Development of a riverbank asset management system for the City of Winnipeg

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ABSTRACT
The City of Winnipeg, located at the confluence of the Red and Assiniboine Rivers, boasts over 240 km of natural riverbank channels. The increased frequency and magnitude of flooding along the Red and Assiniboine Rivers over the past decade appears to have influenced the number and magnitude of slope movements along the riverbanks, resulting in the loss of both public green space and privately owned land. The loss of private and public property adjacent to the river has resulted in the loss of valuable real estate and public parkland amenities. The City is looking at increasing the stability of certain reaches of the Red and Assiniboine Rivers that are prone to movement.

This paper describes the initial development of an asset management system that is being created to provide the City with a rational approach for determining risk levels for certain reaches of the Red and Assiniboine Rivers. The calculated risk levels will allow the City to develop recommended response levels for slope stability remediation along the rivers. This system will also allow the City to facilitate timely and periodic reviews of priority sites as riverbank conditions and input parameters change.

RÉSUMÉ
La ville de Winnipeg se situe au confluent de deux rivieres, la Riviere Rouge, et l'Assiniboine et se vante de 240 km de chenels naturels de berge. Un augmentation dans le frequence et grandeur d'innondation le long des deux rivieres depuis dix ans semble d'avoir influence le mouvement des flancs de berge en numero et en grandeur. Ces movements ont comme resultat une perte d'espace publique verte et une perte de terrain prive. Cette perte de terrain publique et prive contigu aux rivieres se resulte dans un rebaisse de valuer des proprietes privees et un reduction dans la quantite des jardin publics. La Ville de Winnipeg consider augmenter la stabilite le long de certaines parties des rivieres Rouge et Assiniboine qui se tend vers mouvement. Cette redaction decrit les developments initialles d'une systeme de gestion d'actifs que soit cree pour la Ville de Winnipeg pour lui donner un approchement raisonnable en determinant les niveaux de danger pour certaines portions des rivieres Rouge et Assiniboine.

Calculer ces niveaux de risques permettera a la Ville de Winnipeg de developper un reponse conseille en determinant les niveaux de stabilite de flanc de berge correctifs le long des rivieres. Cette system premettra aussi a la Ville de Winnipeg a faciliter des analyses periodiques en temps utile des sites prioritaires ainsi que les conditions des berges et les donnes de parametres se changent.

1 INTRODUCTION

The City of Winnipeg is located at the confluence of the Red and Assiniboine Rivers as shown on Figure 1 and boasts over 240 km of natural riverbank channels. The increased frequency and magnitude of flooding along the Red and Assiniboine Rivers over the past decade appears to have influenced the number and magnitude of slope movements along the riverbanks, resulting in the loss of both public green space and privately owned land. The loss of private and public property adjacent to the river has resulted in loss of valuable real estate and public amenities that are used by the citizens of Winnipeg. The City of Winnipeg is looking at increasing the stability of certain reaches of the Red and Assiniboine Rivers that are prone to movement to ensure that the areas adjacent to the rivers will be preserved for future generations.

Figure 1. Drainage Basins of the Red and Assiniboine Rivers.

This paper describes the initial development of an asset management system that will be created to provide the City of Winnipeg with a rational approach for determining risk levels for certain reaches of the Red and Assiniboine Rivers. The calculated risk levels will allow the City to develop recommended response levels for slope stability remediation along the rivers. This system will also allow the City to facilitate timely and periodic reviews of priority sites as riverbank conditions and input parameters change.

2 BACKGROUND INFORMATION

2.1 Study Location

Winnipeg is located in the broad plain of the Red River Valley at the confluence of the Red and Assiniboine Rivers (Baracos et. al. 1981). The topography can be described as relatively flat (Baracos et. al. 1981).

2.2 Geology

Winnipeg is located on glacial Lake Agassiz sediments which were deposited 10.3 to 9.9 thousand years ago (Teller et. al. 1981). The glaciolacustrine soils are laminated, highly plastic and have a low strength. A till unit that is soft and water bearing in the upper section and dense to very dense in the lower section, underlies the glaciolacustrine material. Beneath the till layer is the Upper Carbonate Aquifer which is comprised of limestone and dolostone.

The Red and Assiniboine Rivers were incised about 10 to 8 thousand years ago after Lake Agassiz finally receded from the Winnipeg area (Teller et. al. 1981). Riverbanks range in height from 9 m to 15 m and the riverbed is typically controlled by the underlying dense till. Frequent floods have resulted in alluvial material being deposited along the inside and transition sections of the Red and Assiniboine Rivers.

Post glacial erosive activities have left the riverbanks in unstable conditions with oversteepened slopes too high for the weak cohesive glaciolacustrine material (City of Winnipeg 2000). This has resulted in massive bank failures generally along the concave bends of the Red and Assiniboine Rivers (City of Winnipeg 2000).

2.3 Riverbank Characterization

The Red and Assiniboine Rivers are classified according to the riverbank geometry. Inside bends (convex curves) are typically composed of alluvial soils while outside bends (concave curves) are generally comprised of glaciolacustrine soil. Transition sections of the river are composed of alluvial soils overlying glaciolacustrine material.

Mishtak (1964) studied 141 bends along the Red River and noted that 135 of these sections had experienced previous slope movement while every outside bend of the river had experienced previous slope movement, was actively moving or required stabilization (Baracos et. al. 1981).

Failure controlled sections, as mentioned above, are typically located on the outside bends of the Red and Assiniboine Rivers in cohesive, low strength glaciolacustrine soil. The majority of the failure controlled sections have experienced previous slope movement. The failures are deep seated, 12 m to 15 m below ground surface, and will typically continue to fail until a slope of 6H:1V to 9H:1V is achieved. The slope failures may extend as far as 80 m from the top of the bank and consequently a significant amount of property loss for both the City and private landowners has occurred. The principle factors controlling riverbank failure along failure controlled sections are groundwater, river hydraulics and progressive soil weakening (City of Winnipeg 2000). A typical failure controlled riverbank found along the Red and Assiniboine Rivers is shown in Figure 2 below.

Figure 2. Typical failure controlled bank along the Red River. Note the retrogressing headscarp and shallow slope angle.

Erosion controlled banks are found on the inside bends of the Red and Assiniboine Rivers and the slope movements are typically shallow. Erosion controlled slope movement is governed by river erosion and consequently a significant loss of City and private property has occurred. The erosion controlled banks are typically comprised of alluvial soils and since the alluvial soils have a higher strength than the glaciolacustrine soil, the slopes on an inside bend typically have slope angles of 1H:1V to 3H:1V. The principle mechanisms controlling erosion-controlled banks are: river hydraulics, waves, freeze/thaw cycles, drying/wetting cycles and precipitation (City of Winnipeg 2000). An example of an erosion controlled bank is shown below in Figure 3.

Figure 3. Typical erosion controlled bank encountered along the Red River. Note the steep and well drained riverbank face.

Transition banks are found upstream or downstream of inside or outside bends and include straight sections (City of Winnipeg 2000). These banks are typically composed of alluvial soils overlying glaciolacustrine material and may experience deep seated or shallow slope movement depending on the relative depths of the two soil units. Therefore, significant property loss has occurred along these banks as well.

3 SITE INVESTIGATIONS

3.1 Previous Site Investigations

A Riverbank Stability Characterization Study was completed in 2000 by the Waterways Section of the Planning, Property and Development Department at the City of Winnipeg. This report was compiled to characterize, assess and monitor the riverbank stability of 108 km of City owned property (City of Winnipeg 2000). The report provided a priority list and cost estimates for sites that required remediation along the waterways within the City of Winnipeg.

A monitoring report was also completed in 2004 updating the information collected in 2000, 2002 and 2004. A mathematical assessment of the data collected from the 2000 Riverbank Stability Characterization Study and the monitoring program conducted between 2000 and 2004 was completed to provide a numerical ranking for the sites requiring riverbank stabilization works. The results of the investigations and numerical analyses are provided in Table 1 below. The locations of these sites are shown in Figure 4.

Table 1: "First Phase": Priority Riverbank Stabilization Sites (2004)

Site	*Preliminary Cost Estimate ($)
Red River – St. Vital	$1,645,000
Red River – Churchill Park Drive (Montague to Cockburn)	$2,000,000
Red River – St. John's Park	$600,000
Red River at Bunn's Creek	$165,000
Red River – Lyndale Drive	$1,455,000
Red River –King's Park (Inside Bend)	$450,000
Red River – Crescent Park	$765,000
Assiniboine River – Fort Rouge Park	$400,000
Red River – King's Park (Outside Bend)	$2,720,000
Red River –Minnetonka	$440,000
Seine River –Evans at Cusson Street	$240,000
Assiniboine River – Granite Curling Club	$870,000
TOTAL	**$12,915,000**

*The dollar amount is based on the 2000 Riverbank Stability Characterization Study and does not reflect additional work that may be required if stability conditions have changed.

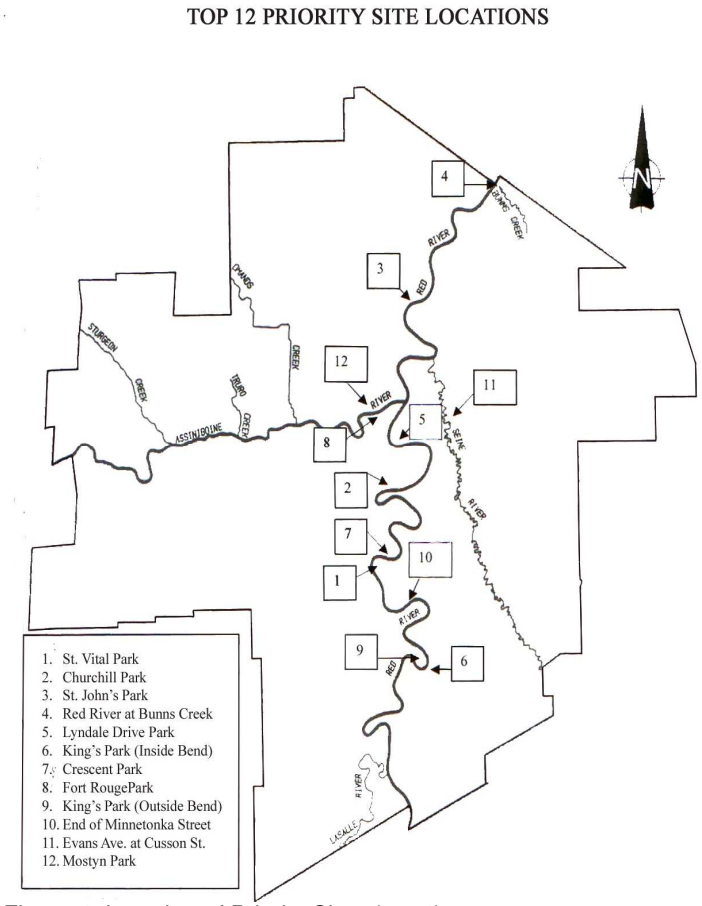

Figure 4. Location of Priority Sites (2004)

The one limitation in the ranking system is that it did not explicitly take into account both likelihood of failure

and consequence of failure considerations. As such, there is a considerable amount of engineering judgment that factors into the ranking of sites. With the development of a more comprehensive decision making tool, priorities for riverbank stabilization in the City of Winnipeg can be better defined and appropriate response levels identified such that works are carried in a fiscally responsible manner.

3.2 2007 Site Investigations

Thirty six (36) sites identified in the 2000 Riverbank Stability Characterization Study were inspected during the 2007 monitoring program. This monitoring program provided a comprehensive update of visual site inspections and photographic records at each site. Five (5) sites that were stabilized between 2000 and 2007 were also inspected for purposes of confirming post construction performance.

Appropriate attributes were determined based on local engineering experience. A typical riverbank observation checklist was prepared for the field reconnaissance and applied consistently for all sites inspected on the Assiniboine and Red Rivers. Factors such as bank height and slope, retrogression ratio, limits of bank type, till depth and bank failure extents were collected from a City database composed of local consulting reports for each site. Parameters such as: bank geometry, soil type, vegetation cover, groundwater and surface water conditions, bank drainage, evidence of movement, edge erosion, loading at top of the bank, accumulation of overbank deposits, existing work, anthropogenic influences and consequence factors were all recorded during the site reconnaissance.

Detailed site inspections were conducted on foot and by boat between May and June 2007 and in late October 2007 when the water levels had receded after drawdown. Digital photos taken during the site reconnaissance were entered into Google Earth Pro to aide in the development of the asset management system. Two selected photos illustrating typical failures are show in Figures 2 and Figure 3.

3.2.1 Airphoto Review

Aerial photographs with a 1:5000 scale from 1988, 1998 and 2004 were reviewed to determine if significant riverbank stability issues have surfaced over the last twenty years. Air photos from before and immediately following the 1997 flood were reviewed to determine if there was any visual evidence of new or reactivated riverbank movements following the “Flood of the Century”. The air photos taken in the fall of 2004, after the completion of the 2004 Monitoring Report, were also utilized as they provided the most up to date aerial information for the riverbanks. The sites selected for review were based on field observations between 2000 and 2007.

The results of the air photo interpretation for 1988, 1998 and 2004 were overlain on a Google Earth Pro image for the City of Winnipeg as shown in Figure 5. The air photo analysis completed for 1988, 1998 and 2004 was displayed as separate layers in Google Earth Pro. By creating separate layers, it was possible to visually note the changes in slope geometry and scarp location at a specific site over a sixteen (16) year period. Also, the Google Earth Pro software enabled a comparison of the present slope configuration to the most recent aerial photograph interpretation. Therefore, it was possible to determine if significant slope movement occurred between 2004 and 2007.

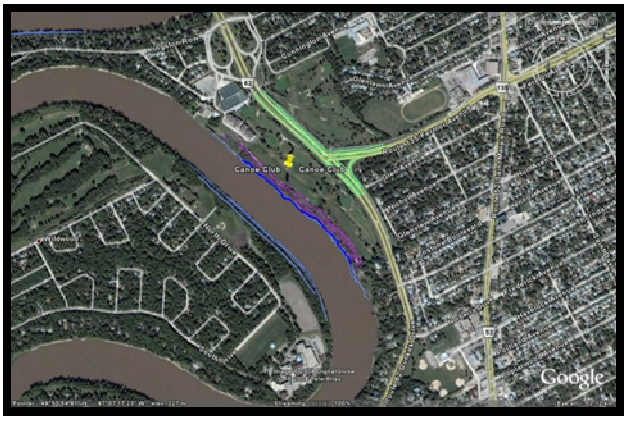

Figure 5. Example of air photo analysis conducted for sections of the Red and Assiniboine Rivers for the three time periods. (http://www.earth.google.com)

3.2.2 Potential Priority Sites

Potential priority sites were determined by comparing the magnitude of slope movement that occurred between 2000 and 2007. The results were based on observations made during the 2007 site reconnaissance and air photo interpretation. When conducting the site reconnaissance, the approximate timeline of the observed slope movement was assessed. Two sites were stabilized during the winter of 2006-2007 and one in the winter of 2007-2008 and, hence, were not considered for the 2007 potential priority sites.

Table 2 outlines potential priority sites identified during field investigations conducted in 2007. Table 2 was prepared by reviewing the thirty six (36) priority sites identified in the 2000 Riverbank Stability Characterization Study and doing a comparative assessment from monitoring dating back to 2000. Of particular interest, were site changes that have occurred since 2004. The sites in Table 2 were identified to be “potential priority” sites and do not represent a new priority sites list. The listed sites have not been assigned a ranking like in 2004.

The results from the 2007 site investigations and monitoring will be used in the next step of the project. This step will assimilate the 2007 data into a riverbank asset management system to establish an updated priority listing for riverbank stabilization of City owned properties. This will allow the City to effectively assess its riverbanks from a risk analysis perspective and to facilitate timely reviews of priority sites as riverbank conditions and input parameters change.

Table 2: Potential Priority Riverbank Stabilization Sites (2007)

Site	River Co-Ordinates	Preliminary Cost*
Red River – RRR56.00 to RRR56.50		$2,000,000
Red River – RRR62.35 to RRR62.86		$765,000
Red River – RRR71.40 to RRR72.08		$2,720,000
Red River - RRR 71.10 to RRR71.40		$450,000
Red River – RRL58.79 to RRL59.34		$2,200,000
Red River – RRL51.33 to RRL52.30		$1,455,000
Red River – RRL72.15 to RRL72.50		$525,000
Red River – RRL64.39 to RRL64.72		$1,320,000
Red River – RRL53.50 to RRL53.64		$560,000
Red River – RRL49.10 to RRL49.37		$1,100,000
Red River – RRL67.00 to RRL67.11		$440,000
Red River – RRL69.75 to RRL70.42		$2,680,000
Assiniboine River – ARL1.12 to ARL1.24		$400,000
Red River – RRR47.24 to RRR47.29		$75,000
Red River – RRR55.64 to RRR56.01		$550,000
Red River – RRR52.23 to RRR50.83		$1,080,000
Red River – RRR47.49 to RRR47.82		$825,000
Red River – RRL48.63 to RRL48.79		$640,000
TOTAL		**$19,785,000**

*The preliminary costs were based on Riverbank stability Characterization Study (2000).

4 DEVELOPMENT OF A RIVERBANK ASSET MANAGEMENT SYSTEM

Asset management principles are being utilized to develop recommended response levels based on specific risk levels for slope stability applications on the Red and Assiniboine Rivers. The response level is interconnected to the risk. Risk is identified as the probability of the occurrence a slope failure and the resultant consequences. An asset management database is being developed utilizing measured, experiential and public data. A map will be prepared outlining the calculated risk levels of City owned properties along the Red and Assiniboine Rivers within the City of Winnipeg.

4.1 Probability of Failure

Attributes affecting the probability of slope movement along the Red and Assiniboine Rivers were determined and are shown in Figure 6. The information required to properly assess the probability attributes were collected during the 2007 site investigations and from works conducted at each site by local consultants.

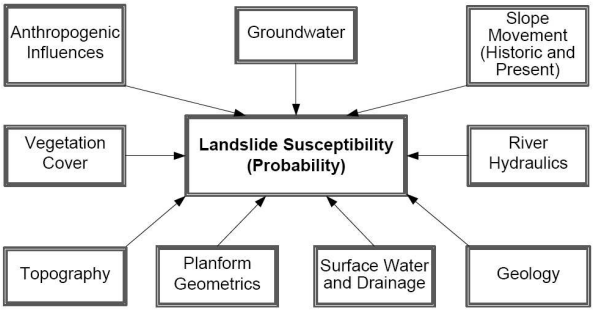

Figure 6 – Potential landslide susceptibility (probability) attributes identified for the Red and Assiniboine Rivers

These attributes will be assigned a weighting factor to calculate the probability of failure for the various reaches of the Red and Assiniboine Rivers. Attributes that have a greater influence on local riverbank stability, will be assigned a higher weighting than attributes determined to have a minor influence on riverbank stability.

A survey was sent to local consultants in the Winnipeg area asking them to rank the landslide susceptibility attributes in order of importance and to also provide a priority ranking for each of the attributes based on their engineering experience. The responses to the survey are confidential but they will be used to facilitate development of the weighting factors in the final landslide probability computations.

4.2 Consequence of Failure

The consequences of slope movement along the Red and Assiniboine Rivers were determined from the 2007 site investigations and are shown in Figure 7. Affects on the receiving environment, transportation corridors, infrastructure, utilities, property and public perception all need to be considered.

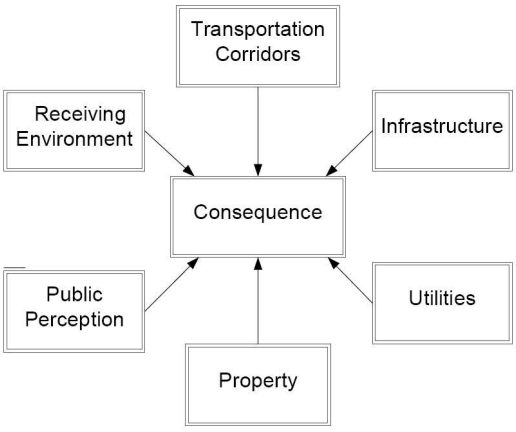

Figure 7 – Potential consequence attributes for the Red and Assiniboine Rivers in Winnipeg.

The consequence attributes will also be assigned weightings. Higher weightings will be assigned to consequence attributes of greater significance.

4.3 Future Work

Additional work will be completed in 2008 to finalize the asset management system for the City of Winnipeg. By utilizing the appropriate consequence and probability factors for the selected reaches of the Red and Assiniboine Rivers, the risk will be calculated using a selected formulation so that all sites can be ranked taking into account the likelihood of failure and the consequences should a failure occur. From the determined risk level, appropriate response levels will be determined for the selected sites along the Red and Assiniboine Rivers.

The asset management system for The City of Winnipeg will be managed using Google Earth Pro. Summary sheets, photographic collections and the consequence and probability attributes for the thirty six (36) sites can be visualized in Google Earth Pro. The appropriate weightings for the probability and consequence factors will be defined and computed in an Excel spreadsheet that will be imported into the Google Earth Pro software once the weighting values are finalized. The spreadsheet will be automatically updated in Google Earth Pro with new risk and response levels to reflect any changes made to the input parameters.

Response levels will be developed from the calculated risk levels for the sites. The response levels will dictate the frequency of subsequent site inspections (i.e. bi yearly or annual site visits) and instrumentation requirements; therefore creating a management tool that can easily be utilized by The City of Winnipeg.

5 CONCLUSIONS

Asset management principles are being utilized to provide the City of Winnipeg with a semi quantitative approach for determining risk levels for its riverbank properties along the Red and Assiniboine Rivers. With the riverbank asset management system in place, the City will be able to effectively assess its riverbank properties from a risk analysis perspective and establish appropriate response timelines for implementation of riverbank stabilization works. The system will also facilitate timely reviews of priority sites as riverbank conditions and input parameters change for best use of public funds towards stabilization of City owned riverbank properties.

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