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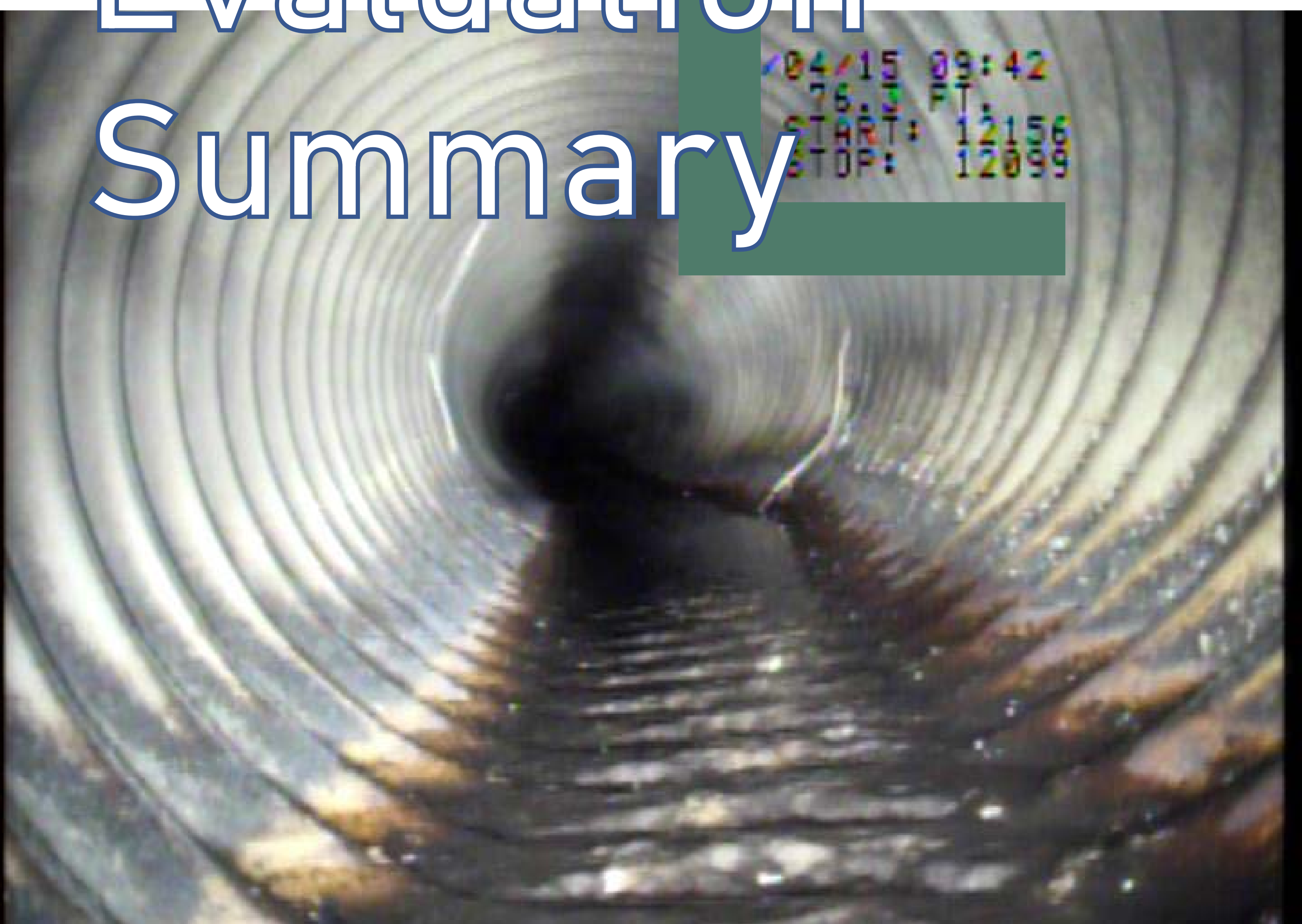
Pipe Evaluation Summary



Stormwater Conveyance Pipe Evaluation Tool

Stormwater runoff is conveyed in stormwater pipes, culverts, ditches, and outfalls before ultimately discharging to receiving waters such as streams, wetlands, or lakes. Stormwater pipes (including those classified as culverts and outfalls) make up the bulk of the City's stormwater conveyance system with over 200 miles city-owned stormwater pipes.

There are also areas in the City that are missing stormwater conveyance assets that provide a system connection. Sixty-eight locations were identified by City operations and maintenance crews and through Geographic Information System (GIS) analysis where pipes do not appear to connect to a structure, outfall, ditch, receiving water, or other conveyance feature.

The Utility cleans and inspects stormwater conveyance pipes to (1) assess condition and plan for necessary maintenance or replacement, (2) monitor condition of pipes that are known to have deficiencies, and (3) evaluate potential opportunities for repairs in conjunction with roadwork, such as pavement overlays.

The number and length of stormwater pipes in the City's inventory makes it challenging to track condition and plan for eventual system repairs. A GIS-based stormwater pipe evaluation tool was developed during this planning process. This tool builds on asset management principles of understanding asset inventory, condition, and risk to make decisions for how the asset is maintained and replaced, and what resources are needed to do so.

Methodology

GIS was used to develop the pipe evaluation tool to characterize pipes based on estimated risk. Risk was assessed by overlaying characteristics of potential likelihood of failure (i.e., condition of the pipe) with characteristics of consequence of failure (i.e., what the impacts would be to the surroundings if the pipe were to fail).

Stormwater pipes are mapped in the City's GIS system and include the following data for each individual asset: age, length, diameter, material, connecting structures, and invert elevations at each end of the pipe (to calculate slope and direction of flow). The attribute data may not be complete for a given pipe, and the age of most pipes is not populated.

Additionally, the City conducts a pipe condition assessment program that evaluates pipe condition using CCTV (closed circuit television) methods to identify pipe defects, such as holes, corrosion, offsets at joints, cross-connections, debris that is clogging the pipe, and other conditions that are not visible without a camera entering the pipe remotely. This data is collected, and pipes are rated for structural and maintenance integrity according to NASSCO (National Association of Sewer Service Companies) PACP (Pipeline Assessment Certification Program) protocol. This data is available for pipes that have been assessed, however, not all stormwater pipes have been assessed, and therefore the condition of many pipes is not known. Additionally, industry standard recommends re-evaluation of condition on a 5-year basis. If the score of the pipe is more than 5 years old, the condition data is no longer considered reliable. For this planning exercise, pipe condition was included only from the past five years.

The geographic locations of stormwater pipes matter for what the impacts could be to human health, infrastructure, and the environment, if a pipe were to fail. GIS coverages for transportation, critical facilities, and environmental features were used to identify potential consequences of pipe failure.

Staff from stormwater engineering and maintenance participated in multiple meetings to develop criteria used in the final evaluation tool, with multiple iterations to test assumptions and results. A description of the final categories used for the consequence of failure and likelihood of failure and weighting criteria is described below.

Consequence of Failure

Impacts resulting from a stormwater pipe failure can vary depending on where the pipe is located and how much flow the pipe typically conveys. The following geographic and pipe characteristics were used to estimate potential consequence of failure in the pipe evaluation model:

- Pipe Size

  Pipe size was used as a surrogate for flow, since larger pipes are designed to carry more stormwater than smaller ones.

- Transportation

  Different road classes are designed for different types of traffic levels. Impacts from a pipe failure that results in a road closure for repair could have more serious impacts on transportation movement on roads that are designed for more traffic or where alternative routes aren't available.

- Landside Hazards

  Slope failures that are caused or exacerbated by stormwater pipe failures can have cumulative impacts on downstream resources.

- Critical Facilities

  Critical facilities, such as infrastructure (major pipelines, hospitals, etc.) in the vicinity of stormwater pipes that fail may be more seriously impacted.

- Culverts

  Culverts are stormwater pipes that convey stream flow. This special class of stormwater pipe requires special consideration since flow is typically year-round and failure of culverts can have unique consequences.

These consequence of failure factors were assigned weighting based on City staff decisions on what was most important to consider. Table 1 shows the factors, total points, and weights given for different characteristics. Table 2 provides additional detail on the transportation buffers used in the analysis.

Table 1. Factors, total points, and weights used for consequence of failure.

Factor	Total Points (out of 100)	Sub-categories[1]	Weight for Factor	Points Allocated
Pipe Size	25	Pipes 24" diameter or larger (greatest 10% of pipes)	1	25
		Pipes 14 – 23 inches diameter	0.75	18.75
		Pipes 9 – 12 inches diameter	0.5	12.5
		Pipes 8 inches diameter or less	0.25	6.25
Transportation	23	Principal arterials, access to critical customers (hospitals, fire station), snow/ice routes	1	23
		Minor arterials, sole-access streets	0.75	17.25
		Collector Streets, neighborhood greenways, regional trails/CKC	0.5	11.5
		Local Streets/neighborhood access streets, non-motorized infrastructure	0.25	5.75
Landslide Hazards	22	Known or historic slide	1	22
		High or moderate probability of slide	0.5	11
		Low or no probability of slide	0	0
Structures or Other Utilities	20	Pipes within 15 ft. buffer of utilities, 80 ft. buffer of critical customers/buildings.	1	20
		Pipes under or within 5 ft. of any occupied single-family residence.	0.5	10
		Not near any structures or utilities.	0	0
Culverts	10	Is it a culvert? If yes, then apply points.	1	10
Total	100			

[1] Additional detail for transportation sub-categories is provided in Table 2.

Table 2. Transportation weights and buffers used for different road types.

Factor	Road Types	Weight	GIS Analysis Buffer[1] (feet)
Transportation	Principal Arterials (85th St/Central Way, Market St, Totem Lake Blvd	1	80
	124th St, 98th/100th Ave, Simonds Rd, 124th Ave	1	70
	132nd St, 116th St, Lake St/Lake Wash Blvd	1	60
	Interstate 405	1	180
	Access to critical customers (hospitals, fire station), snow/ice routes	1	0
	Minor arterials (128th St, 116th Ave) , All Others - Buffer 60 ft), Sole-Access Streets (Rachel working on map)	0.75	70
	All Others Minor arterials except 128th St. and 116th Ave.	0.75	60
	Sole-Access Streets	0.75	0
	Collector Streets	0.5	50
	Neighborhood Greenways	0.5	40
	Regional Trails/CKC	0.5	14
	Local Streets/Neighborhood access streets	0.25	40
	Non-motorized infrastructure (local connections/ pathways)	0.25	10

[1]GIS buffer is distance from the road centerline, in both directions. For a Principal Arterial, pipes within 80 feet of either side of the road centerline would be assigned a transportation factor equal to 1.

Each pipe was assessed a consequence of failure score, based on the points for each factor and criteria used above. As an example, the following pipe and characteristics would result in a consequence of failure score of 36.5.

- Large diameter pipe over 24 inches – Pipe size /25 points
- Located on collector street – Transportation/11.5 points
- Not in a landslide hazard area – Landslide Hazards/0 points
- No utilities or critical customers in vicinity – Utilities and Critical Customers/0 points
- Not a culvert – Culvert/0 points

Total points = 36.5

The entire inventory of pipes were scored in this manner. Following scoring, the distribution of scores was calculated using the Jenks natural breaks method to determine appropriate divisions to assign high, medium, and low consequences of failure. The highest distribution of scores were assigned to be high consequence of failure, equivalent to 3 points, middle distribution was medium consequence of failure (2 points), and low consequence of failure for the bottom distribution category (1 point).

These high, medium, and low consequences of failure were used with the likelihood of failure estimates to estimate overall pipe risk.

Likelihood of Failure

Likelihood of failure was estimated using a combination of available condition and pipe characteristic data. Where available, the highest (worst condition) structural CCTV grades were used for pipe condition based on rating scores calculated from type and number of serious defects.

The rating scores and defect grades generally used by NAASCO are shown below and are what were used to estimate likelihood of failure categories.

Grade 0 or 1 = Excellent (no defects or minor defects)

Grade 2 = Good (Defects present but have not begun to deteriorate)

Grade 3 = Fair (Moderate defects that will continue to deteriorate)

Grade 4 = Poor (Severe defects that will become grade 5 defects within the foreseeable future)

Grade 5 = Immediate Attention (defects requiring immediate detention within next 5 years)

Stormwater pipes were assigned an assumed likelihood of failure in the model, based on the CCTV scores. In the absence of CCTV condition data, stormwater pipes were assumed to be in the low category for likelihood of failure, based on average CCTV structural grades for most stormwater pipes inspected by Kirkland. The exception was corrugated metal pipes that were all assumed to have a medium likelihood of failure based on the Storm Crew’s experience and recommendation.

The following categories of likelihood of failure were used in the model:

- High likelihood of failure = pipe that has condition data with grades equal to or greater than 4 (poor or fair condition).
- Medium likelihood of failure = pipe that has condition data with grades between 2.5 and 4 All corrugated metals pipes without CCTV data were assumed to be medium likelihood of failure.
- Low likelihood of failure = pipe that has condition data with grades less than 2.5 OR no CCTV condition data available.

Similar to the consequence of failure methodology, the likelihood of failure categories, high, medium and low were assigned numeric values of 3, 2, 1.

Calculating Overall Pipe Risk

Baseline pipe risk was calculated in the pipe evaluation model by multiplying the consequence of failure value by the likelihood of failure value. The highest baseline score is equal to 9 (CoF = 3 multiplied by LoF = 3). Additional factors were determined important to consider besides baseline risk in the prioritization of pipes, including pipes that are already on the aging and failing pipe program list and pipes that have required excessive maintenance or are considered not maintainable based on the potential damage caused by maintenance activities. These stormwater pipes may not have been assessed for condition and therefore not rank very highly for likelihood of failure, and/or the consequence of failure may not be significant either, but nonetheless these are challenging pipes that the maintenance crew must attend to that takes them away from other important activities. Two additional points were added for excessive maintenance and/or if the pipe was part of the aging and failing pipe program. Overall risk of some pipes was elevated due to these factors. The final risk categories and scores were broken down as follows:

Risk Category	Overall Risk Score
Extreme	>9
High	7, 8, 9
Medium	5, 6
Low	3, 4
Negligible	1, 2

Initial Pipe Evaluation Results

The pipe evaluation tool was used to conduct an initial assessment of the stormwater pipe inventory based on existing condition data and current GIS geographic coverages.

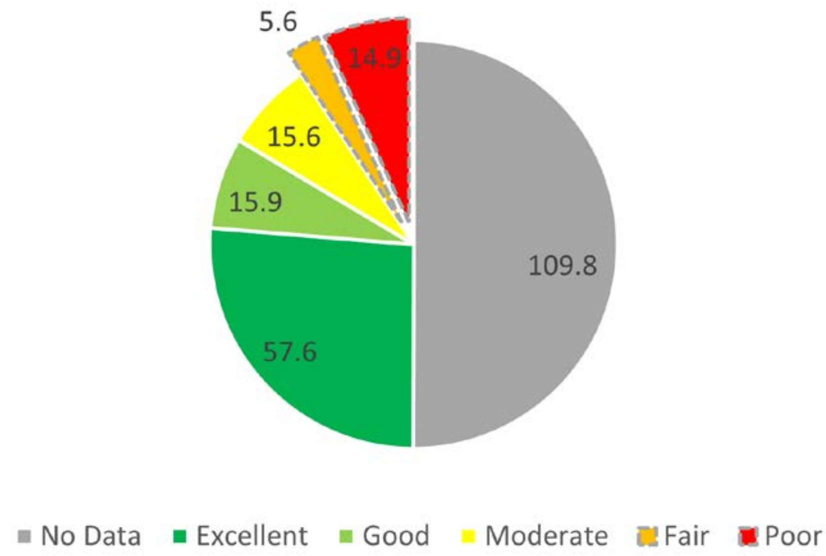
As described above, the tool was built with existing City GIS data layers, and encompassed data used to evaluate risk based on potential consequences of failure and likelihood of failure.

Pipe Condition Data

Pipe condition data was reviewed to determine overall percentage of the system that has been assessed. This data was imported into the pipe evaluation tool that was developed. As of June 2021, approximately 109.6 miles of the City's stormwater inventory had been inspected by CCTV condition assessment at least once. The table at right summarizes the approximate lengths of stormwater pipe characterized by general pipe conditions based on CCTV results.

General Pipe Condition based on CCTV rating	Length of City-owned[1] Pipe (miles)
No CCTV data	109.8
Excellent (Rating ≤1)	57.6
Good (Rating = 2)	15.9
Moderate (Rating = 3)	15.6
Fair (Rating = 4)	5.6
Poor (Rating = 5)	14.9
Total	219.4

[1]City-owned refers to pipes with ownership labeled in GIS as "City of Kirkland."



The figure above shows the data graphically. Pipes with poor and fair ratings represent a fraction of the City's inventory. However, nearly half of the inventory has not been inspected.

Pipes may be rated poorly due to a number of reasons, such as a single serious defect in one location (i.e., a hole or large offset at a joint) or numerous defects that are encountered throughout the pipe (i.e., corrosion, cracks, etc.). The risk of the pipe failing due to its poor condition and resulting in negative consequences was considered in the pipe evaluation model to prioritize pipes that need maintenance, repair, or replacement based on risk.

The tables below summarize risk results of the fair and poorly rated pipes based on their known condition. Risk includes potential consequences of failure and whether these pipes have been flagged as unmaintainable or are on the aging and failing pipe list. The extreme risk pipes are those that are highest priority for repair or replacement.

Risk characterization for fair and poor rated pipes

Overall Risk	Number of Pipes	Number with poor CCTV rating (rating =5)	Number on unmaintainable or aging and failing list	Number with high consequence of failure rating
Extreme	8	4	8	8
High	110	75	17	93
Medium	331	237	4	0
Low	421	300	0	0
Negligible	0	0	0	0
Total	870	616	29	101

All of the pipes identified as extreme risk are also on the City's aging and failing pipe or unmaintainable list, and have a high consequence of failure rating due to location or pipe size. Capital projects were developed for several of these extreme risk pipes.

The high risk pipes did not have all of the criteria of the extreme risk pipes. For instance, although their condition is poor based on the CCTV condition ratings, they may not be on the aging and failing list or have as high of a consequence of failure due to location or pipe size. Similarly, pipes deemed to be lesser risk that are in poor condition, were ranked lower due to less potential impacts if they were to fail. This does not imply that these pipes should not be repaired or replaced, only that the higher risk pipes should be addressed as a higher priority.

CCTV Condition Data

For the pipes that have no condition assessment data, the consequence of failure criteria used in the pipe evaluation model including geographic data (i.e., location relative to major roads, sensitive areas, critical buildings and homes) and pipe characteristics (size and material), can be used to prioritize which pipes should be assessed first. The table below summarizes the consequence of failure ratings for the pipes that have no condition data. The high risk pipes due to consequence of failure only are the pipes that should be prioritized for condition assessment. If resources are limited, the pipes constructed of material that typically has greater numbers of defects, such as corrugated metal, should be assessed first (fourth column in the table below).

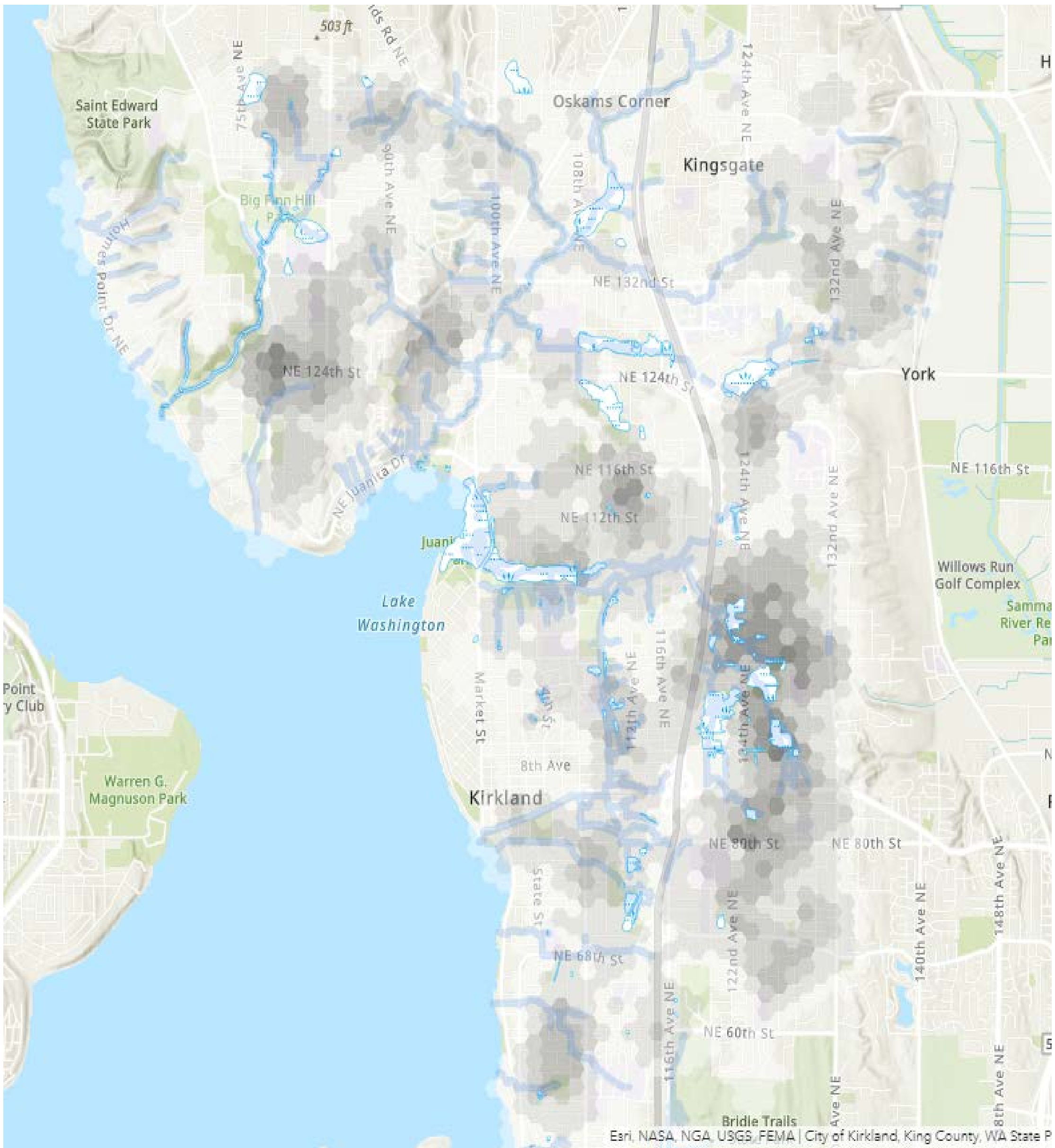
Consequence of failure ratings for pipes with no condition assessment data

Risk Based on Consequence of Failure Only	Number of Pipes	Number on unmaintainable or aging and failing list	Number with higher presumed likelihood of failure based on pipe material
High	1969	16	551
Medium	7106	40	1535
Low	6207	28	1069
Total	15,282	84	3,155

The pipe evaluation tool, on-going collection of condition assessment data, and input from the Storm Crew on aging and failing pipes, and unmaintainable infrastructure help focus the Utility's resources toward solving the highest priority problems. The pipe evaluation tool provides a resource for prioritizing which pipes should be assessed first. Once assessed, the pipes that have serious defects and are deemed to be high or extreme risk due to a higher likelihood of failure and consequence of failure will be reprioritized for repair or replacement with the existing list.

Stormwater Facilities Tool

There are over 800 city-owned water quality, flow control, and combination water quality/flow control stormwater treatment facilities in Kirkland. An analysis was conducted of the facility density to provide a snapshot of where stormwater treatment may be needed. The figure below shows the density of city-owned stormwater facilities (i.e., vaults, tanks, ponds, etc.) across the City.



In addition to the facility locations, an analysis was conducted to identify drainage systems that discharge to outfalls without stormwater treatment. A GIS-based analysis was conducted, tracing treatment of stormwater systems upstream of outfall locations to identify pipe networks without treatment. Almost 300 locations were identified that have upstream stormwater pipe systems that are not connected to stormwater treatment. While many of these are small pipe segments that are connected to ditches or convey very small catchment areas, others represent some of the larger geographic areas shown in the above figure with less stormwater facility density, such as the Kingsgate neighborhood and northern part of the City. These areas represent opportunities for stormwater retrofit.

Private facilities also continue to be constructed at a rapid pace with new development and redevelopment. However, there are also private stormwater pipe systems without treatment in some older neighborhoods that represent an opportunity for improvement with redevelopment. The stormwater facility analysis provides a tool to locate these areas for further investigation.

The Utility will be able to use these GIS-based tools to plan, prioritize, budget, and schedule necessary system repairs and replacement for the next several decades. These tools can also be used to track progress as system repairs are implemented.