2014 Manitoba Southwest Region Bridge Flood Response and Recovery

Prepared By:

Troy Hengen, P.Eng., Bridge Inspection Engineer, Manitoba Infrastructure and Transportation

Co-Authored By:

Russ Andrushuk, P.Eng., Inspections and Maintenance Engineer, Manitoba Infrastructure and Transportation
Ruth Eden, M.Sc., P.Eng., Director, Structures, Manitoba Infrastructure and Transportation
Drew Monnier, P.Eng., Structures Project Engineer, Manitoba Infrastructure and Transportation

Paper Prepared for Presentation
at the Structures Session

of the 2015 Conference of the
Transportation Association of Canada
Charlottetown, PEI

Abstract

In July 2014, the southwest corner of Manitoba experienced an unprecedented high water level event due to near record precipitation that occurred at the end of June. This rain event caused bridge collapses, major culvert failures and road closures, impacting over 100 bridge structures owned by Manitoba Infrastructure and Transportation (MIT), crippling local access and transportation in the area. The Assiniboine River system also simultaneously experienced a record high water level event, similar to previous record flood levels in 1976 and 2011, putting several major MIT bridges at risk.

A state of emergency was declared by the Province of Manitoba in portions of the province and 60 Manitoba rural municipalities declared a state of local emergency in response to flood water impacts. MIT bridge and highway personnel were tasked with responding to this flood event to assess damage and determine plans of action to restore access to flood damaged bridge and road infrastructure. An estimated $70 million in damage occurred to MIT's bridges and province-wide, an estimated $220 million in damage for Disaster Financial Assistance, related to the 2014 summer flooding, was sustained.

This paper will expand on the following points:

1. The background of the flood event and affected areas,
2. The impact to the area residents and stakeholders, including oil production companies and agricultural producers in the region,
3. MIT's action plan implemented immediately during the flood event,
4. How MIT personnel assessed flood damage to structures,
5. How MIT temporarily repaired bridge and culvert structures to re-establish interim restricted access, and
6. MIT's process for fast-tracking replacement of severely damaged structures by direct negotiations with engineering service providers for design and contractors for construction of new bridge structures on strategic routes.

1.0 Introduction and Background of Flood Event

1.1 Introduction

On June 27th, 2014, Manitoba Infrastructure and Transportation's (MIT) Hydrologic Forecast Centre advised that much of western and southern Manitoba and the Interlake region were forecasted to receive 40 to 50 mm of rain by July 1st. The June 27th to 30th rainfall across much of western and southern Manitoba added to an already saturated system from high or record snowpack and precipitation over the past two to three years and resulted in flooding; the record flow levels on 13 Manitoba rivers and streams washed-out roads, threatened infrastructure, flooded homes and caused evacuations. Several tributaries of the Souris River system and the surrounding southwest region were some of the most affected areas.

The late June storm system brought significant amounts of rainfall to parts of western and southwestern Manitoba in particular, with some locations reporting well over 100 mm, including; Deloraine at 155 mm, Virden at 140 mm and Reston at 107 mm. Total rainfall for the month of June in Brandon reached 240 mm, making it the second-wettest month in the city since record keeping began in 1890. Communities across the border in Saskatchewan also reported similar amounts of rainfall, and in certain instances, even more rainfall during the same time period.

The Portage Diversion (on the Assiniboine River system; which protects downstream locations of the diversion, such as Portage La Prairie and Winnipeg, MB, by diverting Assiniboine River flows to Lake Manitoba) began operating on June 30th, 2014, followed by the Red River Floodway on July 1st, 2014. In addition, Manitoba declared a Provincial State of Emergency on July 2nd, 2014, and re-opened the Lake St. Martin Emergency Channel (emergency flood control channel constructed in 2011 due to flooding that year) to lower the high water levels on Lake St. Martin and subsequently Lake Manitoba.

Work had already been underway to re-open the channel on an emergency basis due to the spring flood waters in advance of the June 27th- 30th rainfall however this rainfall exacerbated the emergency situation.
As of July 2nd, 2014, flood warnings were issued for 30 different rivers and lakes in Manitoba, including; the Assiniboine River, from the Shellmouth Dam to Brandon; all points along the Winnipeg River system; Lake St. Martin; Dauphin Lake; Qu'Appelle River and several Souris River tributary waterways.

The flooding experienced in Manitoba during 2014 was related to the weather over the past two to three years and during Spring 2014. Manitoba recorded high levels of snow and then experienced a slower than usual spring melt that caused overland flooding followed by high water levels on creeks, rivers and lakes as the melt waters began to drain through the system. Water levels were starting to decrease in late June, however rains falling on the river and lake systems at or near capacity, caused additional overland flooding with major impacts across southern Manitoba.

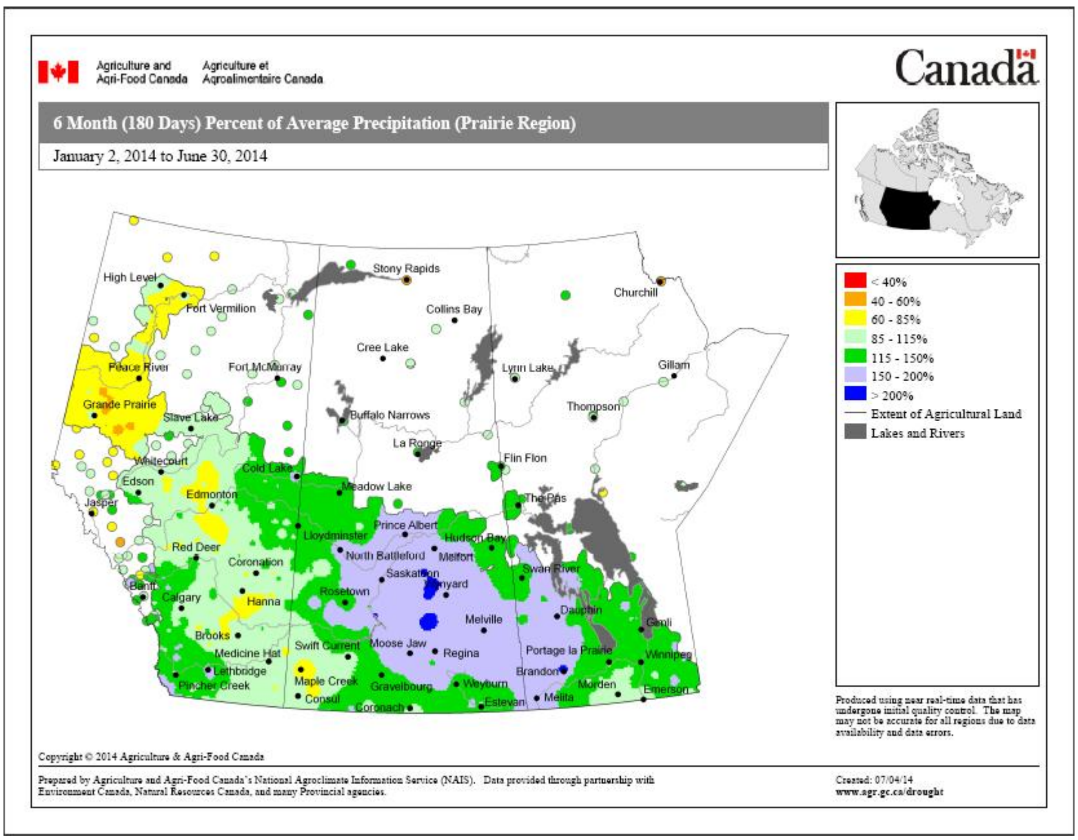

Figure 1: Percent of Average Precipitation Recorded over the Prairie Region from January 2nd to June 30th, 2014

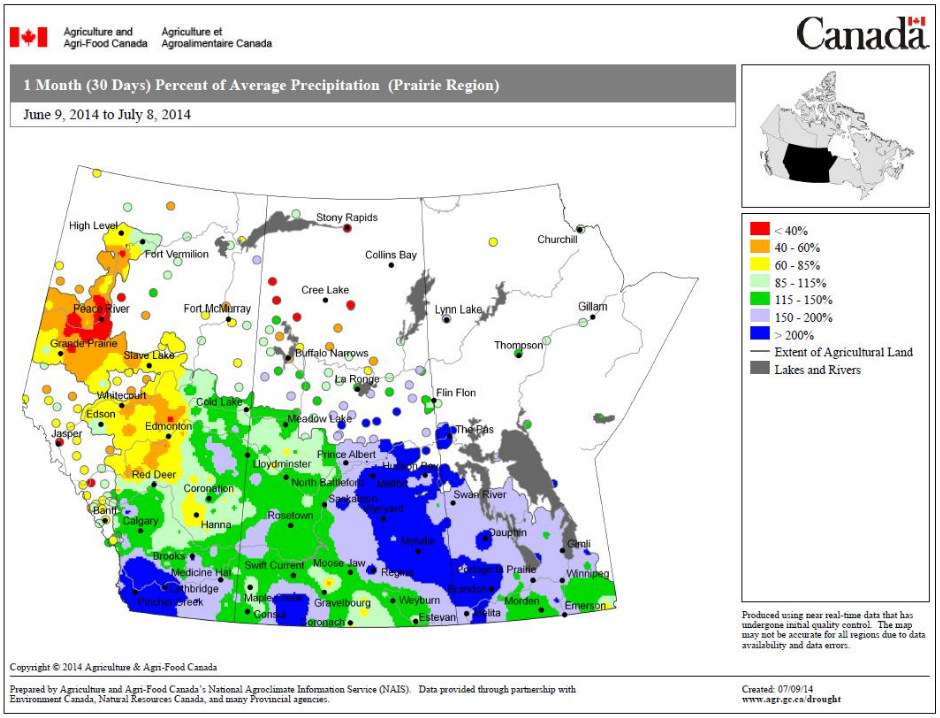

Figure 2: Percent of Average Precipitation Recorded over the Prairie Region from June 9th to July 8th, 2014

1.2 Background of Flood Event and Area Characteristics

1.2.1 Southwest Manitoba Region Characteristics

1.2.1.1 Predominant Industries

The predominant industries in the southwest corner of Manitoba are agriculture and, particularly in recent years, oil production. The southwest flood affected an area bordered by the United States to the south, Saskatchewan to the west, PTH 83 to the east and the TransCanada Highway 1 to the north. Provincial Trunk Highways (PTH) 2, 3, and 83 are strategic shipping routes in the areas; PTH 83 links Canada to United States, as well as being a key North – South highway corridor in the southwest corner of the province, and PTH 2 & 3 are main West – East shipping routes in southwest Manitoba.

1.2.1.2 Structure Inventory in Southwest Flood Affected Area

Over 100 structures were affected by the 2014 summer flash flooding in Manitoba. The predominant structure types on the Souris River tributary waterway crossings, in MIT's structure inventory, are:

1. Timber Bridges – timber pile bent substructures with structural timber caps, timber stringers and nail laminated timber decking
2. Structural Plate Steel Culverts
3. Reinforced Cast in Place Concrete Box Culverts – closed bottom concrete culverts with concrete cutoff walls, head walls and wing walls
4. Reinforced Cast in Place Concrete Arch Bridges on Spread Footings
5. Precast Pre-stressed Concrete Channel Girder Bridges – steel h pile bents and steel caps
6. Precast Pre-Stressed Concrete Box Girder Bridges with Piled Foundations and Reinforced Concrete Abutments

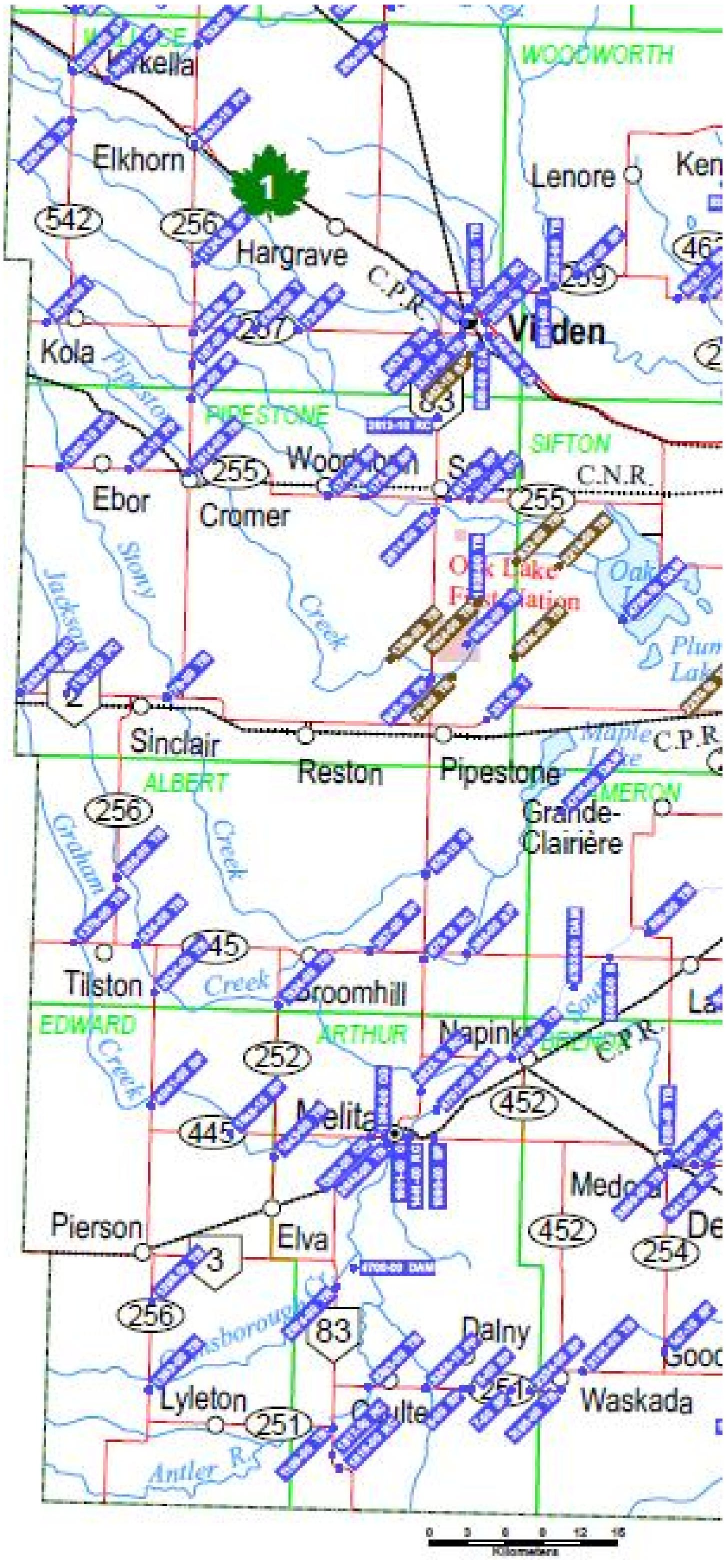

Figure 3: Map Section of Southwest Manitoba Souris River Tributaries Flood Affected Areas, Showing Geographic Location and Distribution of MIT Structure Sites

1.2.1.3 Southwest Region Waterways Affected by 2014 Summer Flooding

The waterways most affected by the 2014 summer flooding were the Souris River tributary waterways and the Assiniboine River. 26 Assiniboine River bridge sites, from Shellmouth Dam near Russell, MB, to the Portage Diversion, near Portage la Prairie, MB, were also affected by the 2014 summer flooding however due to extensive rip rap (stone) armouring completing before and after the 2011 spring flood, flood response at these sites was predominantly limited to routine bridge monitoring, with the notable exception of PTH 41 over the Assiniboine River near St. Lazare, MB, where a pier footing was undermined and an abutment embankment was compromised due to slope instability. As the flow was too high to fully ascertain the extent of the undermining damage at the PTH 41 site, a temporary load restriction of 10 tonnes was placed on the bridge. The load restriction was increased to a single lane 39.5 tonne rating after the channel cross-section could be confirmed and a loading rating analysis was completed.

2.0 2014 Southwest Region Flood Response

2.1 MIT Inspections and Maintenance Initial Inspections and Site Assessments for Southwest Region

MIT Bridge Inspections and Maintenance staff were notified of the washout at the first affected structure at PTH 83 over Gopher Creek the afternoon of June 29th and mobilized onto site that evening. This was the first road closure in the southwest area of Manitoba in 2014 as flows had washed out the approach embankments. After a remedial repair plan was determined at the PTH 83 over Gopher Creek site, MIT personnel (one, two-man inspection team at this time) reviewed other major structures in the area to determine if there was any impact on them; this review was completed until late evening and no other issues were noted.

During June 29th and 30th, portions of the TransCanada Highway near Virden were closed due to being overtopped by water. On the morning of June 30th, several calls were received by MIT Bridge Inspection and Maintenance personnel from MIT Roadway Maintenance staff stating that the majority of the 100 + structures in the southwest area had been significantly impacted by flows, literally over night, and extensive portions of the roadway network were closed. Four additional MIT bridge inspection teams and four MIT maintenance teams were immediately mobilized to the flood affected areas to assist with flood inspection and repair activities.

For the Souris River tributary waterways, the overall flood event in the southwest corner of Manitoba occurred, peaked and began to recede from June 29th to July 3rd. By the end of peak flows, 19 structures had collapsed or were irreparably damaged and 45 - 50 structures required significant backfilling and other remedial works. The majority of the remedial works consisted of the restoration of the approach embankments and scour protection at the affected sites, however several sites would require significant remedial works to be completed on them prior to being able to be re-opened.

Flow in the affected southwest flood areas peaked between June 29th to July 2nd dependant on the waterway. These flows were unprecedented and significantly higher than previous historic peak flows; scour protection around the structure foundations and the existing hydraulic openings were insufficient and could not pass the flow under the existing structures. At culverts sites, significant differential head formed, from the inlets to outlets, due to the barrel sizes being much smaller than required to pass the new peak flows.

During the first week of the flood response, MIT's objective was to initially assess all the impacted structures in the areas, determine the level of damage incurred and monitor the structures until the peak flows subsided. During the second week of the flood response, MIT began formally assessing the damages and developing work plans for each of the affected structures. MIT also began remedial repair works by the end of the first week and into the second week.

Upon initial assessment of the impacted bridges, sites that had severe washout behind the abutment backwalls were generally restricted to 10 tonnes if embedded piling depths could be determined or conservatively estimated. A 10 tonne load restriction was deemed by MIT to be conservative and would still permit passenger and emergency vehicle traffic to access flood impacted areas, lessening the possibility of resident evacuation. Structures with a 10 tonne load restriction were monitored regularly until further analysis could be completed and it could be seen that this level of traffic loading was not negatively impacting the structures. 5 tonne bridge loading restrictions were used on a temporary, emergency measure on key highways, such as PTH 83, to prevent resident evacuation.

On these smaller watersheds, the impact of the rain event and the subsequent run-off, as well as the existing saturated soil conditions, caused flooding to occur in a flash nature versus flooding experienced during spring runoff in Manitoba, where flows generally peak more gradually. The majority of any preventative measures were unable to be completed prior to the unprecedented peak flows and flood response work by MIT personnel had to be completed on a predominantly reactive basis. The record flows also created high water velocities, causing extensive erosion at the bridge and culvert sites in the affected area.

MIT Bridge Inspection and Maintenance personnel would remain in the area actively completing structure inspections, assessments and repairs for 27 straight days to regain critical access in the region and collect information to be used in the flood recovery stage.

2.2 Impact on Roadway Users in the Manitoba Southwest Region

The Manitoba Southwest region was severely impacted from the start of flood flows on June 29th until July 26th, 2014, when the majority of key, urgent remedial repair works were completed. The following summarizes the general impact to the southwest Manitoba region as a result of the flooding, based on time:

1. June 29th to July 4th, 2014: the majority of roads (both provincial and municipal) in the area were closed due to bridge structure and roadway damage, including main strategic shipping routes in the area; PTH 83, PTH 2, PTH 3 and PR 256. MIT would initially assess all structures in the area to determine the impact that peak flows had on them.
2. July 4th to 11th, 2014: structures that were assessed to be repairable had work commenced on them. Roadway usage in the area was still very limited for local residents and stakeholders. Access could only be gained at a select number of crossings and travel times were significantly increased. All timber bridges that had embankment washouts where the remaining piling depth / capacity were required to be assessed, were restricted to a 10 tonne load limit. The majority of structures in the area had withstood flood water damages to various degrees and either repair work or further assessment was still required. As a temporary and conservative measure, MIT implemented blanket 10 tonne load restrictions on all roads in the affected area until bridge repairs and assessments could be completed.
3. July 12th to 19th, 2014: 10 tonne restricted loading was reopened at the majority of sites in the area as the majority of remedial repairs had been completed but assessment of sites was still underway; key repair works such as remedial pile bent installation were in progress of being constructed at five sites.
4. July 19th to July 26th, 2014: all key sites on PTH 83, 2 and 3 were reopened to legal loading (typical only for a single lane over the bridges structures) and secondary roads were opened to single lane legal loading.

3.0 2014 Flooding on Assiniboine River

On July 4th, 2014, the Manitoba government declared a Provincial State of Emergency to allow the Portage Diversion dike raising and Assiniboine River dike reinforcing emergency work and formally requested Canadian Forces support for the flood response. Flows and water levels on the Assiniboine River rose to approach and meet 1976 and 2011 levels, which are the floods of record for the Assiniboine River system (depending on the river section) in a matter of days.

On July 5th, Manitoba government expanded the area that the Provincial State of Emergency covered to include, similar as in 2011, provision to activate a controlled release at the Hoop and Holler Bend on PR 331, should a release be required to prevent a breach along the Assiniboine River dikes. Flows on the Assiniboine River at the Portage Reservoir first crested on July 10th, 2014. On July 12th, 2014 the Manitoba government provided an updated forecast for the second crest on the Assiniboine River at the Portage Diversion advising that the second crest would be of similar magnitude to the first crest. Flows of 52,000 to 53,000 cubic feet per second (cfs) were expected between July 14th and 15th, assuming ideal weather. Record-breaking flows of 38,700 cfs were recorded in Brandon on July 12th.

Although a large amount of flood protection works were completed along the Assiniboine River system as a result of the 2011 flood, the summer 2014 flood response required a substantial amount of flood protection response including:

1. Temporary diking along PTH 110, eastern access into Brandon, and PR 457 (road between the community of Shilo, MB (location of Canadian Forces Base Shilo) and Brandon, MB
    a. PTH 110: 800 m long temporary clay dyke; 8000 m^3 clay used in construction and dike held back 0.5 m depth of water
    b. 1000 m long temporary Hesco barrier dike; dike held back ~1.0 m depth of water
2. Temporarily increasing channel wall height along the Portage Diversion channel to allow re-routing of flow away from Portage La Prairie and Winnipeg into Lake Manitoba and reinforcing the dikes along the Assiniboine River between Portage La Prairie and Winnipeg:
    a. Work was completed in under one week
    b. 18 contractors worked on the dike raising and reinforcing, using a combined 150 + pieces of earth moving machinery
    c. The total equipment cost for this work was approximately $7.2 million
    d. Dike raising work was predominantly completed with borrow material and $0.5 million in other material was purchased for the dike raising / reinforcing works (rip rap stone and other granular materials)
    e. Dike raising work was completed on approximately 13 km length of the Portage Diversion

MIT Bridge Inspection personnel completed daily flood inspections at each of the 26 affected Assiniboine River bridges and monitored the water levels on sites from Shellmouth Reservoir at Lake of the Prairies, near Russell, MB, to the Portage Diversion, near Portage La Prairie, MB. These inspections and monitoring were completed from July 2nd to several days after the second crest passed Portage La Prairie and as water levels dropped, the structures were assessed for damage as well as changes to stream bottom profile.

4.0 Southwest Flood Affected Structure Assessments

4.1 Predominant Soil Types

4.1.1 General

The deposits above the Escarpment in southwestern Manitoba are highly variable. In the vicinity of Melita, Manitoba, west of the Souris River valley, much of the surficial soil is comprised of various sediments deposited in glacial Lake Souris. This deposit varies from glacio-lacustrine clay at the southern extent of the Lake Souris basin (located in North Dakota), to highly erodible shale-rich sands toward the northern extent (located in Manitoba). Northwest of Melita, surficial soils are largely comprised of glacio-fluvial sand and gravel deposits, through which many of the tributaries to the present day Souris River flow.

The valley walls of the Souris River, as well as many of the tributary watercourses in the vicinity of the Souris River, are comprised of highly erodible alluvial sediments of various origins. The surficial deposits in the region are underlain by shale-rich till or interglacial sediment deposits of various thickness, which overlay the Odanah member of the Pierre shale formation.

Figure 4: (top photo) Emergency Dike Raising Works Completed at the Portage Diversion During the 1st Week of July 2014, (bottom photos) Trans Canada Highway Bridges over Portage Diversion, Showing Water Level Difference Between 2014 Flooding (left) and Typical Summer Water Levels (right)

4.1.2 Observations in Southwest Flood Affected Area

The soil in the areas of the flood affected bridge and culvert sites was noted to be highly erodible and the erosion typically occurred down to the underlying shale where it then "spread out." The erodibility of these soils resulted in significant embankment and scour damage at the affected bridge and culvert sites.

4.2 Post Peak Flood Flow Inspection and Determination of Remedial Work Requirements

MIT implemented a repair and recovery plan immediately after the flood waters receeded. The plan entailed the following items of work:

1. Inspection of All MIT Structures in Affected Southwest Region
    a. As early as safely possibly, MIT began the task of assessing the flood impacted structures in the southwest region
    b. All structures in the area were inspected as flow levels reached historic peaks for nearly all waterways in the southwest region.
    c. Inspections were visual and also included streambed depth measurements; using sonar and probing equipment, channel cross-sections were measured to assess the impact flooding had on pile embedment, determining whether spread footing foundations had been undermined and checking if flood waters had caused voids to form under the approach roadways
    d. MIT developed a standardized inspection format to; assess the critical components of the structures (embankments, piling, hydraulic opening, and structural components), record inspection findings and provide recommendations on action to be taken for each affected structure, including structure closure, load / lane restrictions, rip rap backfilling and armouring, grout injection for minor undermining and installation of remedial support steel h-pile bents.
    e. 40 + post peak flow inspections were completed on structures in the southwest region by MIT Bridge Inspection personnel over the course of a week; these inspections were completed concurrently with other inspection teams monitoring peak flows on the Assiniboine River and Souris River.
    f. Structures were initially assessed to determine their competency after peak flows to determine what routes could be used based on damage incurred from flooding and information was also collected regarding the high water levels observed at the site for future hydraulic design information.
    g. As time was of the essence to re-open the affected roadway, inspections were completed as water levels were receding which added to the challenge of assessing the structures and several structures had to be re-visited as water levels lowered (as components could not be seen) to ensure all critical information was collected
    h. Access for the inspections was gained using chest waders (when flows were at a safe level to enter water) and by boat on deeper / faster moving waterways
2. Based on the inspection findings and observations, determination of whether a bridge site could be safely re-opened to full traffic in a short period of time (2 weeks or less) was made
3. If a structure could be re-opened in a short period of time, works required to reopen the structure were determined that were comprised of one or a combination of the following methods:
    a. Load Restriction / Restricting Traffic Usage at Sites
        i. The emergent nature of the flood event and number of impacted sites required MIT to make conservative assumptions with respect to load capacity of bridge sites with embankment washouts, erosion around piling and undermining of support footings
            1. Load posting signage was setup at affected sites, however overweight vehicles still continued using roadways as the overall road network in the region had extensive closures and, at some points in time, could only be accessed over one bridge
                a. To permit only passenger and emergency vehicles to cross sites, concrete barriers were placed in a zig zag arrangement to prevent non-permitted loads from crossing load restricted bridges; this was accomplished by forcing traffic entering the sites to make tight radius turns around the barrier arrangments, preventing vehicles with long wheel bases and hauling trailers from crossing damaged structures.

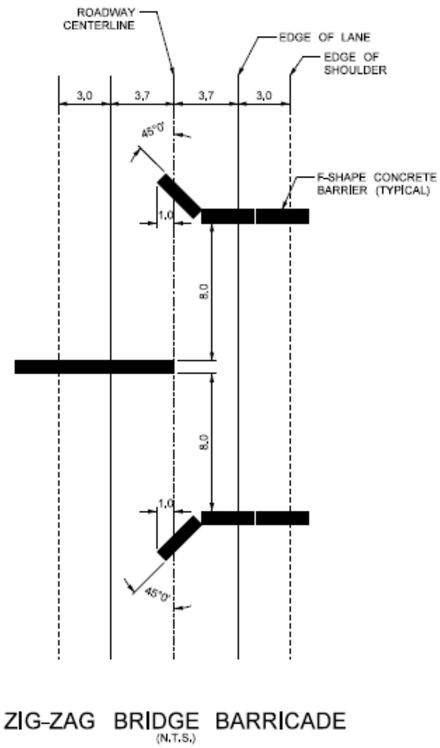

Figure 5: Precast Concrete Barrier "Zig Zag" Barricade Traffic Control Plan, Used to Prevent Overweight Vehicles from Crossing Restricted Structures During Flood Response and Recovery

b. Rip Rap Backfilling
   i. Several sites were observed to have roadway embankment damage behind the backwalls but were otherwise noted to be in satisfactory condition to be reopened.
   ii. Rip rap backfilling was selected as the repair option of choice, for many flood damaged sites, for several reasons:
      1. Significantly higher than normal summer water levels and velocities did not permit granular backfilling
      2. Repairs could begin as soon as possible after flows began to recede due to large size and non erodible nature of material
      3. Rip rap backfill would prevent future washout damage (typically rip rap was minimum 300 mm diameter particle size)
   iii. Rip rap back fill was placed to a level slightly above the water surface and the remaing embankment height was rebuilt with granular material to make the road passable upon completion of the repair work
   iv. While successful in rapidly reopening the roadway, it was noted that due to the large size of the rip rap backfill, the repair areas required monitoring and regular maintaining / patching of the granular surface to make roadway surface passable as the rip rap and granular material settled under traffic loading.
   v. Due to both the required depth of repair fill behind abutment backwalls and wingwalls, as well as the loss of pile embedment, this repair plan imposed a moment on the piling and, in some instances, caused undue stress and timber piling splitting / crushing.

c. Remedial Bent Supports
    i. Structures on key routes with very severe erosion around piling and / or undermining of support footings were determined to require remedial steel pile bent supports to be installed.
    ii. Emergent pile bent installation were completed to re-gain single lane full legal loading on key structures impacted by the flood.
    iii. Three contractors were retained to complete the pile driving works; remedial bent works were completed at five sites, with a total of 18 bents installed in under two weeks.

d. Temporary Bridge Installation
    i. At a key structure on PR 257 over Bosshill Creek near Virden, a temporary steel girder bridge was installed to allow the re-establishment of single lane legal loading, due to undermining of spread footing foundations. The temporary bridge spanned longer than the existing structure and its supports bear on the approach roadway past the locations where the embankments were damaged by the flooding.

4.3 Summary of Performance and Inspection Findings from Assessments of Different Structure Types in Flood Affected Southwest Region

4.3.1 Culverts

4.3.1.1 Structural Plate Culverts

Four structural plate culverts (PR 445 over Graham Creek, PR 542 over Drain into Bosshill Creek, PR 256 over Graham Creek, and PTH 21 over a Drain near Hartney) failed and several other structural plate culverts were significantly undermined at the inlet and outlet ends. The structural plate culvert failures occurred due to the following causes:

1. Inlet uplift (buoyancy failure)
2. Embankment erosion failure
3. Saturation of the roadway embankments due to a significant head differential from the inlets to outlets
4. Tapered end treatments were not used as performance of straight, projecting culverts ends were adequate prior to the 2014 flooding
5. Insufficient scour protection
6. Composition of the roadway embankment materials

On July 1st, 2014, a culvert uplift failure at PR 542 over a Drain, near Kirkella, MB, caused a channel back up approximately 3 km in length and a head differential of approximately 4.0 m between the culvert inlet and outlet. This failure required MIT personnel to plan a contingency controlled embankment release as rapid failure of the embankment would have exacerbated the flooding in the vicinity of Elkhorn, MB, downstream of the release site and aggravated issues already encountered at other critical crossings downstream that, if destroyed, may have required evacuation of residents. MIT determined the most prudent approach was monitoring integrity of the embankment at the culvert failure site until water levels receded. The risks of implementing the contingency controlled release were determined to outweigh the benefits as artificially increasing downstream flows and risk of loosing control at release point could have significant detrimental effects.

May 22, 2008: PR 542 over Drain near Kirkella looking Upstream at Water Level During a Typical Year

July 1, 2014: PR 542 over Drain near Kirkella looking Upstream During Flooding, Note Water Level is ~ 4.0 m Higher than 2008 Photo and is Backed up for ~3 km Upstream of Failed Culvert Site

July 16, 2014: PR 542 over Drain near Kirkella, Structural Plate Culvert Inlet De-Coupled due to Uplift and Erosion

July 2, 2014: PR 256 over Graham Creek, Washed Out Structural Plate Culvert Site, Washout was ~40 metres in Length

July 2, 2014: PTH 2 over Graham Creek, Erosion Around Wingwalls and Headwall and onto Culvert Barrel at Cast in Place Concrete Box Culvert Site

July 2, 2014: PTH 2 over Jackson Creek, Embankment and Roadway Erosion Damage at Precast Culvert Site

	
September 11, 2013: PTH 83 over Jackson Creek, looking at Upstream Channel at Typical Summer Water Levels	June 30, 2014: PTH 83 over Jackson Creek, looking at Upstream Channel, Note Water Level Compared to Stream Sign and Telephone Pole in September 11, 2013 Picture

Figure 6: 2014 Southwest Flooding Culvert Photos (on pages 12 and 13)

4.3.1.2 Concrete Culverts

Several cast in place concrete box culverts performed well during the flood, passing peak flows much higher than design flows with significant differential head (approximately 4 meters), with minimal embankment erosion and inlet / outlet erosion, in comparison to the damages withstood at the structural plate culvert sites. The overall weight of the Cast in Place box concrete culverts resisted buoyancy effects and the cut-off / wing-wall / head-wall details in these culverts allowed them to withstand the flood event with minimal damage, only requiring minimal granular embankment repairs, and grout injection for localized base slab undermining and re-establishment of scour protection as required.

Examples of the performance of concrete culverts in the Manitoba 2014 flood are as follows:

1. Roadway and embankment erosion damage at PTH 2 over Graham Creek (cast in place concrete box culvert) and PTH 2 over Jackson Creek (precast concrete pipes) occurred when the culverts and roadway were overtopped and inundated during peak flows (see photos in Figure 6). However, these sites were able to be repaired in under 5 days, from the time the damage was caused to repairing the embankments with granular backfilling to reopen the road and re-establishing scour protection. A granular wearing surface was utilized on a temporary basis until final repaving could be completed.

2. PTH 83 over Jackson Creek had a ~4 m head differential from the inlet to the outlet (see photos in Figure 6); only minor embankment erosion at the inlet headwall and scouring at the inlet and outlet due to the flow turbulence occurring due to the flood event. This structure was able to remain open to normal traffic operations during the flood event and only required minimal remedial works to re-establish the embankment around the culvert and scour protection at the site.

4.3.2 Bridges

4.3.2.1 Timber Bridges

Timber bridges were the structure type that was most significantly impacted during the 2014 summer flooding in Manitoba. A number of factors created issues with this structure type during the flood event:

1. The majority of the timber bridges in the flood affected area were constructed prior to 1970, (timber bridges being a typical and readily used structure type in Manitoba at this time). Construction equipment during this period had limited pile driving capacity compared to current piling equipment and timber piling, compared to steel or concrete piling, has piling driving depth limitations, due to the susceptibility of timber piles to be damaged during driving through hard soils. Timber piling, for structures in the flood affected area, was typically driven through the softer overlying clay down to the hard clay layer and designed as end bearing piles.
2. As piling lengths were much shorter than current design standards, undermining and erosion around timber piling supports created critical loading conditions.
3. The timber bridges in the flood affected area had insufficient scour protection (stone armouring) around the abutments, permitting peak flows to cause extensive erosion damage to the embankment backfill.
4. Hydraulic openings of the structures would have been sized to past historic flow requirements and design standards and therefore were much smaller than required to pass the 2014 peak flood flows.
5. MIT's timber bridges do not have approach slabs included in their construction that would bridge over voids formed behind the abutment backwalls which increased the risk caused by voids at abutments due to embankment erosion. In several cases, it was found by MIT Bridge Inspection personnel that flows had eroded around the wingwalls and undermined the approach roadway causing voids through the embankment that were bridged by asphalt and granular materials. These voids were only able to be seen after flows receded.
6. Roadway embankment subgrades were built with non-cohesive soils, which increased the amount and rate at which embankment erosion occurred. Also, as the predominant soil conditions in the southwest area are a soft, sandy clay overlying a hard clay-shale layer, erosion proceed downwards until it reached the harder clay layer and then spread in width causing wider erosion damage areas, requiring more extensive backfill repairs.

Although a number of MIT's timber bridges were overtopped or had water levels recorded onto the stringers, the connection details between piling / caps and caps / stringers (steel drift pins) restricted buoyancy forces and the timber bridges performed well in this regard during this flood event.

Figure 7: 2014 Southwest Flooding Timber Bridges, Example of Voids Forming Under Approach Roadways

Figure 8: 2014 Southwest Flooding Timber Bridge Photos; Examples of Approach Embankment Wash Outs Observed at Several Sites.

4.3.2.2 Reinforced Cast in Place Concrete Arch Structures on Spread Footings

Two, Reinforced Cast in Place Concrete Arch Structures on Spread Footings, both on PR 445 and crossing the Graham Creek, were constructed in the 1920s and were both inundated during the peak flood flows. Extensive foundation undermining was the cause of failure of both of these structures. In addition to high flows, meandering / migration of the river channel at these sites also increased embankment erosion and contributed to scour damage.

In addition, the PTH 83 over Gainsborough Creek Bridge (timber superstructure on concrete foundations) had two river piers on spread footings that were undermined, in addition to extensive embankment erosion and erosion around the abutments at the site, requiring the site to be temporarily closed until remedial support pile bents could be installed.

Figure 9: July 10, 2014, PR 445 over Graham Creek, One of Two Concrete Arch Structures on Spread Footings that Failed due to Scour

4.3.2.3 Precast Prestressed Concrete Channel / Box Girder Bridges

The majority of the precast prestressed concrete channel and box girder bridges in MIT's inventory in the southwest flood affected area were constructed after 1980. Improved design details, over older timber bridge designs, such as increased piling depth, additional rip rap armouring, and larger hydraulic openings led to these structures performing well overall during the flood. The only bridges of this type that were significantly affected were the PR 255 over Stony Creek bridge, which had an approach embankment wash out and the PTH 83 over Stony Creek bridge, which had undermining of the abutment, exposing approximately 0.3m of the abutment piling.

4.3.2.4 Other Inspection Observations

The flows observed during the summer 2014 flooding in the southwest region of Manitoba were definitively unprecedented; this was seen by the fact that some of the structures that were destroyed by the flood flows had been in service since the early 1920s and the southwest corner of the province (in the smaller watersheds affected by the flooding) had not been historically prone to this level or type of flooding. Also noted was that the river systems predominantly had steep walled channels that did not permit water to flow over the banks into storage areas, reducing peak flow volumes and velocities.

Based on the timeline of the flash flooding, provincial and municipal jurisdictions as well as local residents and landowners, all responded to the flood event as quickly as possible to assist their various stakeholders in protecting towns and personal property. Decisions such as cutting roads to allow backed up water to drain, closing roadways, and implementing other flood water control measures were completed without fully consulting other affected parties. This added to the difficulty of flood response works however due to the issues and timeframes at hand as well as the number of parties involved, this is assumed by MIT to an anticipated issue in emergent flood events of this nature.

An example that illustrated this issue occurred when multiple creek flow surges occurred at the PR 257 and PTH 83 over Bosshill Creek bridges near Virden, MB, on July 1st (the cause of which is unknown to MIT) that raised water levels by approximately 2.5 meters over 45 minute periods. At the time, the access on PR 257 over Bosshill Creek was one of the remaining West –East crossings for residents West of the bridge to access Virden (which has the only major hospital facility in the area). MIT Inspections and Maintenance personnel responded finding that the approaches were undermined and traffic crossing the structure was being supported on a layer of granular base and asphalt. The bridge was closed immediately upon finding this issue and the structure was armoured with rip rap stone to attempt to prevent the structure from undermining, until flows subsided, and the structure could be assessed.

5.0 Recovery Reconstruction

5.1 General

Innovative design planning and construction procurement models were required to be implemented by MIT based on the number of structures that full replacements were determined to be required.

5.2 Design of Replacement Structures

Four engineering service providers (ESPs) were approached by MIT to complete design work for four separate, urgent replacement sites; two sites on PTH 83 (Bridges over Bosshill Creek and Gainsborough Creek), one on PTH 3 (Bridge over Graham Creek) and one on PTH 2 (Concrete Box Culvert over Stony Creek). The Manitoba Government approved a sole sourced / untendered, direct negotiated process to fast track the design assignments with ESP companies. Considerations made by MIT to increase efficiency in design stages and include area / site specific details for reconstructed structures were as follows:

1. General
    a. All impacted sites were required to maintain legal load traffic during construction; temporary ACROW bridges and corrugated steel pipe culverts (where suitable for flow) on shoo-fly detours were selected as the typical detour designs as suitable route detours were not available and staged construction (constructing half the structure at a time and leaving traffic on the existing structure in the first construction phase) would have reduced construction efficiency. The footprint of all detour construction was required to be contained to MIT's property Right of Way as the project schedule did not permit property acquisition timelines.
    b. MIT Modified AASHTO HSS 30 design live loading was specified to account for current local industry road usage (oil industry, etc.) and future loading on PTH 83, 3 and 2.
    c. Conservative hydraulic opening designs, due to limited water level and flow data available from unprecedented peak flow event, were to be implemented
2. Reinforced Cast In Place Box Culvert
    a. MIT has well developed standards for this type of structure and the ESPs were instructed to follow MIT standards as closely as possibly to expedite design work.
3. Bridges
    a. Use of standard design details, including abutment design, pier design (to the greatest extent possible), bearings, girders, deck and barrier design.
    b. Use of a standard and consistent bridge span length; bridges were designed based on most suitable number of standard span lengths, not necessarily most optimized length, so that all construction was as typical as possible
    c. Assigning the design of specific typical design components of the bridge to each of the ESPs to minimize replication of design and drafting effort.
    d. Pipe pile pier designs were used to forego cofferdam requirements in foundation construction and pier cap heights were deepened and varied to suit ice level conditions; deepening the pier caps also will assist in preventing future debris build up
    e. For the replacement of the three key bridges, implementing typical design elements was more critical than optimizing the design of bridge elements to maintain fast track design process. MIT provided a conceptual design framework to the ESPs which included the following requirements:
        i. Simple spans with exposed cast in place concrete decks
        ii. Span lengths were increased from approximately 10 meters to 25 meters, to increase hydraulic openings and minimize construction of foundations.
        iii. Structures were designed with increased vertical profile (span lengths and girder depths increased) as the underside of girder elevation would be designed to the greater elevation between either the existing structure's underside of girder elevation or July 2014 flood level elevation plus 0.3 meters
        iv. Bridges were to be reconstructed on the existing roadway alignment
        v. Standard bridge widths to maintain constant design
            1. The most recently reconstructed bridge, on MIT's regular capital program, on PTH 83 was reconstructed to 12.6 m clear roadway width and therefore MIT elected to make all the reconstructed bridges 12.6 m clear roadway width to have all structures on this highway corridor match
    f. Construction schedules were to be developed to have traffic on new structures by summer / fall 2015; the overall project duration will be 12 months from the flood event occurring, completion of preliminary design, detailed design and construction of new bridges
    g. Abutments were to be armoured with Class 600 rip rap (maximum particle size 600 mm diameter) to 900 mm thickness to avoid future approach washouts in flood events

4. Future Years Structure Reconstruction
    a. MIT is tentatively proposing to reconstruct seven new bridges in their 2015/16 fiscal year and six new bridges in their 2016/17 fiscal year. These structures are predominantly precast prestressed concrete channel girder bridges on the secondary, Provincial Roads network.

Figure 9: Aerial View of the PTH 83 over Gainsborough Creek Replacement Bridge During Construction, April 2015

5.3 Construction of Replacement Structures

MIT retained four different general bridge contractors by direct negotiation for the replacement of the four key structures on PTH 2, 3, and 83 as re-opening these roadways to two lane legal loading was paramount and time was of the essence to complete the construction of these key structures. This was the first time MIT completed sole sourced, direct negotiation with a contractor for full bridge reconstruction. At the time of preparing this paper, the projects are all on schedule and on budget. The key factors involved with the direct negotiation were:

1. Approval from the Manitoba Government was required to procure contractor services as this type of procurement was unprecedented for MIT
2. Justifying direct negotiation prices to other recent MIT projects of similar scope / location and overall historical square meter prices for recently constructed similar structure types through competitive tendering process.
3. MIT has extensive contract administration experience; the majority (over 90% +) of contract administration on their bridge inventory infrastructure has been completed by MIT personnel, giving MIT personnel considerable knowledge on construction costing.
4. Fixed project costs were set at time of negotiation and the agreements were set with a final construction cost indicated

6.0 Conclusions

The 2014 Flood Response in Manitoba was a significant impact to Manitoba's bridge and roadway infrastructure. Several lessons were learned by MIT's bridge personnel as follows:

1. Tributary river system flooding can have wide spread and significant effects on bridge infrastructure
2. The ability of MIT's experienced internal personnel being able to respond immediately to this type of event was invaluable in terms of preventing as much damage as possible, collecting appropriate data in a timely manner, and continuing to gain knowledge with respect to bridge flood response inspection
3. The methods employed by MIT Bridge Inspection personnel (experienced inspection teams completing visual inspection, stream bottom soundings and sonar measurements for scour determination) are all effective means for assessing flood damage however further investigation is always being completed by MIT to determine methods that may improve flood monitoring and response.
4. Structure details must be thoroughly considered, with respect to: foundation type (piled vs. spread footings and piling material), hydraulic opening and scour protection if there is any chance that they will be affected by flood flows during their service life; additional construction costs for these items typically are recouped by infrastructure owners when their structures are able to withstand higher than design flow levels
5. Knowledge of flood areas, such as soil types, typical structures and construction details and the nature of channels (wall steepness, meandering versus straight) and foundation depths / pile driving records are critical to have on hand during flood response inspections
6. Emergent pile bent installation was able to be completed quickly and was an effective and efficient remedial measure to regain legal loading on key structures in southwest region.
7. Sole source / direct negotiation with ESPs and bridge contractors expedited project schedules and will permit full traffic loading on reconstructed structures in approximately one year from the time of the flood event; by completing the project in this manner, it condensed MIT's typical project planning and construction timelines from two to three years down to one year and only construction methods and design details with proven performance history in MIT's structure inventory were implemented in the reconstruction plans.

7.0 Acknowledgements

The authors would like to thank the following groups for their involvement with this project:

MIT Preservation & Planning and Design & Construction staff involved with the flood response and recovery stages; MIT Regional Maintenance Staff from Virden, Pipestone and Melita yards; MIT Region 2 and 3 engineering staff; your efforts are all greatly appreciated for the roles you played in this flood event and will continue to play moving forward as recovery work continues.

The authors would also like to thank the Winnipeg offices of Dillon Consulting, MMM Group, Tetratech, Stantec Consulting for their efforts in the fast tracked, collaborative design process, all the local truck hauling and heavy equipment companies who assisted with initial flood response works in the southwest region and at the Portage Diversion; ArmCon Construction, Trottier Piling and Preset Piling for their efforts and response on the remedial pile bent works; Vector Construction for their work on the PTH 83 at Stony Creek repairs; Gateway Construction and Engineering, Graham Construction, PCL Construction, MD Steele, and Montcrief Construction for their efforts and quality work on the re-construction of the four key structures in southwest Manitoba.

8.0 References

Manitoba Infrastructure and Transportation (MIT) Emergency Measures Organization, *Disaster Financial Assistance – Order in Council Request on June 27 to 30, 2014, Heavy Rains*, May 2015

Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, Manitoba GIS Map Gallery

Geographic Information System, *Surficial Geology Compilation Map Series (SGCMS)* [online][viewed April 22, 2015] http://www.gov.mb.ca/iem/geo/gis/surfgeomap.html

Agri-Culture and Agri-Foods Canada, *Precipitation Maps* [online][viewed July 9, 2014] www.agr.gc.ca/drought