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MITIGATION OF EROSION IMPACTS FROM 30 AVENUE STORM SEWER OVERFLOW TO WHITEMUD CREEK

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Abstract: The 30th Avenue storm trunk collects storm runoff from a 5,200 ha basin in South Edmonton and conveys the runoff to the North Saskatchewan River. The storm trunk is 5,100 mm in diameter except for the twin 1,950 mm diameter pipes under Whitemud Creek. The reduction in flow area from 20 m^2 to 6 m^2 causes a significant bottleneck. Before 2004, the manhole located adjacent to the creek was capped with concrete. A severe storm in July 2004 broke the concrete cap and caused overflow into the creek and significant erosion damage of the east bank. After this storm, the City installed a steel grate on the manhole and riprap from the manhole to the creek to permit overflows to occur, while protecting against erosion. However, overflow events during heavy rain in 2012 and 2016 caused similar erosion damage and release of rocks and sediment into the creek. The City has investigated many options to address the overflow problems, including elimination of the bottleneck using a new storm tunnel under the creek and constructing a properly designed overflow channel to accommodate the flows. Computer modeling and other assessments were conducted to understand the hydraulics of the bottleneck location, estimate the overflow rates, and assess the downstream impacts of the overflows on Whitemud Creek. The decision was made to construct an improved overflow channel to safely convey overflow stormwater into the creek. Erosion control, regulatory approvals including fish habitat remediation and public safety were all considered in the design.

1 INTRODUCTION

The City of Edmonton owns and operates the 30th Avenue storm trunk that collects storm runoff from a large area in South Edmonton and conveys the flow to the North Saskatchewan River via an outfall in the Riverbend area. The 30th Avenue storm trunk, built in the mid-1970s, is 5,100 mm in diameter for most of its length and services an area of approximately 5,200 ha that contains mostly residential neighbourhoods. Figure 1 shows the 30th Avenue storm trunk and the contributing basin.

The 30th Avenue storm trunk crosses under Whitemud Creek on its way to the North Saskatchewan River. Whitemud Creek is located in a deep ravine and summer flow rates have ranged from 0.001 m^3/s to 33 m^3/s (Water Survey of Canada, 1977-2012 data). Whitemud Creek near the location where the 30th Avenue storm trunk crosses is depicted in Figure 2.

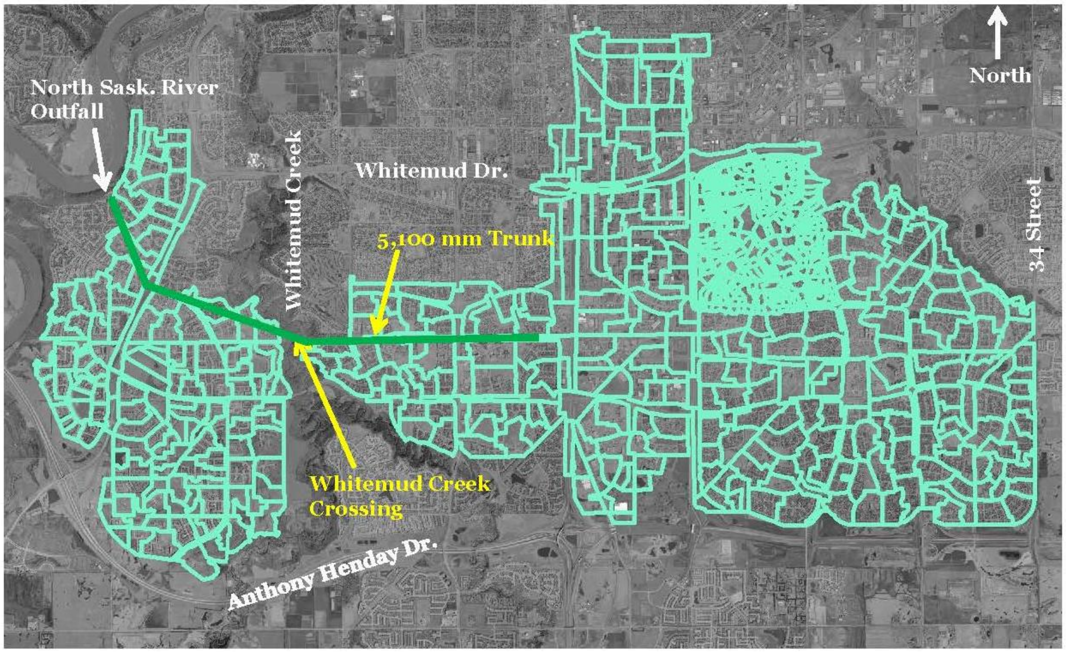

Figure 1: Map of 30th Avenue storm trunk basin and Whitemud Creek crossing

Figure 2: Whitemud Creek near location of 30th Avenue storm trunk crossing

There is insufficient clearance between the 5,100 mm storm trunk and the bottom of Whitemud Creek, and as such, twin 1,950 mm diameter pipes were constructed at the creek crossing. The twin 1,950 mm pipes converge back into a single 5,100 mm pipe on the downstream side of Whitemud Creek. The total cross section area of the twin 1,950 mm pipes is approximately 6 m^2 whereas the cross section area of the 5,100 mm tunnel on both sides is approximately 20 m^2. Therefore, the Whitemud Creek crossing acts as a significant bottleneck in the 30th Avenue storm trunk system. There are manholes located on both sides of the creek crossing, including a 6 m diameter manhole (that was used as a construction working shaft during sewer installation) on the upstream side of the creek crossing. This manhole is located on the east bank, approximately 55 m from the creek and part way up the steep sides of the ravine. The manhole elevation is approximately 9 m above the creek.

2 HISTORY OF 30th AVENUE STORM TRUNK CROSSING WHITEMUD CREEK

Prior to 2004, the 6 m diameter manhole upstream of the Whitemud Creek crossing was capped with reinforced concrete to prevent surcharge flow in the 30th Avenue storm trunk from overflowing to the creek. The storm trunk operated in this configuration for approximately 30 years before a severe rain storm in July 2004 caused extensive surcharging of the 30th Avenue storm trunk upstream of the creek crossing bottleneck. This rainfall event was up to a 1:200 year event in some parts of the 30th Avenue storm basin. The concrete cap on the manhole upstream of the creek crossing was dislodged during this rainstorm and surcharge flow spilled onto the ravine banks and flowed into Whitemud Creek. Significant bank erosion between the manhole and creek occurred during this event, and was subsequently repaired. The repair included replacement of the broken concrete cap with a steel grate to allow overflow to occur in high surcharge conditions, as well as installation of Class 2 riprap beneath a soil cap between the manhole and creek to reduce erosion during overflows.

In 2012, a similar severe rainfall event occurred that was up to 1:200 year frequency in parts of the 30th Avenue storm basin. Overflow occurred at the Whitemud Creek crossing and, despite the erosion protection measures installed after the 2004 damage, caused severe bank erosion in the local vicinity of the overflow manhole and damage to the adjacent pedestrian bridge, as shown in Figure 3. Emergency repairs completed following the 2012 damage included backfilling the erosion scar with gravel and installation of a channel lined with Class 2 riprap.

Figure 3: Damage caused to Whitemud Creek bank during 2012 overflow event (Photo courtesy of Paul Lach, City of Edmonton)

The City completed a concept study in 2014 which investigated several options to address the recurring erosion damage caused by overflows during heavy rainfall (SMA Consulting 2014). Two options were carried forward for future consideration, including redesign of the overflow channel to withstand the flow rates and installation of a third storm sewer under the Creek to reduce or eliminate the bottleneck.

A third overflow event in July 2016, which caused similar but less severe damage compared to the 2012 event, reinforced the requirement to address the overflow to Whitemud Creek to prevent future erosion and sediment release into the creek. The 2016 event resulted in many large boulders and a significant amount of gravel (backfill from the 2012 repairs) entering Whitemud Creek which altered the flow regime of the creek near the overflow channel by partially blocking the creek.

3 PROJECT OBJECTIVES

The objectives of the current project were as follows:

- Examine the options to construct an improved overflow channel or construct a new storm sewer under Whitemud Creek, and determine the preferred option to carry forward
- Develop preliminary and detailed designs for the preferred solution
- Obtain regulatory approvals including assessment of the impacts of the project on Whitemud Creek to support the regulatory approval process
- Project will be tendered and constructed in 2017-2018

Recent upgrading of the storm system in parts of the 30th Avenue storm basin upstream of Whitemud Creek has eliminated some upstream bottlenecks increasing efficiency of conveyance. Therefore, the urgency to improve the overflow channel and protect the creek from damage during overflows has increased as a result of these upstream upgrades.

4 OPTIONS COMPARISON

4.1 Option 1: Improved Overflow Channel

Option 1 was to improve the overflow channel to withstand the overflow rates that would be experienced during heavy rainfall events that surcharge the storm trunk. The improved overflow channel would include grouted riprap, the grout being used to immobilize the rocks which have been washed into the creek during previous overflow events. The channel would also be trapezoidal in cross section shape, designed to convey the estimated overflow rates from the manhole (the existing riprap channel is not properly shaped or sized, and the riprap was basically placed on the ground surface without forming a proper channel). The other key aspect of the improved overflow channel is replacing the gravel backfill used after the 2012 emergency repairs with clay backfill. The intent of the clay backfill is to reduce the infiltration of water into the subsurface and to reduce the movement of groundwater under the riprap channel. Visual evidence following the 2016 overflow damage suggests that complete saturation of the gravel backfill under the riprap may have contributed to the creek bank failure, and could explain why large boulders (Class 2 riprap which has a nominal diameter of 500 mm, as well as some larger boulders), were transported into the creek. A sudden failure of the creek bank slope due to subsurface saturation (Duncan and Wright 2005) combined with the overflowing water (adding additional load on the subsurface and force on the rocks) could explain why the large boulders were transported approximately 20 m into the creek.

The improved overflow channel is less expensive and easier to construct compared to Option 2, which is eliminating the bottleneck by constructing a new storm sewer under Whitemud Creek. The challenges with Option 1 including estimating how much flow the improved channel must convey (discussion in Section 5) and understanding the impacts of overflowing stormwater on Whitemud Creek from an erosion standpoint (discussed in Section 6). Whitemud Creek is already subject to significant erosion due to urban development in its contributing basin (AMEC 2009), and there are private properties located on the top of Whitemud Creek Ravine which are threatened by creek erosion. To proceed with Option 1, it was prudent to demonstrate that the occasional overflowing stormwater from the 30th Avenue storm trunk would have an insignificant impact on creek erosion.

4.2 Option 2: Eliminate Bottleneck

Option 2 was to construct a new storm tunnel under Whitemud Creek to relieve the bottleneck in the twin 1,950 mm pipes. Computer modeling suggested that a new 3,500 mm storm tunnel is required to eliminate the bottleneck and prevent overflow to Whitemud Creek during a 1:100 year rainfall event. Alternatively, two 2,500 mm pipes or four 1,950 mm pipes could be constructed. However, constructing multiple smaller pipes greatly increases the construction cost. Construction of the new storm sewer(s) using trenchless methods such as tunneling, microtunneling or hand tunneling would be required to avoid significant disturbance to Whitemud Creek and the surrounding natural ravine area. As such, the cost of Option 2 is significantly greater than the cost of Option 1. Other challenges include limited clearance between the top of the new storm tunnel and the bottom of the creek and uncertain geotechnical conditions below the creek.

4.3 Preferred Solution

Option 1 was selected as the preferred option for the following reasons:

- Less expensive and more valuable than Option 2 (new storm sewer) as determined at two separate value engineering workshops.
- Computer modeling indicated that the overflows will have a localized impact on Whitemud Creek hydraulics and bank erosion, and that because the impacts are localized, mitigation measures can be implemented to address them.
- Lower construction risk compared to tunneling under Whitemud Creek.
- Regulatory authorities (City of Edmonton, Alberta Environment and Parks) were consulted and are in agreement with the proposed approach.

5 Estimation of Overflow Rates and Development of Design Basis

Computer modeling of the storm sewer system in the 30th Avenue basin was completed using one-dimensional DHI Mike Urban software. The purpose of this modeling exercise was to estimate the flow rate of overflows to Whitemud Creek that could occur during various rainfall events. Model parameters were adjusted based on flow monitoring data from locations both upstream and downstream of the Whitemud Creek crossing bottleneck. Difficulties in modifying computer model parameters (basin characteristics such as imperviousness and pipe characteristics such as Mannings coefficient) to match recorded flow rate data became apparent. The greatest source of uncertainty was the complex hydraulics that exists at the manhole shaft upstream of Whitemud Creek, where the relatively flat 5,100 mm pipe transitions to twin 1,950 mm pipes that have a steeper slope ranging from 12.8% immediately downstream of the overflow manhole to 5% further downstream. The total length of the twin 1,950 mm pipes is 185 m. Previous investigation at this location concluded that for large flows, air pockets in these pipes will be entrained by the hydraulic jumps formed in the steeper part which will transport this air into the downstream sewer and the twin 1,950 mm diameter sewers will run full. In any case, the design team had difficulties matching upstream and downstream flow monitoring data while at the same time simulating realistic overflow rates to Whitemud Creek that are consistent with observed damage in 2004 and 2012. The design team elected to use a higher-than-normal Manning number in the twin 1,950 mm pipes (n=0.02, whereas normal concrete would normally have a Manning number close to 0.013 to simulate realistic water levels in the upstream manhole. This approach generated reasonable overflow rates that are consistent with erosion damage observed during previous overflow events.

Table 1 shows the simulated overflow rates to Whitemud Creek and total duration of overflow for various design rainfall events occurring over the entire 30th Avenue storm basin. Based on these modeling results, overflow may occur for a 1:5 year rainfall event, which is consistent with recently observed overflow events in 2004, 2012 and 2016.

Table 1: Simulated overflow rates to Whitemud Creek and duration of overflow from 30th Avenue storm trunk

Rainfall Event (4 hour rainfall events)	Peak overflow (m^3/s)	Overflow duration (hours)
1:2 year	0	0
1:5 year	34	2
1:10 year	45	3
1:25 year	55	4.5
1:50 year	61	6
1:100 year	67	7.5

The overflow channel was designed to accommodate 70 m^3/s (plus freeboard) for the following reasons:

- The simulated overflow from the 30 Avenue storm trunk to Whitemud Creek, if a 1:100 year 4 hour rainfall event occurred on the entire basin, is 67 m^3/s (Table 1).

- Separate manual hydraulic calculations performed estimated that overflow rates for the 1:100 year rainfall may be less than the computer model output, and as such, the 70 m^3/s design basis is appropriately conservative.

- Surveyed historic high water marks in Whitemud Creek downstream of the overflow channel correspond to between 40 m^3/s and 60 m^3/s. As no Whitemud Creek flows above 50 m^3/s have been recorded since 1985 (upstream of the overflow location) so there is a good chance the 60 m^3/s is from the July 12, 2012 storm that caused erosion damage near the overflow manhole.

6 Assessment of Impacts of Overflow on Whitemud Creek

The primary challenge associated with the redesigned overflow channel was demonstrating to regulators and stakeholders that overflow from the 30th Avenue storm trunk will not cause damage to Whitemud Creek, which is already subject to erosion issues due to urban development in its contributing basin, after appropriate erosion mitigation measures are implemented. To assess the impacts of these flow rates (assumed to be up to 70 m^3/s) on Whitemud Creek, several investigations were initiated:

- A flow duration curve was developed for Whitemud Creek including the overflows from the 30th Avenue storm sewer, and compared to the natural flow duration curve for Whitemud Creek.

- Mean channel velocities downstream of the overflow location were compared for scenarios with and without the overflows from the 30th Avenue storm trunk (using one-dimensional computer modeling).

- A two-dimensional hydraulic model of the improved overflow channel and a 970 m reach of Whitemud Creek downstream of the overflow channel was developed to assess the “zone of influence” of the high flows from the overflow manhole.

The simulated overflow rates in Table 1 were used to develop a flow duration curve for Whitemud Creek including overflows, and this curve was compared to the natural flow duration curve for Whitemud Creek without the overflows during summer months, as shown in Figure 4. The two flow duration curves are nearly identical (the purple and green lines showing both scenarios almost completely overlap) which means that the frequency of high flows in Whitemud Creek does not increase significantly with the overflow, compared to without the overflow. This is because flows that are similar to the 30th Avenue storm trunk overflow rates occur without overflow in Whitemud Creek from time to time during periods of high rainfall. When these natural high flows occur they normally last for a period of days whereas the 30th Avenue storm trunk overflows last only a few hours. Therefore, the overflow discharges do not contribute as significantly to the flow duration curve as the natural discharges do.

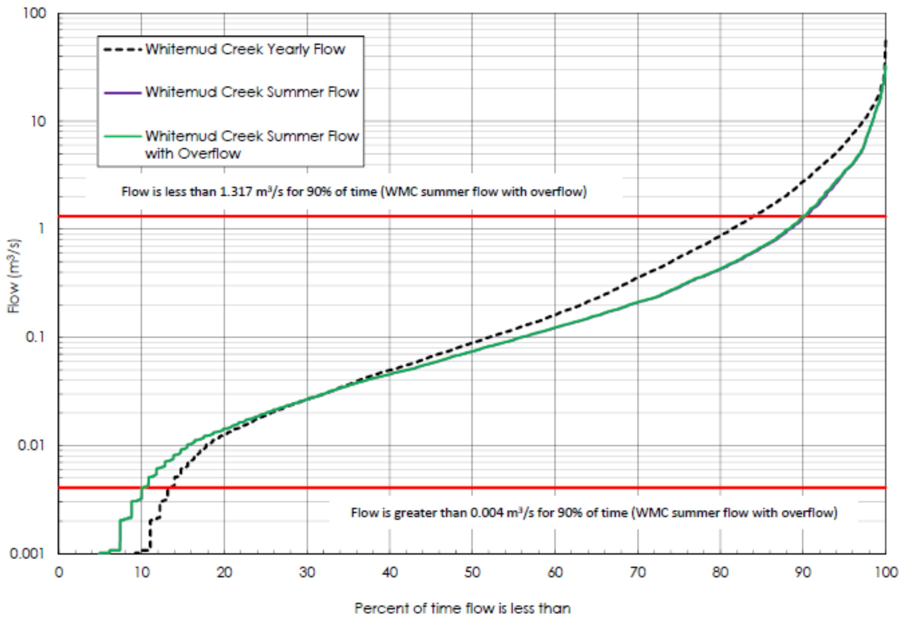

Figure 4: Comparison of flow duration curves in Whitemud Creek for scenarios with and without overflows from the 30th Avenue storm trunk (flow data combined for Whitemud Creek from Water Survey of Canada Stations 05DF006 and 05DF003)

A one-dimensional model of Whitemud Creek between the overflow location and confluence with the North Saskatchewan River was developed using HEC-RAS software to assess the routing of overflows through the creek and to compare the mean creek velocity during a natural 1:100 year rainfall flow event (50.9 m^3/s) to the mean creek velocity during a 1:100 year overflow (70 m^3/s) from the 30th Avenue storm trunk. Peak flows and velocities due to overflow are diminished as the overflow is routed through the creek. Even at a relatively short distance downstream of the overflow location, flow velocities during an overflow event are similar to those observed in the natural 1:100 year flow (and they occur for a period of a few hours, compared to a few days for the natural peaks). Simulated creek flow velocities are summarized in Table 2.

Table 2: Simulated routed flow velocities in Whitemud Creek

Distance downstream from overflow location (m)	1:100 year overflow (70 m^3/s) mean channel velocity (m/s)	1:100 year natural rainfall (50.9 m3/s) mean channel velocity (m/s)
54	1.7	1.6
581	1.8	1.7
868	1.9	1.6
1406	1.6	1.3
2224	1.7	1.5
3248	1.8	1.5
3790	2.1	1.9
4452	1.6	1.6
5019	1.6	1.3
6866	1.5	1.3
8040	2.0	1.7
9124	1.6	1.7

A two-dimensional model of the overflow channel between the overflow manhole and Whitemud Creek, along with a 970 m long reach of the creek downstream of the overflow channel, was developed using TELEMAC software to provide a more detailed assessment of the impact of the overflows on creek velocities (and hence erosion potential) near the confluence of the overflow channel and creek. Model results indicated that the velocity during a 1:100 year overflow event (70 m^3/s) relative to the natural creek velocity during 1:100 year flow (127.6 m^3/s) is significantly increased for a distance of approximately 100 m downstream of the overflow channel (between 1 m/s and 3 m/s higher). Beyond 100 m downstream of the overflow location, the simulated difference in velocity between the 1:100 year overflow event and natural 1:100 year flow is minimal (less than 1 m/s). These results are depicted in Figure 5. This information was used when determining the extent of creek bank armouring to implement as part of the overflow channel improvements. The flow velocities themselves were used to determine the type of bank armouring that is required.

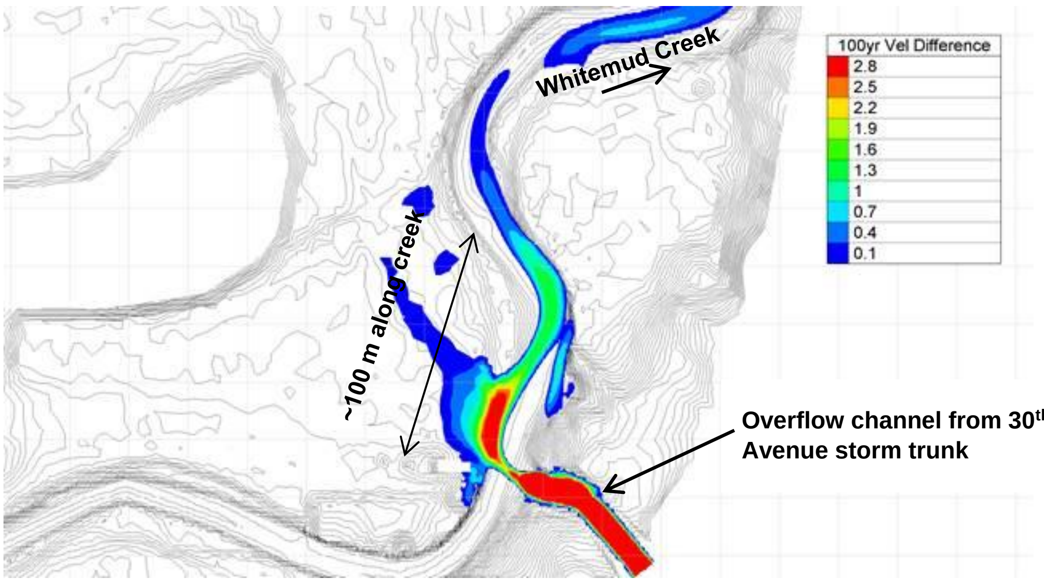

Figure 5: Two-dimensional model output indicating difference in creek flow velocity between a 1:100 year overflow event from 30th Avenue storm trunk (70 m^3/s) and natural 1:100 year flow event (127.6 m^3/s) in Whitemud Creek

The two-dimensional model was also used to assess the impact of the overflow during a more frequent 1:5 year flow event. Figure 6 below shows the difference in velocity of a 1:5 year flow rate in Whitemud Creek (~41 m^3/s) compared to a 1:100 year overflow event from the 30th Avenue storm trunk (~70 m^3/s). Similar to the 1:100 year results, the zone of influence where the difference in velocity is greater than 1 m/s extends to the first bend, approximately 100 m from the overflow location.

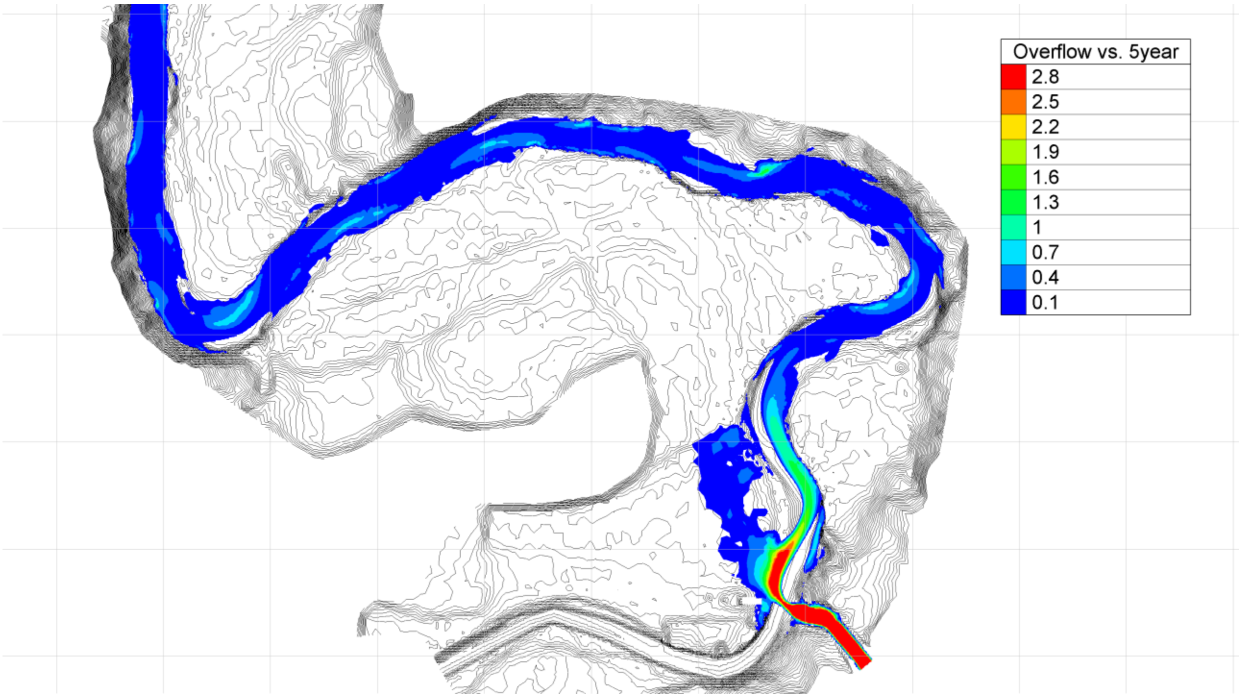

Figure 6: Two-dimensional model output indicating difference in creek flow velocity between a 1:100 year overflow event (from 30th Avenue storm trunk) (70 m^3/s) and natural 1:5 year flow in Whitemud Creek (41 m^3/s)

7 Improved Overflow Channel Design

The improved overflow channel will consist of the following key components:

- Overflow channel will be trapezoidal in shape and designed to accommodate 70 m^3/s with 0.5 m of freeboard.
- Overflow channel will consist of class 2 riprap, with the bottom half of the rocks grouted to increase the stability of the rocks, while maintaining surface roughness to dissipate energy.
- Overflow channel will wrap around the overflow manhole to contain flows that may spill out the sides and back of the manhole. Without this component, flows spilling out the sides and back of the manhole will flow outside of the channel and could undermine the channel.
- Clay backfill will be used under the grouted riprap channel (instead of granular fill used in previous emergency repairs), so that groundwater and water flowing in the subsurface are diverted around the channel, reduces the risk of slope failure under the channel.
- Drainage layer (gravel) will be constructed between the clay backfill and grouted riprap to allow any water that does get below the grouted riprap, such as groundwater or water that seeps through cracks in the grout, to drain towards the creek. This is expected to increase the life of the channel by preventing a buildup of subsurface water that could result in freeze-thaw damage and undermining of the channel.

Simulated creek flow velocities significantly increased as a result of the overflow discharge within approximately 100 m downstream of the overflow channel. Armouring of the bed and banks of Whitemud Creek is proposed in this “zone of influence”. Class 3 riprap (nominal rock diameter of 900 mm) is recommended for the creek bed at the confluence with the overflow channel, where the velocity is highest and there is a large energy loss as water in the overflow channel (at velocities of nearly 8.5 m/s) hits the creek at close to a 90º angle (the adjacent pedestrian bridge does not permit design of the overflow channel to intersection the creek at a lower angle, a practice common in storm outfall design). Class 1 and Class 2 riprap are proposed further downstream of overflow channel and along the creek banks, depending on the simulated flow velocity from the two-dimensional model output.

Creation of enhanced fish habitat was requested by regulators as compensation for previous overflow events that caused erosion damage and release of rocks, gravel and finer sediment into Whitemud Creek. Creation of fish habitat will occur through the strategic placement of riprap in the creek and appropriately sized gravels, large boulders, spawning riffles, and a deep pool.

8 Conclusions and Recommendations

Based on the computer modeling and flow duration curve analyses, it was concluded that the overflows from the 30th Avenue storm trunk will not significantly increase the bank erosion in Whitemud Creek, as long as creek bed and bank protection (riprap) is installed in the “zone of influence” which extends approximately 100 m downstream from the overflow location. Overflow from the 30th Avenue storm trunk is short in duration (several hours) and infrequent (estimated to average one overflow event every five years). Flow routing of the 1:100 year overflow through Whitemud Creek lasts approximately 10 hours, with peak flows lasting approximately 0.5 hours. Erosion processes in natural systems occur every day, but are increased during natural flood events, which last days. The short overflow event will last hours, which is not enough time to implement increased bank erosion mechanisms (Martin et al. 2006). During the overflow events in 2004, 2012 and 2016, there was no reported increase in bank erosion downstream of the overflow channel; the only erosion reported was at the confluence of the overflow path and creek.

Nonetheless, the City should implement an erosion monitoring program to confirm that erosion in Whitemud Creek is not increased because of the overflows from the 30th Avenue storm trunk.

Although there are expected to be some localized effects to the creek and channel during construction, the overall impact of improving the overflow channel is expected to be positive. The channel and creek will be better protected from flow events and there will be less risk to local infrastructure (i.e. the adjacent pedestrian bridge) as a result.

9 References

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