking the globe icon, one can select the various base maps from the list. If a utility asset manager would like to view their infrastructure on various themes and with base maps, they can do so by selecting a base map from this icon. The compass icon is typically a navigational tool that provides the ability to zoom in/out, re-center map, and view the map in full-extent. The cuboidal icon provides various tools for querying, and also a draw tool that can be used by asset managers to mark certain features on the map. The last on this menu is a question mark icon which provides various help features, a basic tutorial about this web-based tool, and the copyright statement of ESRI and Virginia Tech.

Figure 9 Various icons for navigating the web-based geospatial tool

The risk model results, discussed in the previous manuscript, have a range from 1-5 (Very Low Risk to Very High Risk) and is color coded on pipes from light green to dark red. Figure 10 shows a snapshot of the sample risk model results visualized on the web-based geospatial tool.

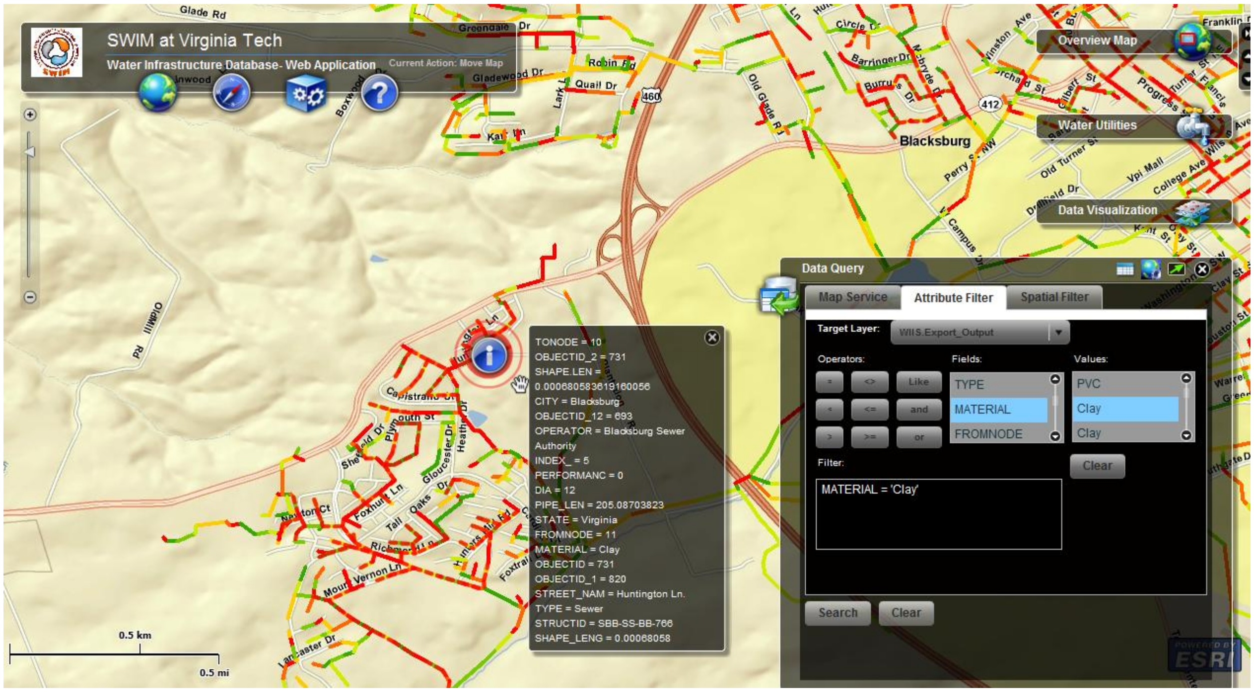


Figure 10 Query tool and sample risk model results visualized in the web-based geospatial tool

4.4 PILOT STUDY

This web-based tool was pilot studied with Washington Suburban Sanitary Commission (WSSC) and Town of Blacksburg's (TOB) GIS data. The following capabilities of the web-based tool were evaluated and presented to WSSC's and TOB's asset managers:

i. To visualize water and wastewater pipelines, manholes, pumps and other related features on maps along with the associated information in a single web interface. An integral part of risk management is to identify existing features and their associated information. This web-based tool provided a single interface for the asset managers to identify all their assets and information without having to look through various documents and files.

ii. Do advanced querying using pipe characteristics such as pipe ID, manhole ID, pump ID, etc.: With the search functionality of the web-based tool, the asset managers were able to locate pipeline infrastructure and manholes using a simple query (Attribute Filter) or by using a spatial query (Spatial Filter).

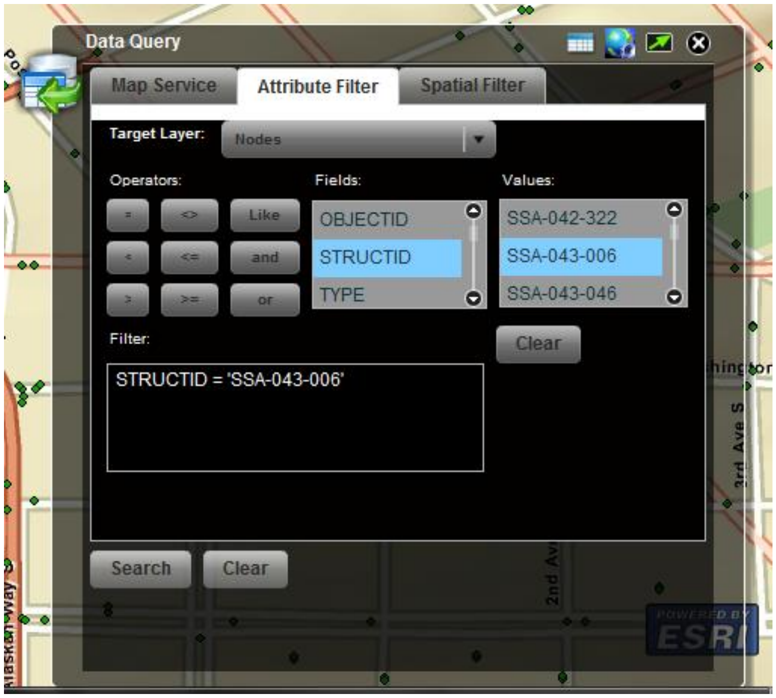


Figure 11 Snapshot of the data query tool

iii. Visualize and Query Model Results: Risk model results for water and wastewater pipeline infrastructure can be visualized and queried in the web-based tool. Thus, regions of risky pipes can be marked with red lines or polygons in the web-based tool for consideration.

iv. The visualized and queried information on the map can be printed or captured as an image in a PDF format.

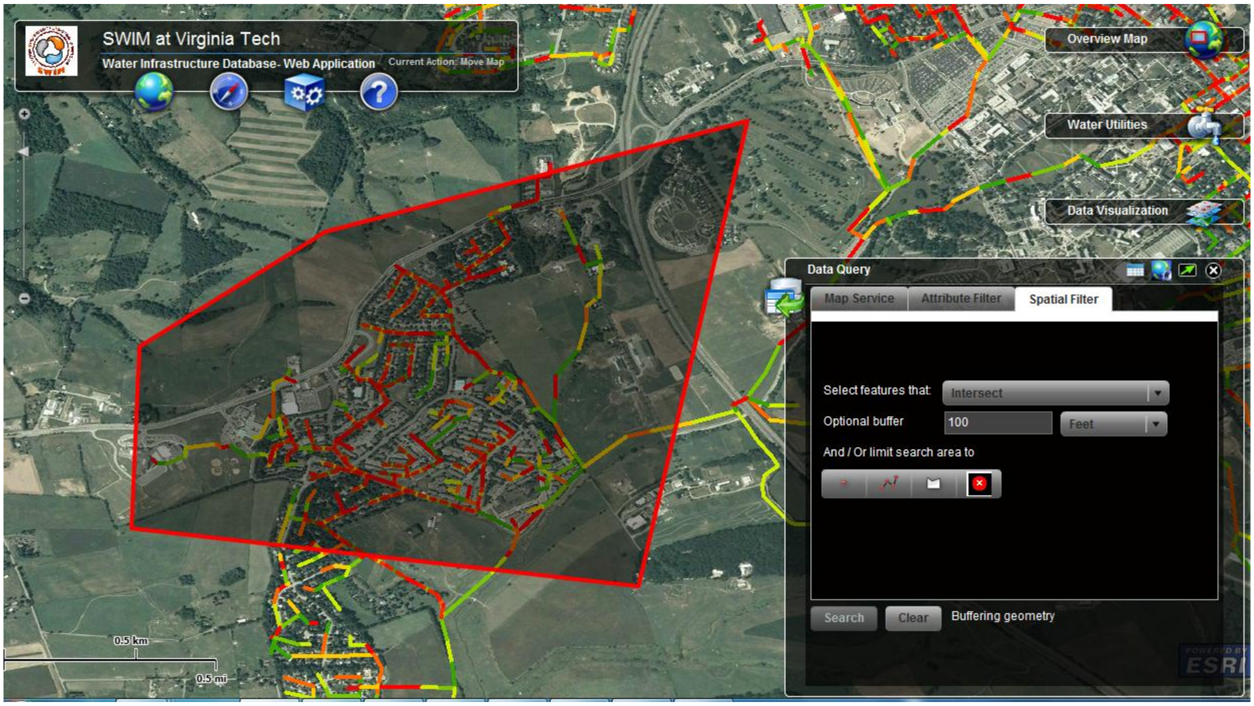


Figure 12 Selecting pipelines within a region for image capture

4.5 CONCLUSION

This manuscript presented the development of a web-based and geospatially enabled proof of concept for water and wastewater pipeline infrastructure risk management. Currently, there are no advanced web-based tools to integrate data visualization and querying of water and wastewater pipeline infrastructure data with risk model results. When this proof of concept was presented to water and wastewater utility asset managers, they acknowledged the potential role it could have in strategic water and wastewater pipeline infrastructure risk management. The contributions of this manuscript include:

i. Development of web-based and geospatially enabled proof of concept using Adobe Flex and ArcGIS Server for water and wastewater pipeline infrastructure risk management,
ii. Customizing web-based visualization and querying tools to visualize and query water and wastewater pipeline infrastructure data along with data from other national databases such as USEPA and USGS, and
iii. Development of capabilities to visualize and query risk model results on the web-based tool, and capture results as an image for strategic water and wastewater pipeline infrastructure risk management.

5. SUMMARY, CONCLUSION, AND FUTURE RESEARCH

5.1 SUMMARY

Literature and the current utility practice with respect to risk models for water and wastewater pipelines were evaluated in this research. The various models available in literature and those used by the utilities were analyzed for their advantages and limitations. The indexing method based risk model was determined to be used in this research for its various benefits over the other type of models. Also, from the literature review, the parameters and their ranges that determine the risk of water and wastewater pipelines were identified. This research developed a risk model for water and wastewater pipeline infrastructure by making utility asset managers an active participant in the model development process. A utility feedback form was prepared and mailed to the utility managers to get their feedback on the selection of parameters and weights for the risk model. Thus, the utility manager's trust on the model was gained in the initial stages of the model development.

An analysis of the standard deviation of the responses received provided the comparison of the variation of weights for each parameter. The responses received were found to be very much realistic and did not vary on a very high range. Also, a comparative study based on the mean of the weights and standard deviation from the responses received from the east coast and west coast utilities did not show much significance in the changes. Thus, it was decided to use the mean of all responses in determining the weights of the parameters. The quantitative equations for risk model as well as the risk scale were developed using the methodology for the indexing model and were based on the literature. A snapshot of how the model results can be visualized in the web-based geospatial tool was also discussed in this research. Finally, for a section of water and wastewater pipelines, this model was tested and it was found to provide realistic results.

The literature and the current utility practice with respect to web-based and geospatially enabled applications for water and wastewater pipeline infrastructure risk management was reviewed. Of all the commercial systems that can be used to display and share GIS data, ArcGIS Server's functionalities were highly recommended. Thus, ArcGIS Server and Adobe Flex were used to develop this web-based geospatial proof of concept for water and wastewater pipeline infrastructure risk management. The available utility GIS data was migrated to a multi-user Oracle database, and the data was published using ArcGIS Server Manager along with the model results. The complete methodology used to transfer the GIS data from desktop based ArcMap to a web service is provided in this thesis. Also, the various functionalities of Adobe Flex and ArcGIS Server which benefits the current research are discussed in this thesis.

A web-based and geospatially enabled proof of concept was developed using ESRI's and Adobe Flex's resources using Adobe Flash Builder. The GIS data of water and wastewater pipelines is hosted on an Oracle database, and the web-based tool is hosted on a web server provided by Virginia Tech. The web-based and geospatially enabled proof of concept was then demonstrated to utility asset managers. Three main components, Visualization Tool, Query Tool, and Risk Model results visualization, are the key features of this proof of concept. The code for the development of the web-based and geospatially enabled proof of concept is provided in the appendix section of the thesis.

5.2 CONCLUSION

This thesis presented the development of a web-based and geospatially enabled tool for water and wastewater pipeline infrastructure risk management. This web-based and geospatially enabled tool provides an improved way to assess the risks associated with the failure of water and wastewater pipelines. Also, the risk model developed in this research is for strategic infrastructure risk management, and it is to be used for asset allocation, financial planning, and determining condition assessment methods on a network level.

Thus, the main contributions of this thesis include:

i. Development of a quantitative index based risk model for water and wastewater pipelines,
ii. Development of a web-based and geospatially enabled proof of concept using Adobe Flex and ArcGIS Server for water and wastewater pipeline infrastructure risk management, and
iii. Development of capabilities to visualize and query risk model results on the web-based tool, and capture results as an image for strategic water and wastewater pipeline infrastructure risk management.

5.3 FUTURE RESEARCH

The future research should aim to:

i. Receive feedback from more utility asset managers in the United States for the parameter weights used in the risk model.

ii. Validate the risk model based on the GIS data received from utilities, and perform the necessary changes to the model if required.

iii. Develop a geoprocessing model using Python scripting inside ArcMap which can do all the necessary geospatial analysis required to execute the model. This would minimize the use of a GIS specialist to execute the model.

iv. Build a widget inside the web-based application to have the following capabilities:

   a. To execute the risk model online, and display results instantaneously over the web.

   b. To execute MATLAB based models developed by other researchers at Virginia Tech in the web-application with the ability to change the model parameters.

v. Develop a robust web-application from the proof of concept developed in this research.

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APPENDIX A

UTILITY FEEDBACK FORM AND RESPONSES RECEIVED

This appendix contains the Utility Feedback Form which was mailed to the asset managers to get their feedback on the parameter weights and selection. Also, the responses received from five utility managers are enclosed in the appendix.

WEB-GIS BASED GLOBAL RISK MODEL FOR WATER AND WASTEWATER PIPELINES

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Utility Review and Feedback

I. Abstract

Advanced pipeline risk assessment is contingent on accurately locating the buried pipelines, the milieu and also the physical condition of the pipelines. This web-GIS based state-of-the-art visualization platform provides a robust way to assess the risk associated with the failure of water and wastewater pipelines. This research focuses on the development of a robust model for the quantitative risk assessment for water and wastewater pipelines by taking into account of the likelihood and consequence of pipeline failure. Extensive global parameters are taken into consideration to determine the likelihoodand consequence of pipeline failure, and these parameters are evaluated heuristicallyby water and wastewater utilities in US, Canada and Australia, and derived by GIS using advanced geospatial tools. A web-based Pipeline Infrastructure Database (PID) has been developed as a tool for utilities to tweak and run the risk assessment model for each type of pipe and simulate it for extended periods. An exclusive working environment is provided for each utility with access to their respective data to run the risk assessment model and output the results in customized formats as reports, shape files and databases, and thus this serves as a comprehensive tool for sustainable utility risk management.

II. Research Methodology

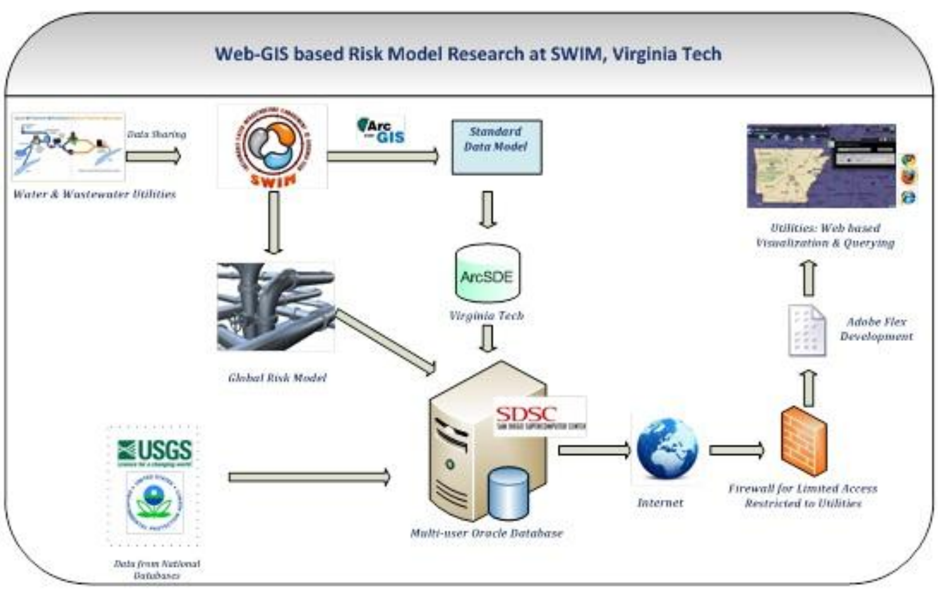


Figure 1: Web-GIS based Risk Model Research at SWIM, Virginia Tech

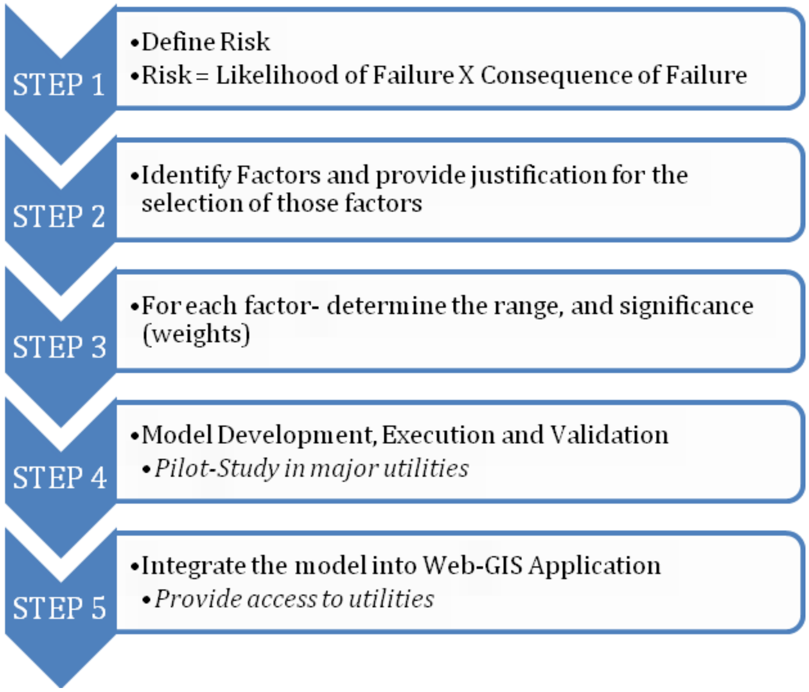
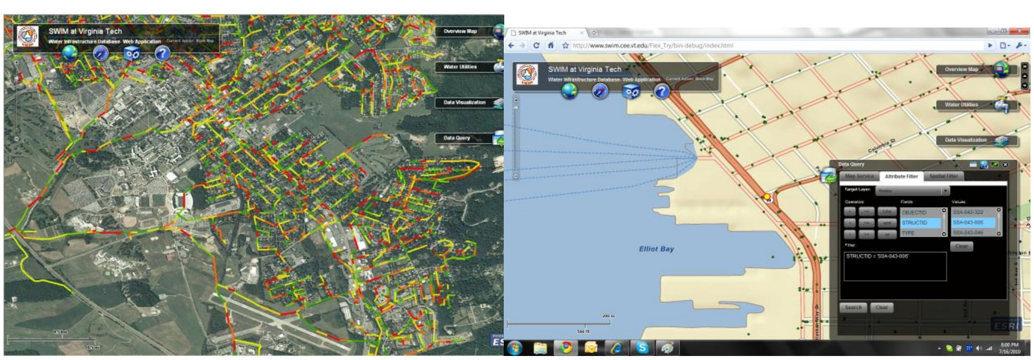


Figure 2: Advanced Global Risk Model Development

III. <u>Benefits to Utilities</u>

- Advanced GIS based web-application for pipeline data visualization and querying using state-of the art technology
- Access to a robust – Global Likelihood and Consequence of Failure Model for Water and Wastewater pipelines integrated into the Web-GIS application
- Simulatemodel results on the web application, and export results in desired formats for effective strategic Infrastructure Asset Management



(a) (b)

Figure 3 (a, b): Risk Model results color coded on Web-GIS application, querying tool of the Web-GIS application

IV. Required feedback

STEP 1: Review the factors for Likelihood of Failure of Pipe and Consequence of failure of pipe- mention if any major parameter is to be added for consideration

STEP 2: Provide significance values for each factor

I. STEP 1

Please review the following parameters to determine the likelihood, and consequence of failure of water and wastewater pipes. If you strongly feel that another factor can be included for consideration in this global risk model then please note down the factor in the space provided as 'other factors', and mention the explanation for including that factor.

Also, please be reminded that this is a global risk model for strategic asset management which may lead to further in-depth modeling studies, or other condition assessment.

A. Water

a. Likelihood of Failure

No.	Factor	Explanation
A.	**Physical**	
1.	Pipe material	Pipes made from different materials fail in different ways, and vary in design life
2.	Pipe age	Effects of pipe degradation become more apparent over time
3.	Pipe diameter	Small diameter pipes are more susceptible to beam failure
4.	Pipe Length	Larger length pipes are prone to failure than smaller length pipes
5.	Pipe Slope	More sloped pipes tend to have better hydraulic condition
6.	Pipe Lining and Coating	Lined and coated pipes are less susceptible to corrosion
7.	Joint Type	Some types of joints have experienced premature failure
8.	*Other Factors- Include Factor Name and Explanation below*	
B.	**Environmental**	
1.	Pipe bedding	Improper bedding may result in premature pipe failure
2.	Soil type	Some soils are corrosive; some soils experience significant volume changes in response to moisture changes, resulting in changes to pipe loading.
3.	Groundwater	Some groundwater is aggressive toward certain pipe materials
4.	Traffic Loads	Pipe failure rate increases with Traffic Loads
5.	*Other Factors- Include Factor Name and Explanation below*	
C.	**Operational**	
1.	Maintenance Frequency	Poor practices can compromise structural integrity
2.	Number of Breaks	Indicator of the performance of the pipe
3.	Hazen-William Coefficient (C)	Low C Factors indicate older pipes and poor internal conditions

4.	*Other Factors- Include Factor Name and Explanation below*	

b. Consequence of Failure

No.	Factor	Explanation
A.	**Societal**	
1.	Traffic Flow	Disruption to traffic due to flooding near or on road
2.	Type of Property Nearby	Pipe break near a particular type of property has a direct relation to the consequence
3.	Proximity to Areas of Interest	Failure near tourist destinations and other recreation centers would pose severe effects
4.	Time Impact	Length of time out of service
5.	Financial Impact on Private Property	The third party damage costs that a utility may have to pay through insurances**.**
6.	*Other Factors- Include Factor Name and Explanation below*	
B.	**Environmental**	
1.	Landslide Potential	Excessive water flooding may potentially cause landslides
2.	Proximity to Environmentally Sensitive Areas	Water Flooding near Environmentally Sensitive Areas is a serious consequence
3.	*Other Factors- Include Factor Name and Explanation below*	
C.	**Operational**	
1.	Pipe Diameter	Failure of large diameter pipes tend to have an adverse effect
2.	Number of Customers Served	Water cut to large number of customers is a serious consequence
3.	Financial Impact	Carrying out the repair of pipe section
4.	*Other Factors- Include Factor Name and Explanation below*	
D.	**Renewal Complexity**	
1.	Access to Pipe	Access to utilities refers to the difficulty or ease of access to buried utilities that may be encountered on the project.
2.	Utility Density	Density of utilities refers to the number of buried utilities that can be expected to be encountered on the project.
3.	Availability of Repair materials	Existing Inventory of the available materials
4.	Utility Pattern	Pattern of utilities refers to the configuration of buried utilities that can be expected to be encountered on the project.
5.	Type of Utility	Type of utilities refers to the various service types of buried utilities that can be expected to be encountered on the project.
6.	Quality of Utility Record	Quality of utility record indicates the reliability of existing records on buried utilities
7.	*Other Factors- Include Factor Name and Explanation below*	

B. Wastewater

a. Likelihood of Failure

No.	Factor	Explanation
A.	**Physical**	
1.	Pipe material	Pipes made from different materials fail in different ways, and vary in design life
2.	Pipe age	Effects of pipe degradation become more apparent over time
3.	Pipe diameter	Small diameter pipes are more susceptible to beam failure
4.	Pipe Length	Larger length pipes are prone to failure than smaller length pipes
5.	Pipe Slope	More sloped pipes tend to have better hydraulic condition
6.	Pipe Lining and Coating	Lined and coated pipes are less susceptible to corrosion
7.	Joint Type	Some types of joints have experienced premature failure
8.	*Other Factors- Include Factor Name and Explanation below*	
B.	**Environmental**	
1.	Pipe bedding	Improper bedding may result in premature pipe failure
2.	Soil type	Some soils are corrosive; some soils experience significant volume changes in response to moisture changes, resulting in changes to pipe loading.
3.	Groundwater	Some groundwater is aggressive toward certain pipe materials
4.	Traffic Loads	Pipe failure rate increases with Traffic Loads
5.	*Other Factors- Include Factor Name and Explanation below*	
C.	**Operational**	
1.	Maintenance Frequency	Poor practices can compromise structural integrity
2.	CCTV Feedback	Sections identified to be in poor condition based on CCTV videos
3.	*Other Factors- Include Factor Name and Explanation below*	

b. Consequence of Failure

No.	Factor	Explanation
A.	**Societal**	
1.	Traffic Flow	Disruption to traffic due to flooding near or on road
2.	Type of Property Nearby	Pipe break near a particular type of property has a direct relation to the consequence
3.	Proximity to Areas of Interest	Failure near tourist destinations and other recreation centers would pose severe effects
4.	Time Impact	Length of time out of service

5.	Financial Impact on Private Property	The third party damage costs that a utility may have to pay through insurances**.**
6.	*Other Factors- Include Factor Name and Explanation below*	
B.	**Environmental**	
1.	Landslide Potential	Excessive water flooding may potentially cause landslides
2.	Proximity to Surface water	Mixing of wastewater into nearby water bodies is disastrous and may be dangerous to aquatic life
3.	Depth of Water Table	Wastewater may seep into the soil to contaminate the water table
4.	*Other Factors- Include Factor Name and Explanation below*	
C.	**Operational**	
1.	Pipe Diameter	Failure of large diameter pipes tend to have an adverse effect
2.	Number of Customers Served	Water cut to large number of customers is a serious consequence
3.	Financial Impact	Carrying out the repair of pipe section
4.	*Other Factors- Include Factor Name and Explanation below*	
D.	**Renewal Complexity**	
1.	Access to Pipe	Access to utilities refers to the difficulty or ease of access to buried utilities that may be encountered on the project.
2.	Utility Density	Density of utilities refers to the number of buried utilities that can be expected to be encountered on the project.
3.	Availability of Repair materials	Existing Inventory of the available materials
4.	Utility Pattern	Pattern of utilities refers to the configuration of buried utilities that can be expected to be encountered on the project.
5.	Type of Utility	Type of utilities refers to the various service types of buried utilities that can be expected to be encountered on the project.
6.	Quality of Utility Record	Quality of utility record indicates the reliability of existing records on buried utilities
7.	*Other Factors- Include Factor Name and Explanation below*	

II. STEP 2

Please provide the significance value (Very High, High, Medium, Low, Very Low) for each parameter based on your experience for the likelihood, and consequence of failure of water and wastewater pipes. The significance values that you record here for each factor would be used to determine the factor weights in the global risk model. Please mark 'X' at the significance level next to each factor.

Also, if you had included any new factor for consideration in STEP 1 then please provide significance values for those too.

Response 1

A. Water

a. Likelihood of Failure

No.	Factor	Significance				
		Very High	High	Medium	Low	Very Low
A.	**Physical**					
1.	Pipe material		x			
2.	Pipe age		x			
3.	Pipe diameter			x		
4.	Pipe Length					x
5.	Pipe Slope				x	
6.	Pipe Lining and Coating		x			
7.	Joint Type			x		
8.	*Other Factors*					
B.	**Environmental**					
1.	Pipe bedding			x		
2.	Soil type		x			
3.	Groundwater		x			
4.	Traffic Loads				x	
5.	*Other Factors*					
C.	**Operational**					
1.	Maintenance Frequency		x			
2.	Number of Breaks	x				
3.	Hazen-William Coefficient (C)				x	
4.	*Other Factors*					

b. Consequence of Failure

No.	Factor	Significance				
		Very High	High	Medium	Low	Very Low
A.	**Societal**					
1.	Traffic Flow		x			
2.	Type of Property Nearby	x				
3.	Proximity to Areas of Interest	x				
4.	Time Impact		x			
5.	Financial Impact on Private Property		x			
6.	*Other Factors*					
B.	**Environmental**			x		

1.	Landslide Potential					
2.	Proximity to Environmentally Sensitive Areas				x	
3.	*Other Factors*					
C.	**Operational**					
1.	Pipe Diameter	x				
2.	Number of Customers Served	x				
3.	Financial Impact		x			
4.	*Other Factors*					
D.	**Renewal Complexity**					
1.	Access to Pipe		x			
2.	Utility Density		x			
3.	Availability of Repair materials		x			
4.	Utility Pattern			x		
5.	Type of Utility			x		
6.	Quality of Utility Record		x			
7.	*Other Factors*					

B. <u>Wastewater</u>

a. <u>Likelihood of Failure</u>

No.	**Factor**	**Significance**				
		Very High	**High**	**Medium**	**Low**	**Very Low**
A.	**Physical**					
1.	Pipe material		x			
2.	Pipe age		x			
3.	Pipe diameter			x		
4.	Pipe Length				x	
5.	Pipe Slope			x		
6.	Pipe Lining and Coating		x			
7.	Joint Type		x			
8.	*Other Factors*					
B.	**Environmental**					
1.	Pipe bedding		x			
2.	Soil type			x		
3.	Groundwater			x		
4.	Traffic Loads					x
5.	*Other Factors*					
C.	**Operational**					
1.	Maintenance Frequency		x			

2.	CCTV Feedback		x			
3.	*Other Factors*					

b. <u>Consequence of Failure</u>

No.	**Factor**	**Significance**				
		Very High	**High**	**Medium**	**Low**	**Very Low**
A.	**Societal**					
1.	Traffic Flow			x		
2.	Type of Property Nearby				x	
3.	Proximity to Areas of Interest				x	
4.	Time Impact			x		
5.	Financial Impact on Private Property		x			
6.	*Other Factors*					
B.	**Environmental**					
1.	Landslide Potential				x	
2.	Proximity to Surface water	x				
3.	Depth of Water Table		x			
4.	*Other Factors*					
C.	**Operational**					
1.	Pipe Diameter		x			
2.	Number of Customers Served		x			
3.	Financial Impact		x			
4.	*Other Factors*					
D.	**Renewal Complexity**					
1.	Access to Pipe			x		
2.	Utility Density			x		
3.	Availability of Repair materials		x			
4.	Utility Pattern			x		
5.	Type of Utility		x			
6.	Quality of Utility Record		x			
7.	*Other Factors*					

Response 2

C. ***Water***

a. Likelihood of Failure

No.	Factor	Significance				
		Very High	**High**	**Medium**	**Low**	**Very Low**
A.	**Physical**					
1.	Pipe material	x				
2.	Pipe age		x			
3.	Pipe diameter			x		
4.	Pipe Length				x	
5.	Pipe Slope			n/a		
6.	Pipe Lining and Coating			x		
7.	Joint Type			x		
8.	*Other Factors*					
B.	**Environmental**					
1.	Pipe bedding			x		
2.	Soil type		x			
3.	Groundwater		x			
4.	Traffic Loads		x			
5.	*Other Factors*					
C.	**Operational**					
1.	Maintenance Frequency		x			
2.	Number of Breaks			x		
3.	Hazen-William Coefficient (C)			x		
4.	*Other Factors*					

b. Consequence of Failure

No.	Factor	Significance				
		Very High	**High**	**Medium**	**Low**	**Very Low**
A.	**Societal**					
1.	Traffic Flow		x			
2.	Type of Property Nearby		x			
3.	Proximity to Areas of Interest		x			
4.	Time Impact			x		
5.	Financial Impact on Private Property			x		
6.	*Other Factors*					
B.	**Environmental**					
1.	Landslide Potential		x			
2.	Proximity to Environmentally Sensitive Areas				x	

3.	*Other Factors* Flooding direction		x			
C.	**Operational**					
1.	Pipe Diameter			x		
2.	Number of Customers Served		x			
3.	Financial Impact		x			
4.	*Other Factors*					
D.	**Renewal Complexity**					
1.	Access to Pipe	x				
2.	Utility Density			x		
3.	Availability of Repair materials				x	
4.	Utility Pattern				x	
5.	Type of Utility			x		
6.	Quality of Utility Record			x		
7.	*Other Factors*					

D. <u>Wastewater</u>

a. <u>Likelihood of Failure</u>

No.	**Factor**	**Significance**				
		Very High	**High**	**Medium**	**Low**	**Very Low**
A.	**Physical**					
1.	Pipe material		x			
2.	Pipe age			x		
3.	Pipe diameter			x		
4.	Pipe Length				x	
5.	Pipe Slope		x			
6.	Pipe Lining and Coating			x		
7.	Joint Type			x		
8.	*Other Factors*					
B.	**Environmental**					
1.	Pipe bedding		x			
2.	Soil type		x			
3.	Groundwater		x			
4.	Traffic Loads		x			
5.	*Other Factors*					
C.	**Operational**					
1.	Maintenance Frequency		x			
2.	CCTV Feedback		x			
3.	*Other Factors*					

b. Consequence of Failure

No.	Factor	Significance				
		Very High	**High**	**Medium**	**Low**	**Very Low**
A.	**Societal**					
1.	Traffic Flow	x				
2.	Type of Property Nearby		x			
3.	Proximity to Areas of Interest		x			
4.	Time Impact			x		
5.	Financial Impact on Private Property			x		
6.	*Other Factors*					
B.	**Environmental**					
1.	Landslide Potential			x		
2.	Proximity to Surface water	x				
3.	Depth of Water Table			x		
4.	*Other Factors*					
C.	**Operational**					
1.	Pipe Diameter			x		
2.	Number of Customers Served		x			
3.	Financial Impact		x			
4.	*Other Factors*					
D.	**Renewal Complexity**					
1.	Access to Pipe	x				
2.	Utility Density			x		
3.	Availability of Repair materials				x	
4.	Utility Pattern				x	
5.	Type of Utility			x		
6.	Quality of Utility Record			x		
7.	*Other Factors*					

Response 3

E. Water

a. Likelihood of Failure

No.	Factor	Significance				
		Very High	**High**	**Medium**	**Low**	**Very Low**
A.	**Physical**					
1.	Pipe material	X				
2.	Pipe age	X				
3.	Pipe diameter			X		
4.	Pipe Length					X
5.	Pipe Slope	X				
6.	Pipe Lining and Coating	X				

7.	Joint Type			X		
8.	*Other Factors*					
B.	**Environmental**					
1.	Pipe bedding					
2.	Soil type		X			
3.	Groundwater		X			
4.	Traffic Loads				X	
5.	*Other Factors*					
C.	**Operational**					
1.	Maintenance Frequency		X			
2.	Number of Breaks	X				
3.	Hazen-William Coefficient (C)					
4.	*Time Impact*			X		

b. ***<u>Consequence of Failure</u>***

No.	**Factor**	**Significance**				
		Very High	**High**	**Medium**	**Low**	**Very Low**
A.	**Societal**					
1.	Traffic Flow	X				
2.	Type of Property Nearby	X				
3.	Proximity to Areas of Interest				X	
4.	Time Impact			X		
5.	Financial Impact on Private Property			X		
6.	*Type of Property Directly Above/Below*	X				
B.	**Environmental**					
1.	Landslide Potential	X				
2.	Proximity to Environmentally Sensitive Areas				X	
3.	*Other Factors*					
C.	**Operational**					
1.	Pipe Diameter			X		
2.	Number of Customers Served	X				
3.	Financial Impact	X				
4.	*Other Factors*					
D.	**Renewal Complexity**					
1.	Access to Pipe	X				
2.	Utility Density			X		
3.	Availability of Repair materials					X
4.	Utility Pattern				X	
5.	Type of Utility				X	

6.	Quality of Utility Record				X	
7.	*Other Factors*					

F. ***Wastewater***

a. ***Likelihood of Failure***

No.	**Factor**	**Significance**				
		Very High	**High**	**Medium**	**Low**	**Very Low**
A.	**Physical**					
1.	Pipe material	X				
2.	Pipe age	X				
3.	Pipe diameter			X		
4.	Pipe Length					X
5.	Pipe Slope	X				
6.	Pipe Lining and Coating	X				
7.	Joint Type			X		
8.	*Other Factors*					
B.	**Environmental**					
1.	Pipe bedding					
2.	Soil type		X			
3.	Groundwater		X			
4.	Traffic Loads				X	
5.	*Directly Downstream of Force Main Outlet*			X		
6.	*Directly Downstream of Pipe Damaging Chemicals*			X		
C.	**Operational**					
1.	Maintenance Frequency		X			
2.	CCTV Feedback					
3.	*Number of spot repairs*		X			
4.	*Time Impact*			X		

b. ***Consequence of Failure***

No.	**Factor**	**Significance**				
		Very High	**High**	**Medium**	**Low**	**Very Low**
A.	**Societal**					
1.	Traffic Flow	X				
2.	Type of Property Nearby	X				
3.	Proximity to Areas of Interest				X	
4.	Time Impact			X		
5.	Financial Impact on Private Property			X		
6.	*Type of Property Directly Above/Below*	X				
B.	**Environmental**					
1.	Landslide Potential	X				

2.	Proximity to Surface water		X			
3.	Depth of Water Table		X			
C.	**Operational**					
1.	Pipe Diameter			X		
2.	Number of Customers Served	X				
3.	Financial Impact	X				
4.	*Other Factors*					
D.	**Renewal Complexity**					
1.	Access to Pipe	X				
2.	Utility Density			X		
3.	Availability of Repair materials					X
4.	Utility Pattern				X	
5.	Type of Utility				X	
6.	Quality of Utility Record				X	
7.	*Other Factors*					

<u>Response 4</u>

G. <u>Water</u>

a. <u>Likelihood of Failure</u>

No.	**Factor**	**Significance**				
		Very High	**High**	**Medium**	**Low**	**Very Low**
A.	**Physical**					
1.	Pipe material		X			
2.	Pipe age		X			
3.	Pipe diameter			X		
4.	Pipe Length				X	
5.	Pipe Slope					
6.	Pipe Lining and Coating				X	
7.	Joint Type		X			
8.	*Other Factors*					
	Casing			X		
B.	**Environmental**					
1.	Pipe bedding			X		
2.	Soil type		X			
3.	Groundwater				X	
4.	Traffic Loads		X			
5.	*Other Factors*					
C.	**Operational**					
1.	Maintenance Frequency				X	
2.	Number of Breaks	X				
3.	Hazen-William Coefficient (C)				X	

4.	*Other Factors*					
	Cathodic protection		X			

b. Consequence of Failure

No.	Factor	Significance				
		Very High	**High**	**Medium**	**Low**	**Very Low**
A.	**Societal**					
1.	Traffic Flow		X			
2.	Type of Property Nearby			X		
3.	Proximity to Areas of Interest			X		
4.	Time Impact		X			
5.	Financial Impact on Private Property			X		
6.	*Other Factors*					
B.	**Environmental**					
1.	Landslide Potential		X			
2.	Proximity to Environmentally Sensitive Areas			X		
3.	*Other Factors*					
C.	**Operational**					
1.	Pipe Diameter			X		
2.	Number of Customers Served		X			
3.	Financial Impact					
4.	*Other Factors*					
	Duration of outage		X			
	Pressure and/or type of failure			X		
D.	**Renewal Complexity**					
1.	Access to Pipe		X			
2.	Utility Density		X			
3.	Availability of Repair materials			X		
4.	Utility Pattern			X		
5.	Type of Utility				X	
6.	Quality of Utility Record				X	
7.	*Other Factors*					

H. Wastewater

a. Likelihood of Failure

No.	Factor	Significance				
		Very High	**High**	**Medium**	**Low**	**Very Low**
A.	**Physical**					
1.	Pipe material					
2.	Pipe age					
3.	Pipe diameter					
4.	Pipe Length					
5.	Pipe Slope					

6.	Pipe Lining and Coating					
7.	Joint Type					
8.	*Other Factors*					
B.	**Environmental**					
1.	Pipe bedding					
2.	Soil type					
3.	Groundwater					
4.	Traffic Loads					
5.	*Other Factors*					
C.	**Operational**					
1.	Maintenance Frequency					
2.	CCTV Feedback					
3.	*Other Factors*					

b. <u>Consequence of Failure</u>

No.	**Factor**	**Significance**				
		Very High	**High**	**Medium**	**Low**	**Very Low**
A.	**Societal**					
1.	Traffic Flow					
2.	Type of Property Nearby					
3.	Proximity to Areas of Interest					
4.	Time Impact					
5.	Financial Impact on Private Property					
6.	*Other Factors*					
B.	**Environmental**					
1.	Landslide Potential					
2.	Proximity to Surface water					
3.	Depth of Water Table					
4.	*Other Factors*					
C.	**Operational**					
1.	Pipe Diameter					
2.	Number of Customers Served					
3.	Financial Impact					
4.	*Other Factors*					
D.	**Renewal Complexity**					
1.	Access to Pipe					
2.	Utility Density					
3.	Availability of Repair materials					
4.	Utility Pattern					
5.	Type of Utility					

6.	Quality of Utility Record					
7.	*Other Factors*					

Response 5

…, if you had included any new factor for consideration in STEP 1 then please provide significance values for those too.

A. Water

a. Likelihood of Failure

No.	Factor	Significance				
		Very High	High	Medium	Low	Very Low
A.	**Physical**	☐	☐	✓	☐	☐
1.	Pipe material	☐	☐	☐	✓	☐
2.	Pipe age	☐	☐	✓	☐	☐
3.	Pipe diameter	☐	☐	☐	✓	☐
4.	Pipe Length	☐	☐	☐	✓	☐
5.	Pipe Slope	☐	☐	✓	☐	☐
6.	Pipe Lining and Coating	☐	☐	☐	✓	☐
7.	Joint Type	☐	☐	☐	✓	☐
8.	*Other Factors*	☐	☐	☐	☐	☐
	Exterior Coatings	☐	☐	☐	☐	☐
		☐	✓	☐	☐	☐
B.	**Environmental**	☐	☐	☐	☐	☐
1.	Pipe bedding	☐	☐	☐	✓	☐
2.	Soil type	✓	☐	☐	☐	☐
3.	Groundwater	☐	✓	☐	☐	☐
4.	Traffic Loads	☐	✓	☐	☐	☐
5.	*Other Factors*	☐	☐	☐	☐	☐
	INSTALLATION "DINGS"	✓	[illegible]	☐	☐	☐
		☐	☐	☐	☐	☐
C.	**Operational**	☐	☐	☐	☐	☐
1.	Maintenance Frequency	☐	☐	✓	☐	☐
2.	Number of Breaks	☐	✓	☐	☐	☐
3.	Hazen-William Coefficient (C)	☐	☐	☐	☐	✓
4.	*Other Factors*	☐	☐	☐	☐	☐
	# of laterals	☐	✓	☐	☐	☐
		☐	☐	☐	☐	☐

b. Consequence of Failure

No.	Factor	Significance				
		Very High	High	Medium	Low	Very Low
A.	**Societal**	☐	☐	☐	☐	☐
1.	Traffic Flow	☐	✓	☐	☐	☐
2.	Type of Property Nearby	✓	☐	☐	☐	☐
3.	Proximity to Areas of Interest	☐	✓	☐	☐	☐
4.	Time Impact	☐	✓	☐	☐	☐
5.	Financial Impact on Private Property	☐	☐	☐	☐	✓
6.	*Other Factors*	☐	☐	☐	☐	☐
		☐	☐	☐	☐	☐
		☐	☐	☐	☐	☐
B.	**Environmental**	☐	☐	☐	☐	☐

7

1.	Landslide Potential	☐	☐	☐	☐	☑
2.	*Other Factors*	☐	☐	☐	☐	☐
	LIFE & LIMB	☑	☐	☐	☐	☐
	PROXIMITY TO WILDLIFE	☐	☑	☐	☐	☐
C.	**Operational**	☐	☐	☐	☐	☐
1.	Pipe Diameter	☑	☐	☐	☐	☐
2.	Number of Customers Served	☑	☐	☐	☐	☐
3.	Financial Impact	☐	☐	☐	☑	☐
4.	*Other Factors*	☐	☐	☐	☐	☐
		☐	☐	☐	☐	☐
		☐	☐	☐	☐	☐
D.	**Renewal Complexity**	☐	☐	☐	☐	☐
1.	Access to Pipe	☑	☐	☐	☐	☐
2.	Utility Density	☑	☐	☐	☐	☐
3.	Availability of Repair materials	☐	☐	☐	☐	☑
4.	Utility Pattern	☑	☐	☐	☐	☐
5.	Type of Utility	☐	☐	☑	☐	☐
6.	Quality of Utility Record	☐	☐	☑	☐	☐
7.	*Other Factors*	☐	☐	☐	☐	☐
		☐	☐	☐	☐	☐
		☐	☐	☐	☐	☐

B. Wastewater

a. Likelihood of Failure

No.	Factor	Significance				
		Very High	High	Medium	Low	Very Low
A.	**Physical**	☐	☐	☐	☐	☐
1.	Pipe material	☐	☐	☑	☐	☐
2.	Pipe age	☐	☐	☐	☑	☐
3.	Pipe diameter	☐	☐	☑	☐	☐
4.	Pipe Length	☐	☐	☐	☑	☐
5.	Pipe Slope	☐	☐	☐	☑	☐
6.	Pipe Lining and Coating	☐	☐	☑	☐	☐
7.	Joint Type	☐	☐	☑	☐	☐
8.	*Other Factors*	☐	☐	☐	☐	☐
		☐	☐	☐	☐	☐
		☐	☐	☐	☐	☐
B.	**Environmental**	☐	☐	☐	☐	☐
1.	Pipe bedding	☐	☐	☑	☐	☐
2.	Soil type	☑	☐	☐	☐	☐
3.	Groundwater	☐	☑	☑	☐	☐
4.	Traffic Loads	☐	☐	☑	☐	☐
5.	*Other Factors*	☐	☐	☐	☐	☐
	INSTALL DINGS	☑	☐	☐	☐	☐
		☐	☐	☐	☐	☐
C.	**Operational**	☐	☐	☐	☐	☐
1.	Maintenance Frequency	☐	☐	☑	☐	☐
2.	CCTV Feedback	☑	☐	☐	☐	☐

3.	*Other Factors*	☐	☐	☐	☐	☐
	ROOTS	☑	☐	☐	☐	☐
		☐	☐	☐	☐	☐

b. *Consequence of Failure*

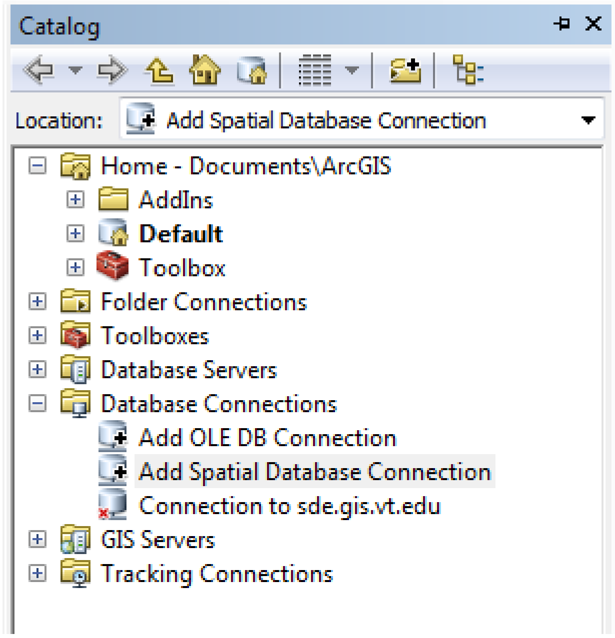
No.	Factor	Significance				
		Very High	**High**	**Medium**	**Low**	**Very Low**
A.	**Societal**	☐	☑	☐	☐	☐
1.	Traffic Flow	☑	☑	☐	☐	☐
2.	Type of Property Nearby	☑	☐	☐	☐	☐
3.	Proximity to Areas of Interest	☐	☑	☐	☐	☐
4.	Time Impact	☐	☑	☐	☐	☐
5.	Financial Impact on Private Property	☐	☐	☑	☐	☐
6.	*Other Factors*	☐	☐	☐	☐	☐
		☐	☐	☐	☐	☐
		☐	☐	☐	☐	☐
B.	**Environmental**	☐	☐	☐	☐	☐
1.	Landslide Potential	☐	☐	☐	☐	☑
2.	Proximity to Aquatic Life	☑	☐	☐	☐	☐
3.	Depth of Water Table	☐	☐	☐	☐	☑
4.	*Other Factors*	☐	☐	☐	☐	☐
	IMPACT LIFE / LIMB	☑	☐	☐	☐	☐
	Water ways	☑	☐	☐	☐	☐
C.	**Operational**	☐	☐	☐	☐	☐
1.	Pipe Diameter	☐	☑	☐	☐	☐
2.	Number of Customers Served	☑	☐	☑	☐	☐
3.	Financial Impact	☐	☐	☑	☐	☐
4.	*Other Factors*	☐	☐	☐	☐	☐
		☐	☐	☐	☐	☐
		☐	☐	☐	☐	☐
D.	**Renewal Complexity**	☐	☐	☐	☐	☐
1.	Access to Pipe	☑	☐	☐	☐	☐
2.	Utility Density	☑	☐	☐	☐	☐
3.	Availability of Repair materials	☐	☐	☐	☐	☑
4.	Utility Pattern	☐	☑	☐	☐	☐
5.	Type of Utility	☐	☐	☐	☐	☑
6.	Quality of Utility Record	☐	☐	☐	☐	☑
7.	*Other Factors*	☐	☐	☐	☐	☐
		☐	☐	☐	☐	☐
		☐	☐	☐	☐	☐

APPENDIX B

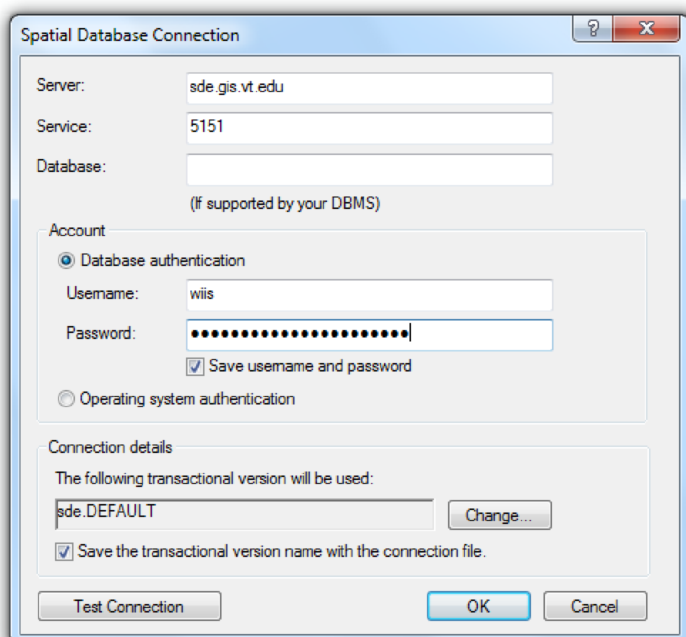
PUBLISHING THE MS ACCESS DATABASE AS A WEB SERVICE

This appendix shows the process used to publish the MS Access Database as a Web Service using ArcGIS. Snapshots are provided in the appendix to provide a better understanding of the process.

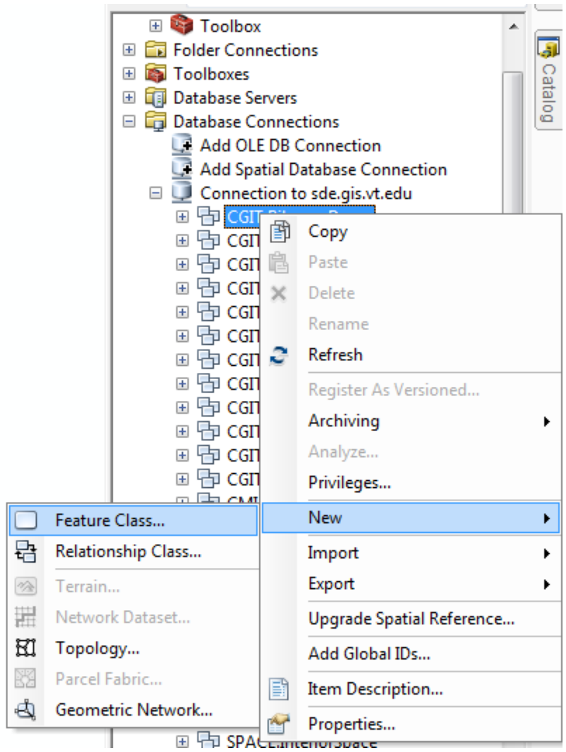
1. In ArcCatalog, select 'Add Spatial Database Connection'.



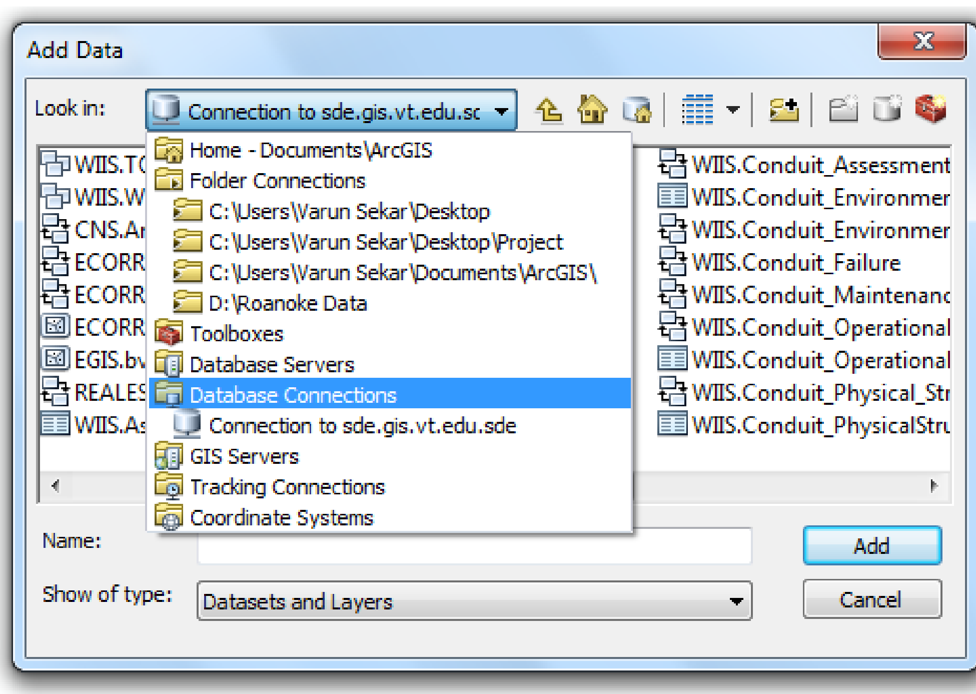
2. Enter the details such as username, password, server name, and service type to create a new spatial database connection to the ArcSDE of ArcGIS Server.



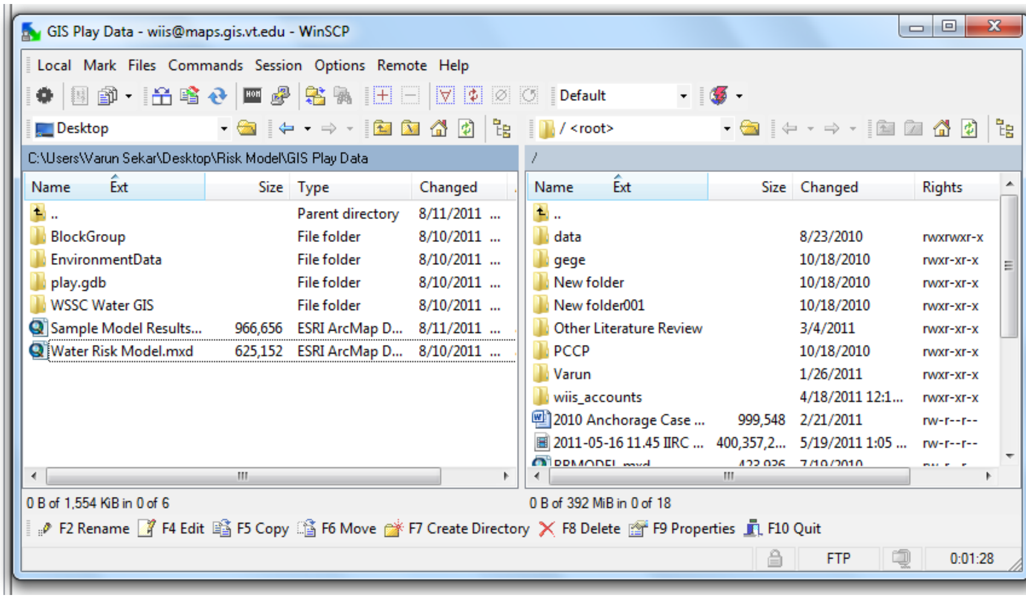
3. Create new feature class inside the ArcSDE and transfer files from the MS Access database to the new feature class.



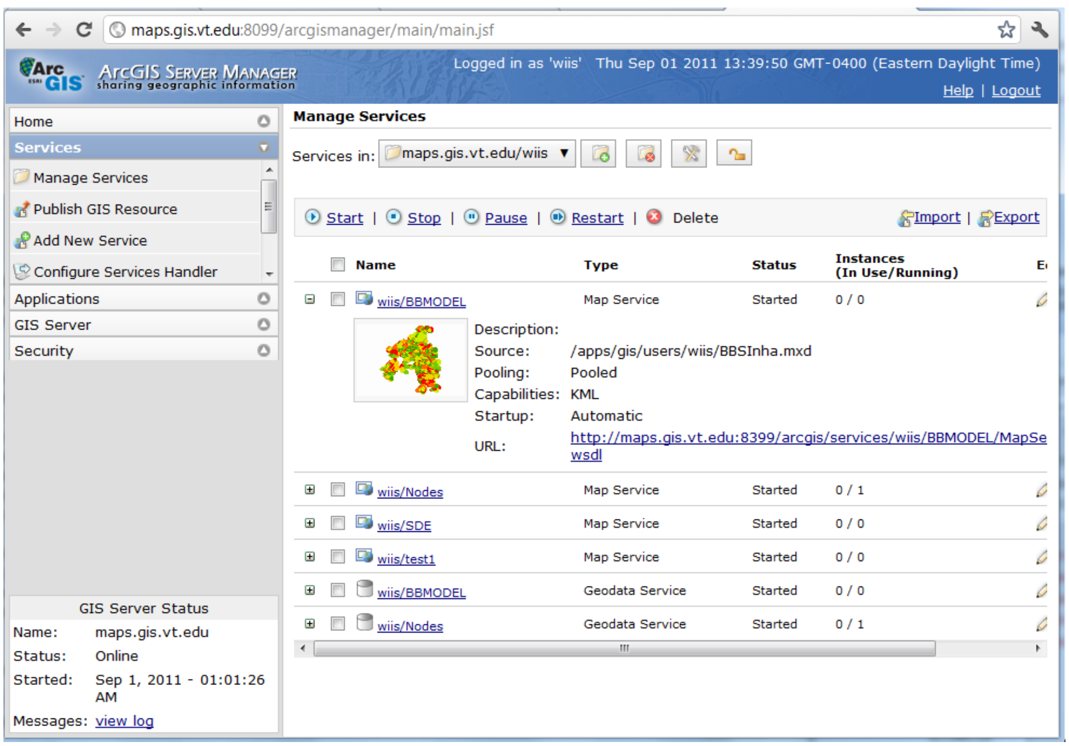
4. Create a new document in ArcMap and add the data from the ArcSDE.



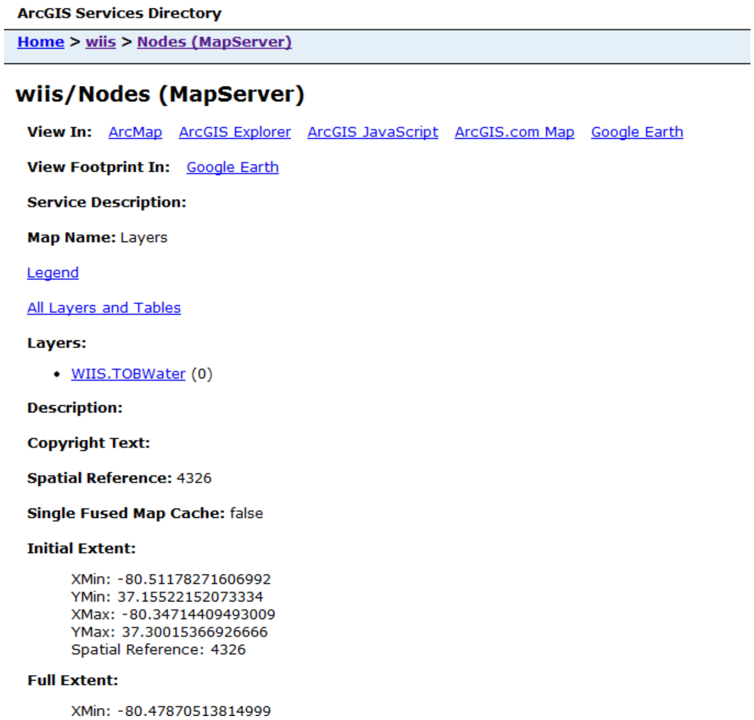
5. Save the document as a *.mxd file and using FTP transfer the file to ArcGIS Server.



6. Publish the map document as a web service using ArcGIS Server Manager.



7. From the ArcGIS Services directory retrieve the URL for the REST service.



ArcGIS Services Directory

Home > wiis > Nodes (MapServer)

wiis/Nodes (MapServer)

View In: ArcMap ArcGIS Explorer ArcGIS JavaScript ArcGIS.com Map Google Earth

View Footprint In: Google Earth

Service Description:

Map Name: Layers

Legend

All Layers and Tables

Layers:

- WIIS.TOBWater (0)

Description:

Copyright Text:

Spatial Reference: 4326

Single Fused Map Cache: false

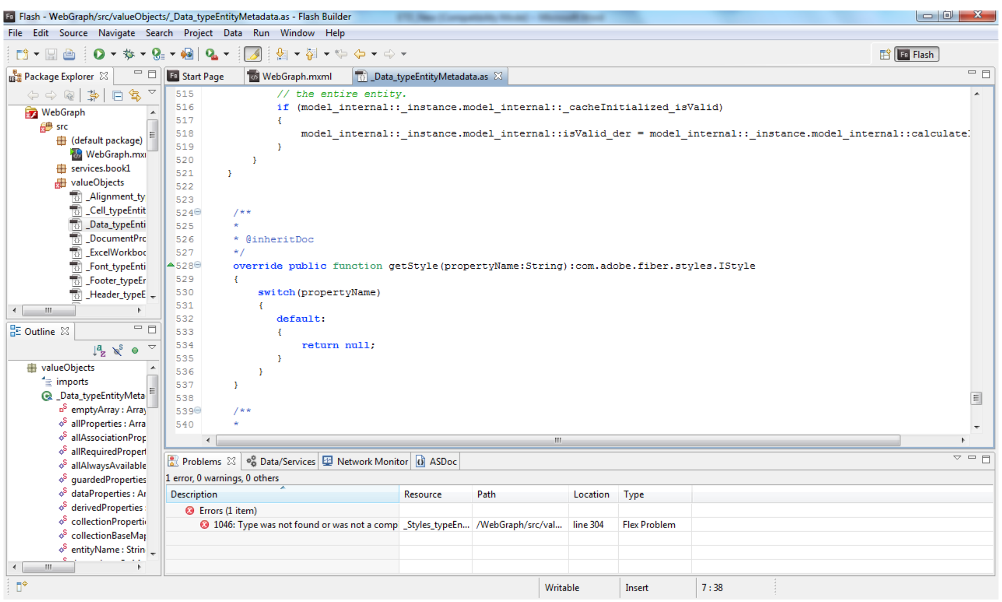
Initial Extent:

XMin: -80.51178271606992
YMin: 37.15522152073334
XMax: -80.34714409493009
YMax: 37.30015366926666
Spatial Reference: 4326

Full Extent:

XMin: -80.47870513814999

8. Embed the REST URL in the master code of the Flex Application to seek access to the GIS services on top of ArcGIS Server.



APPENDIX C

CODE FOR CONFIGURING THE WEB-BASED TOOL

The Adobe Flex based MXML code used to develop the web-based tool in the research is provided in this appendix. Various widgets provided by ESRI can be accessed using this code. Also, the code to get access to the GIS services can be found in this appendix.

```xml
    <?xml version="1.0" ?>
-->
// Copyright © 2008 - 2009 ESRI
<configuration>
	<userinterface>
		<banner>visible</banner>
		<title>SWIM at Virginia Tech</title>
		<subtitle>Water Infrastructure Database- Web Application</subtitle>
		<logo>com/esri/solutions/flexviewer/assets/images/logo.png</logo>
		<stylesheet>com/esri/solutions/flexviewer/themes/darkangel/style.swf</stylesheet>
		<menus>
			<menu id="menuMap" visible="true"
icon="com/esri/solutions/flexviewer/assets/images/icons/i_globe.png">Map</menu>
			<menu id="menuNav" visible="true"
icon="com/esri/solutions/flexviewer/assets/images/icons/i_nav.png">Navigation</menu>
			<menu id="menuWidgets" visible="true"
icon="com/esri/solutions/flexviewer/assets/images/icons/i_widget.png">Tools</menu>
		<menu id="menuHelp" visible="true"
icon="com/esri/solutions/flexviewer/assets/images/icons/i_help.png">Help</menu>
		</menus>
	</userinterface>

	<map initialExtent="-122.2 24.89 -70.59 46.92" fullExtent="-150 -50 150 50">
	<basemaps menu="menuMap">
			<mapservice label="Street Map" type="tiled" visible="true" alpha="1"
icon="com/esri/solutions/flexviewer/assets/images/icons/i_highway.png">http://server.arcgisonline.com/
ArcGIS/rest/services/ESRI_StreetMap_World_2D/MapServer</mapservice>
			<mapservice label="Satellite Map" type="tiled" visible="false" alpha="1"
icon="com/esri/solutions/flexviewer/assets/images/icons/i_shuttle.png">http://server.arcgisonline.com/Ar
cGIS/rest/services/ESRI_Imagery_World_2D/MapServer</mapservice>

	</basemaps>

	//uncomment lines below to view virtual earth maps;comment arcgisonline map configuration
above (elements: map, basemaps, mapservice)
	<!--map initialExtent="-1.3861396457346804E7 2959641.7352047404 -8172035.568026077
6452508.179723226" fullExtent="-1.2836528782099428E7 -4344069.191498438 9920914.775183456
9627396.586575491">
	<basemaps menu="menuMap">
		   <mapservice label="Road" type="virtualearth" visible="true" style="road" alpha="1"
icon="com/esri/solutions/flexviewer/assets/images/icons/i_globe.png">http://[machine]/vetoken.ashx</m
apservice>
		   <mapservice label="Aerial" type="virtualearth" visible="false" style="aerial"
alpha="1"
icon="com/esri/solutions/flexviewer/assets/images/icons/i_globe.png">http://[machine]/vetoken.ashx</m
apservice>
	</basemaps-->

	<livemaps>
		<mapservice label="Seattle Manholes" type="dynamic" visible="false"
alpha="1">http://maps.gis.vt.edu:8399/arcgis/rest/services/wiis/Nodes/MapServer</mapservice>
```

```
                    <mapservice label="Performance Index Blacksburg" type="dynamic" visible="false"
alpha="1">http://maps.gis.vt.edu:8399/arcgis/rest/services/wiis/BBMODEL/MapServer</mapservice>
                    <mapservice label="NOAA Services" type="dynamic" visible="false"
alpha="1">http://sampleserver1.arcgisonline.com/ArcGIS/rest/services/PublicSafety/PublicSafetyFeedSa
mple/MapServer</mapservice-->
                    <mapservice label="USGS NHSS Other Information" type="dynamic" visible="false"
alpha="0.75">http://rmgsc.cr.usgs.gov/ArcGIS/rest/services/nhss_info/MapServer</mapservice-->
                    <mapservice label="USGS NHSS Weather" type="dynamic" visible="false"
alpha="0.75">http://rmgsc.cr.usgs.gov/ArcGIS/rest/services/nhss_weat/MapServer</mapservice>
                     <mapservice label="USGS NHSS Natural Hazards" type="dynamic" visible="false"
alpha="0.75">http://rmgsc.cr.usgs.gov/ArcGIS/rest/services/nhss_haz/MapServer</mapservice-->
          </livemaps>
          </map>
          <navtools>
                    <navtool label="Zoom In"
icon="com/esri/solutions/flexviewer/assets/images/icons/i_zoomin.png"
menu="menuNav">zoomin</navtool>
                    <navtool label="Zoom Out"
icon="com/esri/solutions/flexviewer/assets/images/icons/i_zoomout.png"
menu="menuNav">zoomout</navtool>
                    <navtool label="Full Extent"
icon="com/esri/solutions/flexviewer/assets/images/icons/i_zoomfull.png"
menu="menuNav">zoomfull</navtool>
                    <navtool label="Re-center Map"
icon="com/esri/solutions/flexviewer/assets/images/icons/i_pan.png" menu="menuNav">pan</navtool>
          </navtools>
          <widgets>
             <widget label="Overview Map" preload="minimized"
icon="com/esri/solutions/flexviewer/assets/images/icons/i_overview.png" menu="menuMap"
config="com/esri/solutions/flexviewer/widgets/OverviewMapWidget.xml">com/esri/solutions/flexviewer
/widgets/OverviewMapWidget.swf</widget>
                    <widget label="Water Utilities" preload="minimized"
icon="com/esri/solutions/flexviewer/assets/images/icons/i_bookmark.png" menu="menuMap"
config="com/esri/solutions/flexviewer/widgets/BookmarkWidget.xml">com/esri/solutions/flexviewer/wi
dgets/BookmarkWidget.swf</widget>
                    <widget label="Data Visualization" preload="minimized"
icon="com/esri/solutions/flexviewer/assets/images/icons/gisdata.png" menu="menuMap"
config="com/esri/solutions/flexviewer/widgets/LiveMapsWidget.xml">com/esri/solutions/esa/widgets/Li
veMapsWidget.swf</widget>
                    <widget label="Print"
icon="com/esri/solutions/flexviewer/assets/images/icons/i_print.png" menu="menuMap"
config="com/esri/solutions/flexviewer/widgets/PrintWidget.xml">com/esri/solutions/flexviewer/widgets/
PrintWidget.swf</widget>
                    <!--widget label="Locate"
icon="com/esri/solutions/flexviewer/assets/images/icons/i_pushpin.png" menu="menuWidgets"
config="com/esri/solutions/flexviewer/widgets/LocateWidget.xml">com/esri/solutions/flexviewer/widget
s/LocateWidget.swf</widget-->
                    <widget label="Draw"
icon="com/esri/solutions/flexviewer/assets/images/icons/i_draw.png" menu="menuWidgets"
config="com/esri/solutions/flexviewer/widgets/DrawWidget.xml">com/esri/solutions/flexviewer/widgets
/DrawWidget.swf</widget>
```

```
			<!--widget label="Identify"
icon="com/esri/solutions/flexviewer/assets/images/icons/i_info.png" menu="menuWidgets"
config="com/esri/solutions/esa/widgets/IdentifyWidget.xml">com/esri/solutions/esa/widgets/IdentifyWid
get.swf</widget-->
			<!--widget label="Service Area"
icon="com/esri/solutions/flexviewer/assets/images/icons/i_servicearea.png" menu="menuWidgets"
config="com/esri/solutions/flexviewer/widgets/ServiceAreaWidget.xml">com/esri/solutions/flexviewer/
widgets/ServiceAreaWidget.swf</widget-->
			<widget label="Data Query" preload= "minimized"
icon="com/esri/solutions/flexviewer/assets/images/icons/query.png" menu="menuWidgets"
config="com/esri/solutions/esa/widgets/QueryBuilderWidget.xml">com/esri/solutions/esa/widgets/Query
BuilderWidget.swf</widget>
			<widget label="Find GIS Data"
icon="com/esri/solutions/flexviewer/assets/images/icons/i_search.png" menu="menuWidgets"
config="com/esri/solutions/esa/widgets/gpt/GeoportalSearchWidget.xml">com/esri/solutions/esa/widgets
/gpt/AGSGptRSSWidget.swf</widget>
			<!--widget label="Directions"
icon="com/esri/solutions/flexviewer/assets/images/icons/i_folder.png" menu="menuWidgets"
config="com/esri/solutions/esa/widgets/DirectionsWidget.xml">com/esri/solutions/esa/widgets/Direction
sWidget.swf</widget-->
			<widget label="About"
icon="com/esri/solutions/flexviewer/assets/images/icons/i_about.png" menu="menuHelp"
config="com/esri/solutions/flexviewer/widgets/AboutWidget.xml">com/esri/solutions/flexviewer/widget
s/AboutWidget.swf</widget>

</widgets>

	<links>
			<link label="Help" icon="com/esri/solutions/flexviewer/assets/images/icons/i_help.png"
menu="menuHelp">help.html</link>
			<link label="Home"
icon="com/esri/solutions/flexviewer/assets/images/icons/i_home.png"
menu="menuHelp">http://www.swim.cee.vt.edu</link>
	</links>
	<proxytype>asp</proxytype> <!-- apache|jsp||php -->
</configuration>
```