City of London: Vulnerability of Infrastructure to Climate Change

Status Report #1

Project Definition Report

– Outcome 2 –

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Executive Summary

This project definition report is the first outcome of the “City of London: Vulnerability of infrastructure to climate change” project as put forth in the project proposal. The report summarizes the data gathered to date, provides an overview of the weather modeling process, describes the risk assessment methodology and evaluates the data sufficiency.

Data pertaining to the infrastructure of the City of London was requested and provided. The data may be grouped into four sections: transportation, sewer, critical facilities and additional. Each section is explained in detail with a summary of the information provided.

The report presents a two step methodology to be used in the project. The first is the weather modeling and floodplain delineation. The modelling process includes the use of Weather Generator, HEC-HMS hydrologic, and HEC-RAS hydraulic model. Historic data for precipitation was gathered and processed to create two weather scenarios – historic climate change and wet climate change (‘worst-case’ scenario). A weather generator will be used to generate synthetic climatic data for both of these scenarios. The output will be used to identify important changes in climate variables and as part of hydraulic analysis to delineate floodplains, which will both be used in the second major step: risk assessment. One analysis will assess the changes in important climate variables (i.e., temperature, precipitation, timing, shifts). The result will be an assessment of infrastructure risk due to climate change. The second step will focus on hydrologic and hydraulic responses and assess infrastructure flood risk due to climate change. This will be done both qualitatively and quantitatively. The qualitative portion will include the application of fuzzy set theory. The output of the risk analysis will be a set of summary tables of the six risk or vulnerability indicators pertaining to each infrastructure element. These values will then be represented spatially using GIS to create risk maps.

The data has been identified as qualitative or quantitative and associated to different parts of the methodology. Qualitative data for the fuzzy risk analysis will be collected using interviews with appropriate experts. These experts will be from the following areas at the City of London: building management and inspection, transportation, flood control facilities and pollution control plants.

At this point our assessment is that the data acquisition is sufficient to continue to the next step in the project of preparing and delivering Workshop #1. The purpose of the workshop is to inform stakeholders of the objectives and progress of the study. Example results to be generated by the risk assessment and the next steps in the analysis will also be addressed.
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1 Introduction

This report is part of Step 2: Data Gathering and Sufficiency for the City of London: Vulnerability of infrastructure to climate change risk assessment. The first section gives a description of the data provided by the City of London to the research team pertaining specifically to infrastructure. The second section discusses the proposed methodology of risk assessment and the third section determines if the data is sufficient for this purpose. Refer to Appendix A for a summary of the data files provided.

Table 1, Infrastructure Data Summary, provides a synopsis of the data provided for each infrastructure category. There are four main groups of data: transportation, critical facilities, sewer infrastructure and additional data. Within each group there are more specific data categories, such as: roadways, bridges/culverts, footbridges, retaining walls, public buildings, sewer outlets, sanitary system, storm system, transmission lines, economic and social data. The data has been collected in two formats: GIS shapefiles and reports or documents. The majority of the data was provided in shapefile format.

The methodology section discusses the inputs for the climate modelling leading up to the risk assessment. It then focuses on both qualitative and quantitative risk analysis methods. The quantitative analysis will involve discrete calculations of load and capacity for infrastructure elements. The qualitative method with the use of fuzzy set theory will allow for a quantification of subjective and objective uncertainty. Fuzzy analyses may be used efficiently where numerical data is insufficient.
<table>
<thead>
<tr>
<th>Format</th>
<th>Bridge/Culvert/Footbridge/Pedestrian Tunnels</th>
<th>Roadway</th>
<th>Pollution Control Plant (PCP)</th>
<th>Outlets</th>
<th>Sanitary System</th>
<th>Storm System</th>
<th>Critical Facilities</th>
<th>Other</th>
</tr>
</thead>
</table>
| GIS Shapefiles (and associated ID fields) | • Location  
• Classification of road on which it is located  
• Structure type: function, framing system and material  
• Date of construction  
• Deck area  
• Weight/height/width restrictions  
• Original cost (where available)  
• History of significant maintenance and inspection  
• Design storm level for recently constructed bridges  
• Jurisdiction (boundary structures)  
• Present value  
• Physical condition description and rating (1 to 10)  
• Problems/comments/suggestions found during last inspection  
• Digital photographs  
• Annual Average Daily Traffic (AADT)  
• Significance ratings (for structures tagged for repair/replacement) | • Location  
• Classification of road (arterial or primary collector)  
• Annual average daily traffic (AADT) values  
• Road centrelines  
• Estimated elevation when combined with 'contours' layer | • Combined Sewer Overflow locations and rotation (in arithmetic format)  
• Pumping Station outlet locations and rotation | • Flow direction in graphical form  
• Location of sanitary pipes (x,y,z)  
• Manhole locations  
• Sanitary Outflow and Pumping station locations | • Same information as for sanitary system | For the following buildings:  
- hospitals  
- fire stations  
- ambulance stations  
- police stations  
- Public and separate elementary  
- secondary  
- post-secondary  
- Address  
- URL for institution  
- Full name | For all public buildings:  
- Building footprint | • Location of transmission lines |
<table>
<thead>
<tr>
<th>Reports/Documents</th>
<th>Bridge/Culvert/Footbridge/Pedestrian Tunnels</th>
<th>Roadway</th>
<th>Pollution Control Plant (PCP)</th>
<th>Outlets</th>
<th>Sanitary System</th>
<th>Storm System</th>
<th>Critical Facilities</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>• All of the above available upon request for specific structures</td>
<td>• Transportation Master Plan report and technical appendices – contains traffic information</td>
<td></td>
<td>• Service area</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>• Bridge Inspection Management System 2003 Summary Report</td>
<td></td>
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<td>• Capacity</td>
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<tr>
<td>• Digital photographs of all structures</td>
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<td>• 12 month average flow</td>
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<td>• Available growth (MGD)</td>
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<td></td>
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<td>• Current studies being performed on the PCP</td>
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<td></td>
<td></td>
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<td>• Approximate location</td>
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<td></td>
<td></td>
<td></td>
<td>• Outlet invert elevation</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• Diameter of outlet and pipe material</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Distance from plant to outlet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2 Input Data

2.1 Transportation

The transportation system in London underwent an extensive evaluation, finished in May 2004 which resulted in the Transportation Master Plan (TMP). This document provides information on the quality and state of current transportation infrastructure along with a detailed plan for improvement. The document explains that the majority of movement within the city is done using personal vehicles. Therefore, the accessibility of primary and arterial roads is crucial to city of London residents for daily activities.

2.1.1 Roadways

The data provided for the primary and arterial roads are shapefiles, with the exception of the TMP report. The Annual Average Daily Traffic (AADT) and Equivalent Single Axle Load (ESAL) values for the roads are provided along with road conditions. The transportation data is complete and can be integrated with other GIS data layers. Descriptive road use information is available in the TMP including information such as the popularity of certain routes, city residents’ opinions on traffic loads and proposed expansions.

Contour layers were also provided as shapefiles. Combination of the contour layer with the road layer in a GIS environment yields the road elevations.

2.1.2 Bridges

There are 99 bridges in the city of London. The bridge data (which includes 8 footbridges and 117 culverts) was also provided as shapefiles, along with a report on the inventory of the bridges. The Bridge Inspection Management System (BIMS) 2003 summary report has been provided which has the summary of details for the majority of the bridges for: AADT, framing system, materials, date of construction (age), present value, condition rating and significance rating. Specific reports for each structure are available upon request. However, all of this information is provided as an ID field with the shapefiles.
Bridge elevations and opening dimensions have been provided in HEC-RAS format. Design drawings are available if requested for specific structures. In addition to the infrastructure characteristics, digital photographs have been provided for each structure, totalling 236 pictures.

2.1.3 Pedestrian Tunnels and Retaining Walls

There are 6 pedestrian tunnels and 7 major retaining walls within the city. The locations of all pedestrian tunnels and retaining walls were provided as shapefiles. The majority of these are also included in the BIMS 2003 summary report. The data for this infrastructure includes framing system (if applicable), date of construction, present value, condition rating and significance rating, along with additional notes on maintenance and/or inspection details.

2.2 Critical Facilities

Critical facilities are those which relate to provision of aid, public safety and health (Peck et al., 2007). This includes, but is not limited to, emergency services (EMS, hospitals, fire and police), educational facilities (schools), pollution control plants and sanitary pumping stations.

The locations of emergency services and public buildings were requested. This information is important in determining the vulnerability of an area. For example, if a fire station or a hospital were to be located in a flood plain, the surrounding area would have a higher vulnerability in the event of a flood.

A shapefile was provided which gives the footprints of all buildings in the city. Another one was provided which gives the zoning for the city. All data given in this category is contained in shapefiles.

2.2.1 Schools

Shapefiles showing the point location of schools was provided. In these files, there are layers for: separate elementary, elementary, secondary, and post secondary schools. When
the zoning shapefile is combined with the building footprint file and the school point files, the footprint of the schools may be located along with the school and zoning information. Included with the point file is the full name, address and URL for each school. The URL may be used to link to more information that is provided to the public via the internet website for each institution.

2.2.2 Hospitals and Emergency Services

A file similar to the school files was provided for the city hospitals. Information on the hospitals may be found by combining the zoning, footprint and point files. Again, the full name, address and URL for each hospital were provided.

Other emergency services provided include: fire stations, ambulance stations and police stations. This information is given in point form similar to the schools and hospitals. Included in the file is information on name, address and URL for each building. The URL gives the website address for the building which may be used to gather more information on the structures or services offered.

2.3 Sewer Infrastructure

2.3.1 Outlets

Shapefiles were provided which contain the locations of the outlets for the sewer system. The outlets downstream from pumping station overflows are distinguished from the outlets downstream from combined sewer overflows. The only details provided for these outlets are their location and, where applicable, names.

2.3.2 Sanitary System

The wastewater collection system in the City of London is extensive. There are 1,311km of sanitary gravity sewers, 6.7 km of combined sewers, 32km of forcemains, 18,387 sanitary access holes, 34 pumping stations and 6 pollution control plants (PCPs). The pollution control plants are: Greenway, Vauxhall, Pottersburg, Adelaide, Oxford and Lambeth (City of London, online).
Information relating to the PCPs was given for the outlet invert elevations, diameter of outlet and pipe material, distance from plant to outlet, the service area, capacity, annual average flow, available growth and location. Annual operations reports are available online if required. This information was provided as a document summary with one page for every PCP.

Shapefiles containing a graphical representation of the flow directions for all sanitary links was provided. Additionally, the locations of the sanitary access holes are given. The locations of the sanitary linkages are given and the depths are included in that information. Sanitary outflow and pumping station locations are also provided.

2.3.3 Storm System

The extent of the city’s storm sewers includes: 1, 191km of storm gravity sewers, 17, 125 storm access holes and 92 storm water management (SWM) facilities.

The information on the storm system is the same as provided for the sanitary systems. It includes a graphical flow representation, linkage locations, storm access hole locations, and storm outflow and pumping station locations.

2.4 Additional Data

2.4.1 Transmission Lines

Transmission lines are provided as basic line data. It is simply the location of the major transmission lines on a map of the city. A data request has been made for the locations of electrical transmission stations and natural gas substations.

2.4.2 Economic Data

Economic data for the sewer system was provided in the 20 year plan report. This report contains detailed information on lifecycle replacement, system improvements, growth and operational maintenance costs. According to Appendix C of the report, the total replacement
cost of the sewer system is estimated to be $2.7 billion. About $2.2 billion of this cost is estimated to be the pipe system.

In addition to the sewer system, the replacement cost of the water supply network is estimated to be approximately $1.68 billion. The 2009 operating and Capital Budgets and Nine Year Capital Plan report has been provided by the City of London. This report contains detailed cost information for the Environmental and Engineering Services Department of Water.

The present value of the transportation infrastructure (specifically bridges, culverts and footbridges) was included with the BIMS 2003 report.

2.4.3 Social Data

These population characteristics may be indicators of vulnerability. This data provides insight into those areas which may be vulnerable in a flooding situation which are important to identify for flood management. Social data used in vulnerability analysis and risk assessment is organized by Forward Sortation Areas (FSAs). This is represented by the first three characters of a postal code designation. The most consistent and accurate source of population statistics are the Population Census provided by Statistics Canada national database. These consistent reports are released every five years following a Census of the population. The social data obtained from this Census include: age, differential access to resources, household structures, social status, ethnicity and social economic.

3 Assessment Methodology

The following section will introduce the tools and describe the procedures that will be employed for flood risk assessment under the changing climate.
3.1 Climate Change Modelling

The climate modelling process is represented by the flow diagram in Figure 1. This is the initial step in the assessment methodology and involves the use of Weather Generator, HEC-HMS hydrologic model, HEC-RAS hydraulic model, and GIS modelling to create flood plains for various climate change scenarios.
Figure 1: Climate Modelling Process

**INPUT**
Historic Data:  
- Temperature  
- Precipitation

**DEVELOPMENT OF CLIMATE SCENARIOS:**
- Historic Climate Change & Wet Climate Change  
- Weather Generator

**OUTPUT**
Precipitation & Temperature for Climate Scenarios

**ANALYSIS OF CHANGE IN CLIMATE VARIABLES**
- Temperature, Timing, Duration, Shifts, Precipitation

**HYDROLOGIC MODEL**
- Flows

**HYDRAULIC MODEL**
- Water levels

**FLOOD PLAINS**

**INFRASTRUCTURE RISK ASSESSMENT DUE TO CLIMATE CHANGE**
- Branch a

**INFRASTRUCTURE FLOOD RISK ASSESSMENT DUE TO CLIMATE CHANGE**
- Branch b
The steps in the flow diagram are as follows:

1. Gather historic weather data;

2. Create two climate scenarios to be run in the Weather Generator;

3. Run the Weather Generator;

4. Receive and analyze output such as extreme temperatures, precipitation events and timing shifts of certain climate indicators such as seasons, freeze/thaw, etc.

The steps for the left branch (Branch a) of the flow diagram are as follows:

5.a Identify variables which respond to climate change and quantify changes by analyzing extremes and shifts in weather patterns from the weather generator output;

6.a Perform risk analysis based on infrastructures expected responses to changing climate.

The steps for the right branch (Branch b) of the flow diagram are as follows:

5.b Receive as output from Weather Generator the precipitation values to use with the HEC-HMS hydrologic model and generate streamflow;

6.b Use the streamflows as input to the hydraulic model using HEC-RAS to generate water elevation;

7.b Generate flood plains from the HEC-RAS model output and export to ArcGIS for floodplain mapping;

8.b Perform infrastructure risk analysis.

Each of these steps is explained in more detail below.
Currently, one of the best ways to study the effects of climate change is to use global circulation models. These models are the current state of the art in climate science. Their aim is to describe the functioning of the climate system through the use of physics, fluid mechanics, chemistry, as well as other sciences. All global circulation models discretise the planet and its atmosphere into a large number of three dimensional cells (Kolbert, 2006, p. 100) to which relevant equations are applied.

Two different types of equations are used in global circulation models - those describing fundamental governing physical laws, and those that are termed empirical (based on observed phenomena that are only partially understood). The former are representations of fundamental equations of motion, laws of thermodynamics, conservation of mass and energy, etc, and are well known; the latter, however, are those phenomena that are observed, but for which sound theory does not exist yet. For most studies that are concerned with the response of a smaller area (such as a city) to a changed climatic signal, the global models are inappropriate because they have spatial and temporal scales that are incompatible with those of a city. One way around this is to still use the global input, but downscale its results appropriately for the area under consideration.

Traditional way of studying the impacts of climatic change for small areas involves downscaling the outputs from global circulation models (temporally and spatially) from which user and location specific impacts are derived. A number of studies have implemented such methodologies, and thus estimated local impacts of climatic change (Coulibaly and Dibike, 2004; Palmer et al., 2004; Southam et al., 1999).

Use of global modeling results with downscaling methods involves a number of uncertainties inherent to this approach. First, the global models have temporal scales that are sometimes incompatible with temporal scales of interest at the local level. The global models are only able to produce monthly outputs with a higher degree of accuracy. This is insufficient for the use at local level where often the interest is in changes in frequency of occurrence of short-duration high-intensity events. Temporal downscaling of monthly global output must therefore be employed, and shorter duration events be estimated, thus compounding
uncertainty. Second, spatial scales of global models are also incompatible with spatial scales at the local level. The global models typically have grid cells of 100 km by 100 km, significantly larger than most watersheds (for example, City of London, Ontario covers an area of about 420 km$^2$). Coarse resolution of global models is inadequate for the representation of many physical processes of interest at the local scales (including extreme rainfall).

In this study the weather generator approach is used for downscaling the global information to local scale. This approach takes as input historical climate information, as well as information from the global circulation models, and generates climatic information for an arbitrary long period of time for the local weather station. The main GCM output used as input into the weather generator includes the change fields to modify historic data in accordance to a particular climate change scenario.

Climate change scenarios are the output of Global Circulation Models (GCMs). They do not predict the future but simply offer possibilities of what may happen in the future following a particular course of action (i.e., rapid urbanization). Two different climate scenarios are considered in this study: Historic Climate Change and Wet Climate Change scenarios. The Historic Climate Change scenario represents a future climate that will result from changes already done to natural systems. The Wet Climate Change scenario represents a future climate that is warmer and wetter than present and is used specifically to test a region’s response to flooding. It is considered the most critical climate scenario in addressing potential changes in extreme rainfall magnitudes and frequencies due to climate change. Data from these two scenarios are used as input into the Weather Generating model.

3.1.2 Weather Generator

Weather generating models offer one way of addressing deficiencies of global climate modeling for use at local scales. They are stochastic simulation tools that synthetically create climate information for an area by combining both, local and global weather data. The local data includes historically observed data taken from area weather stations in and around the study area, while the global data includes outputs obtained from global circulation models. The former acts to address the fine spatial and temporal scale needed for impact studies,
while the later provides the global direction of change of the climate within the region of interest (wetter, drier, cooler, warmer, etc).

Weather generators can be parametric and non-parametric (Sharif and Burn, 2006). The parametric weather generators are stochastic tools that generate weather data by assuming a probability distribution function and a large number of parameters (often site specific) for the variables of interest. The non-parametric tools do not make distribution assumptions or have site specific parameters, but rely on various shuffling and sampling algorithms. A common limitation of the parametric weather generators is that they have difficulties representing persistent events such as droughts or prolonged rainfall (Sharif and Burn, 2006, p. 181). The non-parametric weather generators alleviate these drawbacks, and one of them is adopted for use in this project.

The weather generator takes as input historical climate information, as well as inputs from the global circulation models (change fields), and generates climatic information for an arbitrary long period of time for the local weather station. Sophisticated algorithms are used to shuffle (and perturb) the historical data, and generate climatic information not observed in the historic record. The perturbation mechanisms are necessary as long records of historic data are often not available (particularly for shorter durations), or if available, contain a large percentage of missing values. Use of perturbation mechanisms assumes that historic data (of short records) does not capture extreme characteristics likely to be observed in longer data sets. Therefore, they are used to push the generated data outside the historic range, thus providing extremes not been previously recorded. Estimation of extreme rainfall from short data records can underestimate critical values used in the design of municipal infrastructure. Using weather generators with perturbation mechanisms and inputs from global circulation models can therefore produce adequate synthetic data with high spatio-temporal resolution. The outcome of weather generator includes precipitation, minimum and maximum temperature for an arbitrary long period of time.

### 3.1.3 Hydrologic Model

In this study, the US Army Corps of Engineers (USACE) Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) is used for hydrologic analysis. HEC-HMS is a
precipitation-runoff model that includes a large set of mix-and-match methods to simulate river basin, channel and water control structures. It is designed for application to a wide range of geographic areas for solving a variety of hydrologic problems (USACE, 2000).

An event-version of the HMS model will be used for simulating short rainfall-runoff events. The structure of the event HMS model comprises six components describing main hydroclimatic processes in the river basin. The meteorological component is the first computational element by means of which rainfall input (provided by weather generator) is spatially (interpolation, extrapolation) and temporally (interpolation) distributed over the basin. The simulation of evapotranspiration is not included in the meteorological component since it can be negligible in the simulation of short rainfall-runoff events.

Spatially and temporally distributed rainfall that falls on pervious surface is subject to losses (interception and infiltration) modeled by the rainfall loss component. In the initial and constant-rate loss method, the maximum potential rate of rainfall loss, \( L_r \), is constant throughout an event. An initial loss, \( L_i \), represents interception and depression storage. The effective rainfall, \( R_{e,t} \), at time \( t \), is then given by (USACE, 2000):

\[
R_{e,t} = \begin{cases} 
0 & \text{if } \sum R_t < L_i \\
R_t - L_r & \text{if } \sum R_t > L_i \text{ and } R_t > L_r \\
0 & \text{if } \sum R_t > L_i \text{ and } R_t < L_r 
\end{cases}
\]  

where \( R_t \) is the rainfall depth during the time interval \( \Delta t \).

The effective rainfall from the loss component contributes to direct runoff and to groundwater flow in aquifers. The Clark unit hydrograph is a frequently used technique for modeling direct runoff resulting from individual storm events. In the Clark method, overland flow translation is based on a synthetic time–area histogram and the time of concentration, \( T_c \). Attenuation is modeled with a linear reservoir. The average outflow, \( O_t \), from the reservoir during a period \( \Delta t \) is (USACE, 2000):

\[
O_t = C_A I_t + C_B O_{t-1}
\]

where \( I_t \) is the average inflow to basin storage, \( S_b \), at time \( t \), and \( C_A \) and \( C_B \) are routing coefficients given by:
Both overland flow and baseflow enter river channels. The translation and attenuation of streamflow in river channels is simulated by the modified Puls method. This method can simulate backwater effects (e.g. caused by dams), can take into account floodplain storage, and can be applied to a broad range of channel slopes. The modified Puls method is based on a finite difference approximation of the continuity equation, coupled with an empirical representation of the momentum equation. The continuity equation has the form (USACE, 2000):

\[
\frac{Sc_t}{\Delta t} + \frac{O_t}{2} = \left(\frac{I_{t-1} + I_t}{2}\right) + \left(\frac{Sc_{t-1} - O_{t-1}}{\Delta t}\right)
\]

(3)

where \( I_t \) is the inflow at time \( t \), \( O_t \) is the outflow at time \( t \), \( \Delta t \) is the computational time step, and \( Sc_t \) is the channel storage at time \( t \).

The movement of water in aquifers is modeled by the baseflow component. In the exponential recession model adopted in this study the baseflow at time \( t \), \( B_t \), is defined as:

\[
B_t = Bi \cdot Rc^t
\]

(4)

where \( Bi \) is the initial baseflow at time \( t_0 \), and \( Rc \) is the exponential decay constant. A threshold flow parameter, \( T_d \), is added to define the point on the hydrograph where baseflow replaces overland flow as the source of flow from the subbasin (USACE, 2000).

Finally, the effect of hydraulic facilities (reservoirs, detention basins) and natural depressions (lakes, ponds, wetlands) is reproduced by the reservoir component of the model. Outflow from the reservoir is computed with the level-pool routing model. The model solves recursively the following one-dimensional approximation of the continuity equation (USACE, 2000b):

\[
I - O = \frac{\Delta Sr}{\Delta t}
\]

(5)

where \( I \) (\( O \)) is the inflow (outflow) during the time interval \( \Delta t \), and \( \Delta Sr \) is the reservoir storage change during this interval.

The output of hydrologic model will be the flow that is used by the hydraulic model to generate the water elevation which will determine the extent floodplain.
3.1.4 Hydraulic Model

The U.S. Army Corps of Engineers Hydrologic Engineering Center’s River Analysis System (HEC-RAS) is a software tool used for hydraulic modelling. This software is used to perform one-dimensional steady and unsteady flow calculations, in addition to water temperature modelling. The program is designed to perform hydraulic calculations for a network of natural and constructed channels. It considers the effects of various obstructions on hydraulic flows including: bridges, culverts, weirs, spillways and structures (USACE, 2005).

HEC-RAS requires input of historic flow data (stream flows), channel characteristics (i.e., Manning roughness coefficient) as well as geo-referenced infrastructure profiles (in the form of cross-sections).

HEC-RAS uses these inputs and performs hydraulic computations to calculate water elevations at each point within the region of interest. The computational procedure is based on equations of energy and momentum. Energy losses are evaluated by friction and contraction/expansion. The momentum equation is used whenever there is rapidly varied flow. The steady flow system is used to evaluate floodway encroachment. Similar procedures will be repeated for the wet climate change scenario. The model output includes water surface elevations that will determine the extent of floodplains.

3.1.5 Flood Plain Mapping

HEC-RAS is incorporated with HEC-GeoRAS for processing geospatial data in ArcGIS. The GeoRAS software is used for preparing geometric data for import into HEC-RAS and processing simulation results exported from the HEC-RAS program.

Exported HEC-RAS simulations results (water surface elevations) are processed by HEC-GeoRAS for GIS analysis. The first step in the floodplain mapping process is to create a water surface Triangular Irregular Network (TIN) from the water elevations associated to each cross section. Then, in the floodplain delineation, the water surface TIN will be converted to a GRID based on the Rasterization Cell Size. It is then compared with the raster DTM to compute the elevation difference within each bounding polygon. Water surface elevation greater than the terrain elevation are included in the inundation depth grid. Then, the inundation depth grid is converted to a vector data set defining the floodplain boundary.
Finally, the floodplain lines will be laid over infrastructure GIS maps to be used in flood risk assessment. Figure 2 provides a graphical representation of the flood plan mapping procedure.

3.2 Risk Assessment

As defined by the Public Infrastructure Engineering Vulnerability Committee (PIEVC), engineering vulnerability is “the shortfall in the ability of public infrastructure to absorb the
Figure 2: Process Flow Diagram
(Based on the diagram from USACE, 2005)
negative effects, and benefit from the positive effects, of changes in the climate conditions used to design and operate infrastructure” (Engineers Canada, online) This section of the report will describe the methodology that will be used to determine the vulnerability of the City of London’s infrastructure to changes in the frequency and intensity of floods due to climate change.

This vulnerability assessment will examine the three main elements of engineering vulnerability as put forth by the PIEVC:

1. *Character, magnitude and rate of change in the climatic conditions to which infrastructure is predicted to be exposed*

2. *Sensitivities of infrastructure to the changes*

3. *Built-in capacity of infrastructure to absorb any net negative consequences*

(Engineers Canada, online).

Figure 3 shows the process for the risk assessment.

The risk assessment is the continuation of the process described in section 3.1 Climate Change Modelling. The assessment uses an original methodology that has been modelled after parts of the PIEVC Protocol to assess infrastructure risk due to changing climatic conditions and flood risk. The output variables of the weather generating model include: temperature and precipitation. An analysis of these variables including changes in timing and shifts in variable sequences are used to assess the impact of climate change on infrastructure. The weather generator precipitation and temperature outputs are used in a second risk analysis to assess the impact of climate change on flood events. These variables will be used to project future streamflows and then water levels to produce floodplains. The floodplains will be used to assess the risk of flooding due to climate change.
Figure 3: Risk Assessment Process

Risk Assessment

Workshop

Qualitative Analysis
- Environmental Impacts;
- Serviceability;
- Policies;
- etc.

Quantitative Analysis
- Performance Response
  Loads;
- Capacity

Output
- Risk Tables
- & Risk Maps
The steps in the risk assessment are:

1) Conduct Workshop #1 to inform stakeholders of project status and work to-date

2) Perform quantitative and qualitative analysis

3) Create risk tables from the output of the analysis

4) Translate the risk tables into risk maps in a GIS format

These steps are explained below.

3.2.1 Workshop

The main goal of the first workshop is to inform the stakeholders of the study objectives and work completed to-date. In addition to providing the status and describing the study, the workshop will aim to confirm the completion of data gathering and sufficiency, describe the modelling done to-date (with results), provide the list of infrastructure to be used in the risk analysis and provide examples of the final results. The last objective of the workshop is to update the stakeholders on the next course of action.

3.2.2 Quantitative Vulnerability Analysis

The quantitative method of determining vulnerability will involve the calculation of three values: the vulnerability ratio (VR), adaptive capacity ratio (AR) and capacity deficit (CD). The input required to calculate these values are: the loads on the infrastructure (current and due to climate change) and the capacity of the infrastructure (current, maturing and other).

Load and Capacity Analysis

The total load applied to the infrastructure will need to be calculated based on the current load, applied load due to climate change and other. It will be calculated using the following formula:

\[ L_T = L_E + L_C + L_O \]  

(7)

Where \( L_T \) is the total load; \( L_E \) is the existing load; \( L_C \) is the climate load and \( L_O \) is the load caused by other effects.
The total capacity, $C_T$, of the infrastructure component will be calculated based on its existing capacity, $C_E$; the maturing capacity, $C_M$; and any additional capacity, $C_A$ using the following formula:

$$C_T = C_E + C_M + C_A$$

(8)

The data given for bridges and culverts and some outlet elevations will be used in these calculations. Load values which relate to flooding can be defined as floodplains and water elevations. This data will be provided by the hydraulic modelling team. The infrastructure data which will be used include, for example, the elevation and opening size of the bridges and culverts.

The roadway capacities with regards to flooding can be determined using their location and elevations. The roads will be analyzed based on their specific drainage characteristics.

The elevation of the PCP outlets will be used to determine the impact of flooding on their capacity. The time-dependent loads will be provided by the hydrologic modelling team.

The vulnerability of public buildings will be determined using the footprints that are available and their location within the generated floodplain. Similar analyses will be made for emergency services or hospitals (or access to them), located in the floodplains.

Throughout these quantitative and qualitative analyses, if a data gap is found, the team must return to the first step in the assessment process to gather more information. If data is not available, the data gap will be noted in the findings.

**Risk Analysis**

The outcome of quantitative analysis will include determination of three risk indices: vulnerability ratio, adaptive capacity ratio and the capacity deficit. These three indices determine which infrastructure is vulnerable. They also provide an indication of how much additional capacity is required to mitigate these vulnerabilities. These risks will be represented spatially in a GIS environment.
3.2.3 Qualitative Vulnerability Analysis

Qualitative analysis will use AADT values to show which roadways and bridges are high-traffic. This analysis will result in a vulnerability factor relevant to whether routes are connected to a hospital or emergency service area, and whether they are highly travelled or not. Using fuzzy set theory, an assessment of risk will be made.

The assessment methodology will use engineering expertise and/or technical judgement to complement the qualitative analysis. First, a list of performance responses will be generated by the team. These are responses of an infrastructure component to the climate change loads. For example, responses could be economic, public health and safety, serviceability, environment etc. Then a summary will be made in tabular form to associate each infrastructure component with the performance responses – for example, traffic lights vulnerability would affect public health and safety, but not the environment. The purpose of this step is to provide input for ranking that is described below.

A matrix will then be developed to link descriptions of extreme climate events and infrastructure components (example: bridge deck, roadway surface, etc. previously determined by the team and the stakeholders). The data collected is sufficient for this analysis. Table 1 provides a complete list of data provided. This analysis will be performed on each infrastructure component identified in Table 1.

Extreme climate events descriptions will use 4 further descriptors: Yes/No, $S_C$, $S_R$ and $P_C$ (described below). They will be determined using experience, judgement and considering all performance responses associated with each infrastructure component.

Vulnerability Matrix

Yes/No: This descriptor indicates whether the particular description of climate event being considered has an impact on the infrastructure element that is being considered. If “No” is selected, the next three columns will be assigned zero.
SC: The Probability Scale Factor. This factor will be a qualitative rating, on a scale of 0 to 7, of the probability of damage to the infrastructure component when exposed to the climate event.

SR: This is the Severity Scale Factor. This scale factor describes the severity of the damage to the infrastructure component when exposed to the climate event (on a scale between 0 and 7).

The scale, suggested by the PIEVC is in Table 2:

Table 2: PIEVC suggested scale factors

<table>
<thead>
<tr>
<th>Scale</th>
<th>Probability (SC)</th>
<th>Severity (SR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Negligible/Not Applicable</td>
<td>Negligible/Not Applicable</td>
</tr>
<tr>
<td>1</td>
<td>Improbable/Highly Unlikely</td>
<td>Very Low/Unlikely/Rare/Measurable Change</td>
</tr>
<tr>
<td>2</td>
<td>Remote</td>
<td>Low/Seldom/Marginal/Change in Serviceability</td>
</tr>
<tr>
<td>3</td>
<td>Occasional</td>
<td>Occasional – Loss of some capacity</td>
</tr>
<tr>
<td>4</td>
<td>Moderate/Possible</td>
<td>Moderate – Loss of some capacity</td>
</tr>
<tr>
<td>5</td>
<td>Often</td>
<td>Likely Regular – Loss of capacity and some function</td>
</tr>
<tr>
<td>6</td>
<td>Probable</td>
<td>Major/Likely/Critical/Loss of function</td>
</tr>
<tr>
<td>7</td>
<td>Certain/Highly Probable</td>
<td>Extreme/Frequent/Continuous/Loss of asset</td>
</tr>
</tbody>
</table>
**P_C**: The Priority of the Relationship. This priority is calculated as the product of S_C and S_R.

Data that will be used at this stage of the assessment process will include the bridge inspection records for example, that show the history of certain components which have been vulnerable.

**Vulnerability Rankings**

The next step will be to choose which interactions to study further. This is where the interactions from the vulnerability matrix will be evaluated and the ones determined to be the most critical will be analyzed further. The PIEVC Protocol suggests ranking based on the P_C number. A PC ≤ 12, or a relationship with either scale factor ≤ 2, represents low vulnerability and therefore no further action is taken. 17 < PC < 36 represents potentially high vulnerability and further analysis is required. A PC ≥ 36 indicates high vulnerability.

**Fuzzy Risk Analysis**

Potentially high vulnerability indicators are subject to Fuzzy Risk Analysis.

For the interactions deemed vulnerable in the above step, and for the ones with a PC ≥ 36, the fuzzy risk analysis will be performed using the methodology proposed by El-Baroudy and Simonovic (2003; 2006). The three fuzzy risk measures will be calculated: the reliability index, the robustness index and the resiliency index. Fuzzy set theory is used in cases where there exist uncertainties, ambiguities or a lack of knowledge (El-Baroudy and Simonovic, 2003).

The fuzzy reliability index is combined with a fuzzy vulnerability index to describe infrastructure performance and failure magnitude, respectively, in the event of a failure. The fuzzy robustness index is used to determine adaptability of a infrastructure to changing climate conditions. It is measured using change in reliability. Finally, the fuzzy resiliency index is used to describe the time infrastructure takes to recover from a failure event.
The interactions identified in the previous step will be subject to more detailed analysis. The fuzzy total load, $\tilde{L}_T$, and fuzzy total capacity, $\tilde{C}_T$, values combined with fuzzy $\tilde{L}_E$, $\tilde{L}_C$, and $\tilde{L}_O$ values in the calculation of three fuzzy risk indices. The combined fuzzy reliability – vulnerability index is a measure of the frequency of failure, $(\tilde{L}_T > \tilde{C}_T)$ and magnitude of failure, $(\tilde{L}_T - \tilde{C}_T)$. The robustness index is calculated as the adaptability of the changing climate conditions in $\tilde{L}_T$, and the resiliency index is calculated as the ability of the infrastructure to recover from the failure state.

According to El-Baroudy and Simonovic (2003), the three fuzzy indices in general form are expressed as:

\[
\text{Fuzzy Reliability Index} = \frac{\max_{i=K} \{\tilde{C}_{M_1}, \tilde{C}_{M_2}, \ldots, \tilde{C}_{M_{i}}\} \times \tilde{L}_{R_{\text{max}}}}{\max_{i=K} \{\tilde{L}_{R_1}, \tilde{L}_{R_2}, \ldots, \tilde{L}_{R_i}\}} \tag{9}
\]

where:

- $\tilde{L}_{R_{\text{max}}}$ is the reliability measure of acceptable level of performance with which the system-state has the maximum compatibility value (CM);
- $\tilde{L}_{R_i}$ is the reliability measure of the i-th acceptable level of performance;
- $\tilde{C}_{M_i}$ is the compatibility measure for system-state with the i-th acceptable level of performance; and
- $K$ is the total number of defined acceptable levels of performance.

\[
\text{Fuzzy Robustness Index} = \frac{1}{\tilde{C}_{M_1} - \tilde{C}_{M_2}} \tag{10}
\]

where:

- $\tilde{C}_{M_1}$ is the compatibility measure before the change in conditions; and
\( \tilde{C}_{M2} \) is the reliability after the change in conditions.

\[
\text{Fuzzy Resilience Index} = \left[ \frac{\int_{t_2}^{t_1} \tilde{T}(t) \, dt}{\int_{t_1}^{t_2} \tilde{T}(t) \, dt} \right]^{-1}
\]

(11)

where:

\( \tilde{T}(t) \) is the system fuzzy maximum recovery time;

\( t_1 \) is the lower bound of the support of the system recovery time; and

\( t_2 \) is the upper bound of the support of the system recovery time.

The process of fuzzifying the discrete capacity and load values involves the use of membership functions. This function describes the amount to which the element belongs in an ill-defined set. An ill-defined set is one which does not have discrete boundaries. It can be used when data is ambiguous. For example, the condition of a bridge may be described as being ‘poor’, ‘fair’, ‘good’ or ‘excellent’. Fuzzy set theory can be applied to this type of information to allow for description uncertainty. Various techniques, explained by Despic and Simonovic (1997), that may be applied in the fuzzy membership development include: horizontal methods, vertical methods, S-curves and \( \pi \)-curves, implicit definitions, rational functions of polynomials, piecewise linear membership functions, clustering and relative preference methods.

The description of bridge and road conditions is subjective to the inspector, and may contain uncertainties. Therefore, this data will be processed using the fuzzy set theory. In addition, there exists a lack of sufficient quantitative data for the pipe networks with respect to their age and condition. Fuzzy set theory will be applied to this network to determine the fuzzy risks and vulnerabilities. Finally, in the case of critical facilities, the data provided will be also processed using fuzzy risk methodology. In all of these cases, the risk assessors will be
required to use engineering judgment and expertise to decide acceptable performance levels. Interviews with various experts will need to be performed to acquire the input required for the development of the membership functions in the fuzzy analysis.

An example of the type of input required from an interview would be an acceptable failure region for an infrastructure component. Where the expert believes the component is at complete failure the membership function is assigned a value of zero. Where the component is completely safe, the membership function is assigned a value of one. The function in between can be determined using a combination of the methods described above and the description of acceptable failure by the expert being interviewed. Another example of input is for a component with specific design values for capacities. A membership function can be created using a minimum, modal and maximum design values (El-Baroudy and Simonovic 2005) for a specific infrastructure component.

3.2.4 Presentation of Risk Assessment Results

The output of the risk assessment will include a table which contains a list of the infrastructure elements and the deterministic and fuzzy risk associated with each one. An example of the table format is shown in Table 3.

The purpose of this output is to summarize the results of the risk assessment (both quantitative and qualitative) in a concise and easily referable format. It will also be used for the spatial representation of risk described in the next section. These tables will show at a glance which infrastructure elements show high risk or vulnerability across each category. This will facilitate decision making with respect to modifications and upgrades to the infrastructure elements. It will also facilitate prioritization of the upgrades and budgetary planning.
### Table 3: Risk Indices Summary

<table>
<thead>
<tr>
<th>Infrastructure Element</th>
<th>Vulnerability Ratio</th>
<th>Adaptive Capacity Ratio</th>
<th>Capacity Deficit</th>
<th>Reliability Index</th>
<th>Robustness Index</th>
<th>Resiliency Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bridge Deck</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
</tr>
<tr>
<td>Hospital</td>
<td>…</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arterial Road Surface</td>
<td>…</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Etc…</td>
<td>…</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Risk Mapping

Regulatory implications of climate change risk (land use rezoning and similar) will benefit from spatial presentation of risk to infrastructure. The output of the risk assessment will include risk and vulnerability tables relating infrastructure and climate events. Spatial distribution of risk will be a function of spatial distribution of infrastructure elements and their vulnerability to climate change. Vulnerabilities may be present across an entire geographic area however, this risk study is only focusing on those regions which have the potential to be flooded (i.e. within the floodplains).

Vulnerability (represented by indicators) and hazard (represented as floodlines) can both be represented spatially. It is the intersection of these two that is of particular importance (risk). When multiple infrastructure vulnerability indicators are present in the same region, there is the possibility that these vulnerability values can be summed together; identifying regions of multiple risks. These areas will be represented spatially using risk maps and implementing colour gradients to show raster cells with different risk levels.
GIS will be used to process the tabular data in these important regions and represent it graphically (spatially). These maps are useful to different stakeholders for the purposes of: land development planning; developing emergency response strategies; building site selection; infrastructure operations guidelines; and in general for policy development at all levels. Figure 4 represents an example of a possible risk map in a GIS environment.

![Example Risk/Vulnerability Map](image)

Figure 4: Example Risk/Vulnerability Map
4 Data Sufficiency

The initial review of data indicates that the data is sufficient for the next step of organizing the workshop. After this, the qualitative and quantitative assessment will begin. At present, it appears that the data is sufficient to continue with this step. However, this process is iterative in nature, meaning that a data insufficiency could be found during the analysis which will need to be addressed at that point.

The economic data gathered will aid in determining the impact of an extreme climate event. It consists of present values of infrastructure systems such as the sewer system, critical facilities and transportation network. In addition to economic data, social data has also been compiled. This data shows the social impacts of an extreme climate event and has been obtained from census information. The social data consists of population and population characteristics such as income and age; divided into sections by forward sortation areas.

It should be noted that the river crossing infrastructure data is not available in a georeferenced form for the hydraulic modelling team; meaning that all cross sections for the river crossings must be processed manually.

4.1 Qualitative and Quantitative Data

The following table summarizes the infrastructure elements and whether quantitative or qualitative data was provided:
Table 4: Data Sufficiency

<table>
<thead>
<tr>
<th>Infrastructure Sector</th>
<th>Category</th>
<th>Element*</th>
<th>Quantitative</th>
<th>Qualitative</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transportation</strong></td>
<td>Arterial Roadway</td>
<td>Surface Drainage</td>
<td>x</td>
<td>AUR</td>
</tr>
<tr>
<td></td>
<td>Primary Roadway</td>
<td>Surface Drainage</td>
<td>x</td>
<td>AUR</td>
</tr>
<tr>
<td></td>
<td>Bridge</td>
<td>Deck Drainage Supports</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Culvert</td>
<td>Culvert</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Footbridge</td>
<td>Deck Supports</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pedestrian Tunnel</td>
<td>Surface Drainage</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pollution Control Plant</td>
<td>Capacity Outlet Plant</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Sewer</strong></td>
<td>Outlet</td>
<td>Combined Sewer Overflow (CSO) Pumping Station (PS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sanitary System</td>
<td>Pipe Network Access Hole Outflow PS</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Storm System</td>
<td>Pipe Network Access Hole Outflow PS Inlet</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Critical Facilities</strong></td>
<td>Public Buildings</td>
<td>Hospital Fire Station Police Station Ambulance Station Public Elementary School Separate Elementary School Secondary School Post Secondary School</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Electrical</td>
<td>Transmission Line Transformer Station</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Natural Gas</td>
<td>Substation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Economic</td>
<td>n/a</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Social</td>
<td>n/a</td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>

* More elements may be added during Workshop 1 by stakeholders
x = acquired
AUR = available upon request
INT = may be acquired in an interview
Where qualitative data is available, the fuzzy risk assessment will be performed. Where quantitative data is available, the deterministic risk assessment will be performed. The qualitative vulnerability matrix will be developed by all of the elements.

The infrastructure elements to be analyzed will only be those within the floodplains (as explained in section 3.1.4). The flood plains will be overlaid on the infrastructure GIS layers to determine the infrastructure elements to be incorporated in the assessment of risk.

4.2 Fuzzy Analysis Requirements

Additional qualitative data will need to be obtained for the fuzzy risk analysis. This data will be obtained using an interview process with various experts and stakeholders. Separate interviews for each sector will be arranged privately with The City. The experts will be selected based on their areas of expertise. The sectors to be addressed include: building management and inspection, transportation, flood control facilities, and sanitary and storm systems. Data to be obtained in these interviews will be used to create the membership functions as explained in the fuzzy methodology section. Questions must be asked to determine the acceptable, minimum, maximum and critical risk as perceived by the interviewee. Depending on which key issues are identified, elements which require qualitative input may include: pedestrian tunnel drainage capabilities, pollution control plant conditions, transformer station locations and flood prevention measures, natural gas substation locations and flood prevention measures.

Other qualitative data which will influence the fuzzy analysis includes employee experience and flood response preparedness, community members’ exposure to past flood events or flood preparedness training and the demographics of an area. This information will also be acquired in interviews with plant managers, critical infrastructure chiefs and managers and city officials.

There are different ways to gather information from stakeholders. Possible types of input which are considered to capture the sensitivity of stakeholder responses include: numeric scale responses, linguistic answers (for example, ‘very good’), and arguments (one option is
considered more desirable if other conditions are satisfied). These responses are based on stakeholders’ knowledge, warning and prior experiences to flooding hazards.

5 Conclusion

Data has been provided by the City of London for the city’s infrastructure systems. The general categories of data include: transportation, sewer system, critical facilities and additional data. The majority of the data was presented as shapefiles for a GIS environment. This includes the locations of all major transportation infrastructure (bridges, culverts, roads etc.), sewer infrastructure (outlets, linkages, sanitary service access holes, etc.), critical facilities and electrical transmission lines. Detailed numerical information for the bridges, culverts, pedestrian tunnels and footbridges was also provided in ID fields associated with the shapefiles.

Reports were provided for some infrastructure. This includes the Transportation Master Plan, which describes the traffic volumes and public transportation information for the city; along with future plans for expansion. Also included is the Bridge Inspection Management Systems Summary report which explains the data fields provided with the GIS data. Included with this report are digital photographs of each of the bridges and culverts displayed by the shapefiles.

The risk assessment may continue with the next step of preparing and presenting a workshop to update the stakeholders on the status of the study. In addition, interviews will be scheduled to gather more qualitative data. This information will be used to complete a vulnerability assessment using an original risk assessment protocol influenced by the PIEVC protocol.

Next, quantitative risk assessment may be performed with the numerical data provided, including: bridge elevations and openings, road elevations, critical facility elevations and locations and pollution control plant outlet invert elevations and capacities. Fuzzy risk assessment may then be performed using the qualitative data and some quantitative data.
Information such as the age and current conditions (the condition rating and significance rating, etc.) of the infrastructure may be used in this step.

Economic and social (population and demographic) data has been gathered to aid in the risk assessment and vulnerability study. At this point of time in the project, the data is sufficient to proceed.
6 References


“Appendix B.3 – Metro Vancouver, British Columbia”. Available online:
http://www.pievc.ca/e/Appendix_B.3_Metro_Vancouver_British_Columbia.pdf.

“Appendix B.5 – City of Edmonton, Quesnell Bridge Refurbishment”. Available online:
http://www.pievc.ca/e/Appendix_B.5_City_of_Edmonton_Quesnell_Bridge_Refurbishment.pdf.


Appendix I: Data Organization Chart

The following chart shows the organization of the data files provided by the City of London. It is simply a map of where the files are located on the disk.
<table>
<thead>
<tr>
<th>Location</th>
<th>Category (map title)</th>
<th>Layer Title</th>
<th>Data Type</th>
<th>Geometry Type</th>
<th>Coordinate System</th>
<th>Item</th>
<th>Files Associated</th>
<th>File format</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Transportation (transportation map)</td>
<td>Bridges (BR)</td>
<td>Shapefile Feature Class Point</td>
<td>&lt;Undefined&gt;</td>
<td>Structures DBF</td>
<td>tblBridgeCulvertData</td>
<td>*.DBF</td>
<td></td>
<td>in Co.L BMS Update 2007</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Col BMS Update 2007</td>
<td>.mdb</td>
<td></td>
<td>(incl. All the tbl files plus tblReports, tblPics, tblInventoryType</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>GIS Shapefiles</td>
<td>.shp</td>
<td></td>
<td>3 layers</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>pics</td>
<td>JPEG</td>
<td></td>
<td>236 subfolders - each subfolder is one structure</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Transportation Master Plan Final Report - May 2004</td>
<td>Adobe Acrobat</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Transportation Master Plan Technical Appendices - April 2004</td>
<td>Adobe Acrobat</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Inventory of Infrastructure Data provided by City of London
<table>
<thead>
<tr>
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Sanitary Shapefiles

( sanitary system)

BlowBack

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ForceFlow

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ForceMh

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ForceOther

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wtrpoly

Shapefile Feature Class Polygon <Undefined>

* SHP

* SHX

* SBX

* SBX

* SHP

* SHX

* XML

Note for Sewer Shapefiles

Text Document explains flow representation

Text

BlowBack

DBF

SHP

SHX

ForceFlow

DBF

SHP

SHX

ForceMh

DBF

IDX

SHP

SHX

ForceOther

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