Lehigh Comprehensive Flood Mitigation Analysis Report

Drumheller Flood Mitigation
Lehigh, AB
Project # CW238408

Prepared for:

Drumheller Resiliency & Flood Mitigation Office
224 Centre Street
Drumheller, AB TOJ 0Y4

Prepared by:

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31 January 2022

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Executive Summary

Objective

This report was completed for the Drumheller Resiliency & Flood Mitigation Office (DRFMO) and contains the results of the Lehigh comprehensive flood mitigation analysis, which assesses Red Deer River surface water and groundwater flood risks and potential mitigation works.

Detailed hydrogeologic investigations and analyses were conducted as part of this study to better define the extent of groundwater related flooding.

In addition, potential flood mitigation measures such as channel widening and dredging were assessed. Northwest Hydraulic Consultants (NHC) recently completed (NHC 2020a, NHC 2020b) the Drumheller flood hazard studies and undertook the surface water component for this comprehensive study.

This report provides an overview evaluation of structural and non-structural flood mitigation measures investigated based on the findings of the above noted hydrogeologic and channel conveyance studies. The study builds upon the recent work conducted by The Government of Alberta (GOA) for the Drumheller Flood Study which contains a detailed assessment of flood risk, including flood maps that identify where water will flow during a flood and what land could be flooded for different sized floods.

Site Description

Lehigh is on the north bank of the Red Deer River, approximately 21 km east of downtown Drumheller. Lehigh experienced flooding in both 2005 and 2013 and both events required emergency temporary diking and evacuation orders. Geotechnical and seepage issues are significant due to the permeability of the soils. Currently there are no existing dikes protecting the community. There are approximately twenty properties that are located in Lehigh and the land use varies from agricultural to residential. Many of the Lehigh residences are manufactured homes that do not have basements. The typical ground elevation at the residences varies from 675.0 m to 675.5 m (geodetic elevation). The design flood for the DRFMO studies is 1,850 m^3/s and the associated typical flood levels in Lehigh vary from 676.6 m to 676.7 m.

Flood Risk Profile

Most of the community of Lehigh is located in the floodway of the Red Deer River. The floodway is defined as the portion of the flood hazard area where flows are deepest, fastest and most destructive. The floodway typically includes the main channel of a stream and a portion of the adjacent overbank area. New development is typically not permitted in the floodway. Water depths in the floodway are 1 m or greater. In comparison, the design flood for the DRFMO studies is 1,850 m^3/s and the associated typical flood depths in Lehigh vary from 1.1 to 1.7 m.

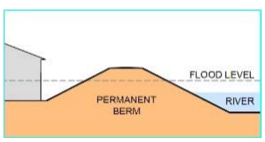
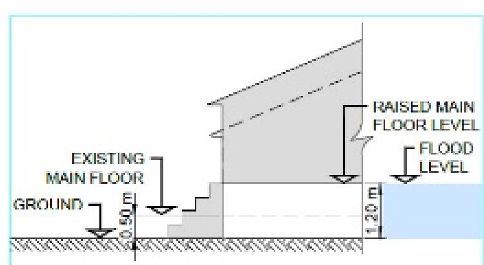
Alberta Environment & Parks (AEP) has produced a draft flood likelihood map for the community of Lehigh (https://floods.alberta.ca/), which illustrates the cumulative flood risk over 30 years. Different sized floods can occur any year, but smaller floods tend to occur more often than larger floods over time. The flood likelihood zone delineation for Lehigh (west and south of Highway 10) indicates a 78.5% to 100% likelihood of flooding in 30 years (depending on location).

Based on the above the Lehigh flood risk profile is rated as high.

Summary of Flood Conveyance Improvements and Flood Barrier Measures

The table below contains an evaluation summary of Flood Conveyance Improvements and Flood Barrier Measures – Structural Measures.

Table ES1: Evaluation Summary – Structural Measures

Mitigation Measure	Discussion
1) Conveyance Improvement Evaluated increasing the channel capacity by up to 35% through the removal of channel bed and bank material over a channel length of up to 290 m.  	Measures such as channel dredging, widening and straightening are not effective flood mitigation measures as they have minimal impacts on reducing (in the order of 0.1 m) flood levels, as compared with the expected depth of flooding of 1.1 to 1.7 m in the community. Additionally, these measures have numerous issues as noted below. Given the challenges of carrying out such work and the limited impact on water levels, conveyance improvement is not an effective flood mitigation measure. • Removing sediment has adverse impacts to aquatic habitat over a relatively large instream footprint, resulting in disturbances to fish resting and spawning areas and increased instream suspended sediment loads. Hence, it may not be possible to obtain environmental regulatory approvals. • The effects of dredging are often short lived, as sediment deposition will continue to occur, and routine maintenance dredging would be required.
2) Permanent Berm Berm would be 1,250 m in length with an average height of 3 m.  	In Lehigh, the subsurface (i.e., ground) conditions are more permeable than other locations in Drumheller, which results in a greater degree of seepage occurring at a lesser magnitude and more frequent flood event. These seepage issues are a concern for flood mitigation solutions such as berms because when river levels rise the groundwater level behind the berm also rises. These greater seepage impacts greatly reduce the effectiveness of a Lehigh dike and the structure does not adequately protect residents from flooding. This measure has a benefit-cost ratio of less than one and the GOA only funds projects with a ratio greater than one.
3) Temporary Berm or Barriers Placed in advance of flood conditions, Temporary measures could include temporary fill placement/sandbags.	Temporary berms would be subject to similar constraints on effectiveness as the permanent berm. The scale required for the entire community of Lehigh is not feasible within the expected time available between notifications of the flood and the peak flow. The Town would not have adequate resources to construct temporary barriers in Lehigh.
4) Raising Residential Involves raising houses and critical utilities (e.g., electrical/ mechanical) above the design flood.	• No funding currently available for this measure. • Risk to public safety remains. This includes the potential for injuries and fatalities for citizens and emergency responders. • Infrastructure/properties are still susceptible to damage during flood events. • These types of measures have significant issues with respect to public safety, costs, accessibility and zoning/bylaw changes. 

The table below contains an evaluation summary of Non-Structural Measures for flood mitigation.

Table ES2: Evaluation Summary – Non-Structural Measures

Mitigation Measure	Discussion
5) Buyouts	• Provincial and federal funding currently available for this measure • Purchase of properties and moving or demolition of buildings • Removes flood impact risk
6) Land Zoning and Status Quo	• The community is zoned as floodway by AEP and Flood Conveyance Zone under the Town of Drumheller Land Use Bylaw, which does not allow for new development. • The rules for Disaster Recovery Program (DRP) funding have been revised such that there will only be one DRP claim allowed for each property. Damages resulting from subsequent DRP claims would not be allowed and this applies in perpetuity for the future owners as well as current owners. This could result in a liability to the property owner and possibly the Town if future owners are unable to make a DRP claim because it had been applied previously. • DRP funding is only available for "extraordinary" events, which are typically defined as those equal to or greater than the 1:100- year return period flood. Funding would not be available for lesser magnitude floods (e.g., 2005, 2013) that result in flooding of the community. • In considering the status quo, it is important to note that not only is there a high risk of flood damages to property, but it also poses a risk to public and first responder safety. This includes the potential for injuries and fatalities.

Future Steps

At this time, based on the Comprehensive Flood Mitigation Analysis study, a full buyout of the community of Lehigh was deemed to be the best solution to mitigate future flood impacts to people and property. It is recommended that the Flood Mitigation Office meets with Lehigh residents to discuss next steps in the buyout process and determine what supports will be needed.

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List of Acronyms and Abbreviations

AEP	Alberta Environment & Parks
DRFMO	Drumheller Resiliency and Flood Mitigation Office
GOA	Government of Alberta
NHC	Northwest Hydraulic Consultants

1.0 Introduction

The Drumheller Resiliency & Flood Mitigation Office (DRFMO) retained Wood Environment & Infrastructure Solutions (Wood) to undertake a comprehensive flood mitigation analysis at Lehigh, which assesses Red Deer River surface water and groundwater flood risks and potential mitigation works. The results of which are contained in this report.

Based on the current Government of Alberta (GoA) flood hazard maps, Lehigh is located entirely within the Red Deer River floodway and is not currently protected by dikes. Wood (March 2021) completed a conceptual level design report of flood mitigation works which included hydrogeologic (groundwater) and geotechnical investigations and analyses. This previous hydrogeologic analyses indicates that sub-surface flooding would occur behind a dike if one were to be constructed. However, this previous study may have underestimated the extent of groundwater related flooding, based on anecdotal evidence of previous floods and the pervious nature of the sub-surface materials (i.e., gravels and sands). Further hydrogeologic investigations and analyses were conducted as part of this study to better define the extent of groundwater related flooding.

In addition, this comprehensive report contains an assessment of potential flood mitigation measures such as channel widening and dredging. Northwest Hydraulic Consultants (NHC) recently completed the Drumheller flood hazard studies (NHC 2020a, NHC 2020b) and undertook the surface water component for this comprehensive study (NHC 2021). Wood undertook the dike design and hydrogeological component of the study.

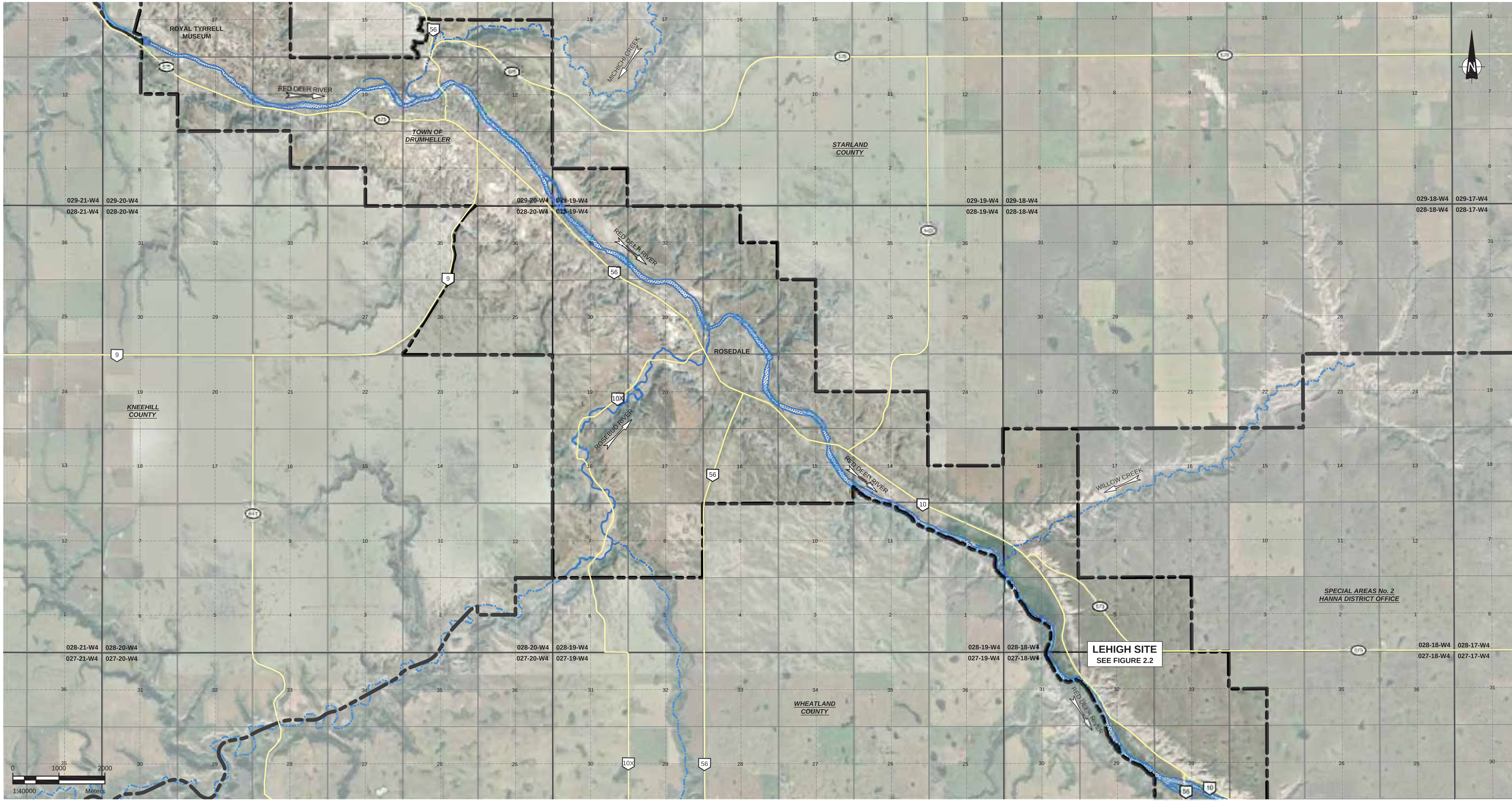
This report provides an overview evaluation of structural and non-structural flood mitigation measures based on the findings of the above noted hydrogeologic and channel conveyance studies. Floodplain management measures that are typically considered are listed below. The first three items are structural measures and the remaining are non-structural:

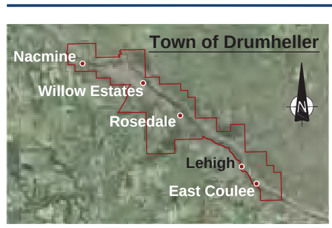
- Permanent flood mitigation structures such as dikes;
- Temporary dikes or barriers constructed in advance of flood condtions;
- Raising structures by using methods such as raising the local grade;
- Buyouts and removal of existing structures; and
- Land zoning and planning policies that direct development away from flood hazard areas.

2.0 Site Description

Lehigh is on the north bank of the Red Deer River, approximately 21 km east of downtown Drumheller, as shown on **Figure 2-1**. Lehigh experienced flooding in both 2005 and 2013 and both events required emergency temporary diking and evacuation orders. Geotechnical and seepage issues are significant due to the permeability of the soils. Currently there are no existing dikes protecting the community.

LEHIGH LOCATION PLAN





LEGEND:

MUNICIPAL BOUNDARIES

MAJOR ROADWAYS

Project Number: CW238408

Date: OCTOBER, 2021

wood.

DRUMHELLER RESILIENCY AND FLOOD MITIGATION PROGRAM

LEHIGH COMPREHENSIVE FLOOD MITIGATION ANALYSIS REPORT

Figure 2.1

2.1 Infrastructure

Appendix A, **Table A.1** lists miscellaneous information on the approximately twenty properties that are located in Lehigh, including, address, legal land location, lot area, type of residence and surveyed elevations (discussed in the following section). Many of the Lehigh residences are manufactured homes that do not have basements.

Select photos of the properties are contained in **Appendix B**.

2.2 Topography and Survey

Hunter Surveys completed ground truthing topographic surveys to obtain elevations of the yards and ground floors of the approximately 20 properties located in Lehigh. The Hunter survey information is listed in **Appendix A**, **Table A.1** and was used to confirm the depth of flooding at each property. The Hunter survey information supplements the GOA 2019 Lidar data that was used to characterize site topography. **Appendix A**, **Figure A.1** is a site plan showing the location of the survey information.

2.3 Hydrotechnical

A summary of Red Deer River hydrology and hydraulics is contained in the Conceptual Design Report (Wood, March 2021). **Table 2-1** lists the 'regulated' flood frequency estimates for the Red Deer River near Drumheller. The regulated flow accounts for the influence of the Dickson Dam (and the associated reservoir), which reduce flood peaks in Drumheller.

Table 2-1: Flood Frequency Estimates – Regulated (NHC, 2020a)

Recurrence Interval (Years)	Peak Instantaneous Discharge (m^3/s)
1:2	330
1:5	542
1:10	702
1:20	869
1:50	1,430
1:100	1,850
1:200	2,450

NHC undertook a study of river improvement flood mitigation measures including dredging and channel widening as part of this comprehensive study, which is contained in **Appendix C** and discussed in **Section 4.1.1** of this report.

2.4 Hydrogeology

The Lehigh hydrogeology study is contained in **Appendix D** and is discussed in **Section 4.2.1** of this report.

3.0 Flood Risk Profile

Figure 3-1 is a site plan of Lehigh that shows many of the features that are discussed below and in subsequent sections of the report. The existing floodway delineation extends from the river to Highway 10 and includes most of the community of Lehigh. Alberta Environment & Parks (https://floods.alberta.ca/) defines the floodway as:

The portion of the flood hazard area where flows are deepest, fastest and most destructive. The floodway typically includes the main channel of a stream and a portion of the adjacent overbank area. New development is typically discouraged in the floodway.

As previously noted, the existing floodway delineation extends from the river to Highway 10 and includes all of the community of Lehigh. **Appendix A**, **Table A.1** lists the grade at the house and the main floor elevation for the approximately 20 residences/buildings located in Lehigh. Also listed is the regulated return period flood event corresponding to the inundation of the ground adjacent to the residence. The properties start to flood at approximately 800 m^3/s, which corresponds to between a 1:10 and 1:20-year regulated return period flood event (**Table 2-1**).

The Red Deer River is regulated by the Dickson Dam, which is located further upstream in the watershed. The Dickson Dam provides a significant level of flood protection to the Town of Drumheller. The Red Deer River 100-year design flood flow rate was reduced from 2,260 m^3/s to the regulated discharge of 1,850 m^3/s, by taking into account the operation of Dickson Dam.

The depth of flooding adjacent to the residences, for the project design discharge of 1,850 m^3/s, typically ranges from 1.1 to 1.7 m, with a median value of 1.2 m. The flood protection dike structure that is discussed in **Section 4.2** has an average height of approximately 3 m, which is higher than the depth of flooding adjacent to the residences. This is because the dike is located adjacent to the river where the ground elevation is lower and because the dike includes a freeboard of 0.75 m above the design flood level.

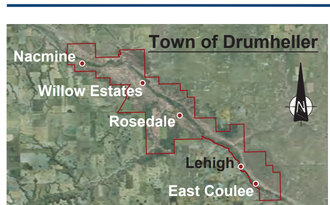
LEHIGH SITE PLAN

NOTES:

1. EXISTING GROUND CONTOURS INFORMATION WAS DERIVED FROM LIDAR (2018) AND PROVIDED BY DRFMO.
2. HIGH RESOLUTION AERIAL PHOTO FROM 2019 AND PROVIDED BY DRFMO.
3. FOR DIKE CROSS SECTIONS SEE APPENDIX E, FIG E.3.

LEGEND:

- POTENTIAL DIKE AND SWALE EXTENTS
- FLOW BOUNDARY 1850 cms
- RIVER CROSS SECTION STATION LABEL (XS XX+XXX)
- BOREHOLE
- WATER WELL



Project Number: CW238408

Date: JANUARY, 2022

DRUMHELLER RESILIENCY AND FLOOD MITIGATION PROGRAM

LEHIGH COMPREHENSIVE FLOOD MITIGATION ANALYSIS REPORT

Figure 3.1

Figure 3-2 shows the Draft Lehigh flood likelihood map (https://floods.alberta.ca/), which illustrates the cumulative flood risk over 30 years. Different sized floods can occur any year, but smaller floods tend to occur more often than larger floods over time. The following two flood likelihood zone delineations apply to Lehigh (west and south of Highway 10): (1) the darker blue zone closer to the river delineates that area that has a 95.8% to 100% likelihood of flooding in 30 years; and (2) the lighter blue zone further from the river delineates that area that has a 78.5% likelihood of flooding in 30 years. **Figure 3-2** is based on the Draft Drumheller Flood Risk Mapping Study, NHC (2020), which shows naturalized flows rather than the regulated flows adapted for the Drumheller Flood Mitigation Works. Although the regulated data sets may result in some change of the above noted likelihood percentages, the general finding is that the Lehigh flood risk profile is high.

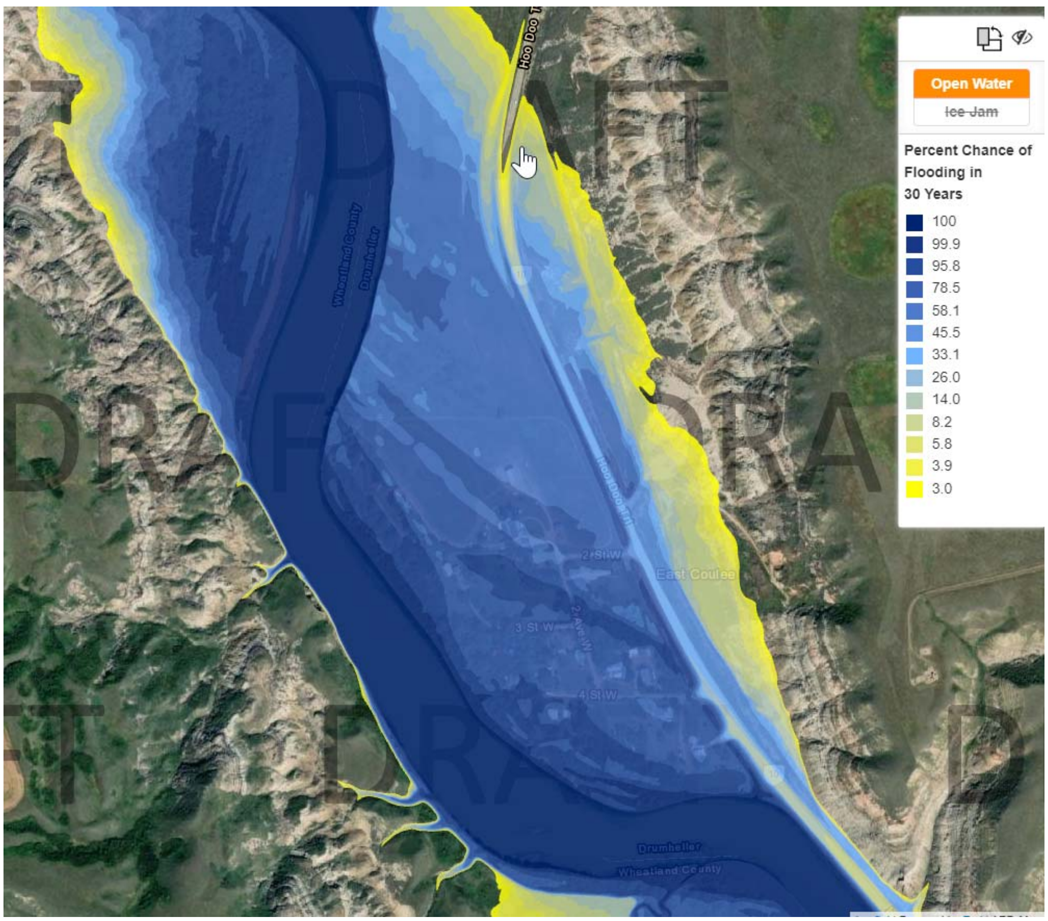


Figure 3-2: Lehigh Flood Likelihood Map

Additionally, the NHC hydrotechnical assessment, contained in **Appendix C**, contains the following commentary on Lehigh flooding:

- A series of spurs were constructed in 1992 along the left bank of the river between Lehigh and East Coulee to protect the highway embankment. These structures appear to have functioned as designed, stabilizing the river bank and promoting bed scour near the tips of each structure. Upstream water levels are not expected to be affected by the spurs during a flood event.

- The two largest recorded flood events occurred in 1901 and 1915. While no definite indication of magnitude could be found for the 1901 flood, the 1915 flood had an estimated instantaneous discharge of 2,020 m^3/s. Two other flood events were observed in 1952 (1,360 m^3/s) and 1954 (1,530 m^3/s). Two floods have occurred more recently: 2005 (1,450 m^3/s) and 2013 (1,270 m^3/s).
- Based on a comparison of the 1984 and 2018 river bed elevation profile surveys by NHC (2020c), there has been no significant change along the Drumheller reach, and some general lowering of the river bed profile was actually noted in the area of Lehigh. Channel width has tended to decrease slightly through Drumheller since 1950, largely as a result of lateral deposition and vegetation encroachment along the river. Conditions at Lehigh were observed to be consistent with trends elsewhere in the valley.

The above commentary indicates that: (1) the spurs downstream of Lehigh are not exacerbating flood conditions in Lehigh; (2) flooding in Lehigh pre-dates the spurs; and (3) Dickson Dam construction in the 1980's has not resulted in significant channel changes that would exacerbate flooding in Lehigh.

4.0 Structural Flood Mitigation Measures

Structural measures requiring construction include measures such as dredging/channel widening and permanent or temporary diking, which are discussed below.

4.1 Conveyance Improvements

NHC undertook a study of river improvement flood mitigation measures including dredging and channel widening. The NHC study is contained in **Appendix C** and the results are summarized below and are based on the NHC study and discussions with the Town. It was determined that these types of measures were not effective flood mitigation measures.

- The hydraulic model from the recently completed Drumheller River Hazard Study for AEP was modified to determine the effects of channel widening and river dredging as possible flood mitigation measures. Three scenarios were developed to quantify changes in water levels through Lehigh: (1) 10% channel widening over 290 m; (2) 30% channel widening over 290 m; and (3) dredging of the channel bottom over 240 m. The second scenario resulted in the largest reduction in water levels of between 0.09 and 0.12 m throughout Lehigh for the design flood, as compared with the typical expected depth of flooding of 1.1 to 1.7 m in the community of Lehigh. This scenario involved increasing the channel capacity by 12-35% through the removal of an estimated 81,800 m^3 of material. Effects also included a slight increase in water velocity throughout Lehigh of 0.04-0.08 m/s. A reduction in water level for a given flow can result in an increase in velocities.
- The model results for all mitigation scenarios show relatively small decreases in water surface elevation (or flood level) throughout Lehigh despite relatively sizable increases in channel capacity. A decrease in water level of approximately 0.1 m would not significantly reduce the flood risk or need for other structural mitigation measures. There are also practical issues to consider with channel widening or dredging in this area. The area of potential channel widening is located within Wheatland County and outside of the Town of Drumheller so

coordination with the County would be required. Additionally, access to this area is difficult as there is no road access and steep valley walls along the floodplain. Removing sediment from a watercourse would have adverse impacts to aquatic habitat over a relatively large instream footprint, such as disturbances to fish resting and spawning areas and increased suspended sediment loads in the water during instream work. Therefore, there are likely to be significant difficulties in obtaining regulatory approvals under the Alberta Water Act and Canada Fisheries Act for this type of work and it may not be possible to obtain them. There is also the challenge of finding a place to dispose of the 81,800 m^3 of excavated and dredged material that is not suitable for other flood mitigation construction purposes. It should be noted that the effects of dredging are often short lived, as sediment deposition will continue to occur and routine maintenance dredging would be required. Given the challenges of carrying out such work and the limited impact on water levels at Lehigh, neither channel widening nor dredging are considered effective flood mitigation measures for the area. Based on a very approximate unit cost for $40/$m^3$ for dredging/widening, order of magnitude construction costs for the above noted scenarios vary from $1.2 million to $3.2 million. Overall lifecycle costs would be significantly greater once engineering/regulatory approval and maintenance costs are included.

- Additionally, the 'channel straightening' measure, shown in **Figure 4-1**, was evaluated. This consists of a cutoff of the meander bend that is located between Lehigh and East Coulee. This would reduce the channel length by 226 m (from 1,595 to 1,397 m). A reduction in flood depth in the order of 0.1 m could be expected based on the design flood levels. The excavation quantities would be in the order of 750,000 m^3, which is an order of magnitude (i.e., ten times) greater than the channel widening/dredging measure discussed above. The costs associated with channel straightening would also be an order of magnitude greater than those noted above. Similar to the above noted channel dredging and widening measures, channel straightening is not an effective flood mitigation measure as it has minimal impact on reducing flood levels as well as having the associated environmental, economic and regulatory issues.

Figure 4-1: Channel Straightening Measure

4.2 Permanent Flood Mitigation Structure

An evaluation was undertaken for the feasibility of large scale, earthen embankment structure to protect Lehigh from river overland flooding. Protection of the community would require a dike structure approximately 1,250 m in length and an average height of 3 m. The structure would wrap around the community and tie into Highway 10 at both the west and east end. The Lehigh site plan **(Figure 2-1**) shows the dike footprint**.** Dike cross sections are shown on **Figure E1** and a more detailed plan/profile is shown on **Figures E2 and E3** in **Appendix E**.

4.2.1 Hydrogeologic Considerations

As discussed previously, the primary concern at Lehigh is the high permeability of the soils which could result in significant seepage under the dikes if it was constructed. **Appendix D** contains the Lehigh detailed hydrogeologic assessment. The main findings are summarized below:

- Theoretical calculations of groundwater seepage and hydraulic head changes relative to ground surface under flood conditions show that impact to residential basement structures within a distance of 105 m (shown on **Figure D1**) from the flood-dike interface can occur within two to three days of peak flooding.
- Groundwater seepage to basement structures could likely impact 10 properties (shown on **Figure D1**) located at the south and west extents of the area, including four current residences understood to include basements.
- Daylighting of seepage at ground surface could be observed within approximately 60 m of the dike.
- Seepage of groundwater to surface may occur on the eight properties that are closest to the river along the west and south extents of the community, and seepage could likely occur close to three current residential buildings.
- Minimal/no impacts would be expected in areas to the north and northeast which are sparsely developed, and/or where ground surface elevations are higher (close to 676 masl). Estimated distances of observed impacts are sensitive to uncertainty in hydraulic parameters such as hydraulic conductivity and specific yield.

Additional measures are required to deal with these seepage issues and ensure the dike is stable and effective. Potential seepage control measures include key trenches or cutoff walls. However, these types of measures are expensive and drive construction costs up substantially. Additionally, these types of measures would obstruct the local groundwater flow from draining back into the river during non-flood conditions. These types of measures may also adversely impact groundwater wells, which are closely connected to the river level. These types of seepage control measures are not recommended, given the above noted economic and technical considerations.

Flood protection dikes at other Drumheller sites (including existing structures at Newcastle/Midland and proposed structures at Nacmine and Rosedale) are not intended to prevent groundwater seepage under the dike. Some basement flooding may occur in certain locations at these other sites and is an accepted outcome. However, at Lehigh, the subsurface (i.e., ground) conditions are more permeable than these other sites, which results in a greater degree of seepage which occurs at a lesser and more frequent flood event. Additionally at Lehigh, the above noted daylighting of seepage occurs. These greater seepage impacts greatly reduce the effectiveness of a Lehigh flood protection dike.

4.2.2 Quantity and Cost Estimate

A detailed construction cost/quantity estimate for the permanent dike structure is contained in **Appendix F**. The total construction cost (including 30% contingency) is estimated to be $3,590,000. The total estimated capital cost for the permanent dike structure is $4,785,404, as summarized in **Table 4-1**.

Table 4-1: Total Estimated Capital Costs Permanent Dike Structure

Item	Estimated Cost ($)
Construction Cost (incl. 30% contingency)	$3,590,000
Engineering/Environmental/Permitting/Public & First Nations Engagement Cost (30% of Construction Cost)	$1,077,000
Land Acquisition Cost (Based on $\$10/ft^2 = \$107.64/m^2$)	$118,404
Total	$4,785,404

In comparison, the approximate total 2021 assessed value (including buildings and improvements) for the properties listed in **Table A.1** is $2,050,510. The appraised value of properties is greater than the assessed value. Based on recent data for properties appraised in Lehigh, we have assumed a 50% additional property value for an approximate appraised value of $3,075,765. This is considerably less than the total estimated permanent dike structure capital cost contained in **Table 4-1**.

Lifecycle costs for the permanent dike structure would also include Operation and Maintenance (O&M) costs, in addition to the capital costs listed in **Table 4-1**. Lifecycle costs were estimated based on the following assumptions:

- A 50-year evaluation period was selected for estimating the lifecycle cost. This duration is often selected for the long-term evaluation of engineering works of this kind. Although, the structure would be expected to have a longer lifespan, major upgrades/repairs may be required after such a period. We have assumed more typical repairs that would be undertaken annually (e.g., inspection, grass trimming/vegetation control), or every few years (e.g., replacement of any displaced riprap, repair of any minor soil displacement/cracking, re-seeding, replacement of vegetation, etc.).
- We have estimated an annual O&M value of 3 percent of the total construction cost, or a value of $10,770 in today's dollars.
- A Net Present Value (NPV) cost analysis is required to obtain the long-term O&M costs. NPV is a standard economic method for evaluating long-term projects. It takes into account future costs which occur over a defined evaluation period. The future costs are discounted or adjusted to take into account the uncertainty and time value of money (i.e., inflation). The

NPV of the cost is calculated by using the average annual O&M cost (estimated above) over the 50-year evaluation period at the selected discount rate to account for inflation, etc. A Discount Rate of 3 percent was selected for this study.

The NPV values were estimated for O&M and are listed below. They are based on an annual average maintenance cost (in 2021 dollars) of $10,770. The detailed calculation is contained in **Appendix G**.

- O&M Net Present Value Total Cost (over a 50-year period) = $1,251,267
- Net Present Value Average Annual O&M Cost = $25,025
- Total lifecycle cost (sum of capital cost from **Table 4-1** plus the O&M Net Present Value Total Cost over a 50-year period) = $6,036,671

In summary, the permanent flood mitigation barrier measure has significant issues, including the considerable extent of groundwater related flooding that is expected to occur during the design flood event. Additionally, the associated costs are significantly greater than the value of the properties that would be protected. This results in a benefit-cost ratio of less than one and the GOA only funds projects with a ratio greater than one.

4.3 Temporary Dikes or Barriers

Temporary diking, erected in advance of flood conditions, can be an effective means of protecting small areas from flood waters (e.g., around individual or groups of nearby properties). Temporary measures could include temporary fill placement, sandbags and structural solutions like aquadams or flood walls. Some of these techniques require advance design, trial fit, and storage ready for deployment. Fill material is required to construct flood wall products and a water supply is required to fill aquadams. Additionally, a pre-cleared path clear of vegetation, fences and structures is required.

Temporary diking on the scale required for the entire community of Lehigh is challenging. As previously noted in the section on the permanent dike, a structure with a length of approximately 1,250 m and 3 m in height is required. Given the large footprint and significant quantity of fill material required for temporary diking in Lehigh, it could take several days or more to successfully deploy such measures for the entire community. There is a risk that these measures may not get fully deployed prior to the onset of flood conditions, as river conditions can change suddenly. In addition, river flood conditions are often associated with significant rainfall events. These wet conditions could make placing temporary structures challenging and the measures could be less effective if not properly constructed. Even with flood preparedness plans in-place and regular drills, it is unlikely that the system could be effectively deployed prior to the onset of flood conditions, for the design flood event.

Temporary measures implemented on either the individual or community level would still be subject flood damages and to the same seepage/groundwater flooding constraints previously identified for the permanent dikes/barriers.

4.4 Raising Structures and Critical Utilities

Given the above noted difficulties in flood mitigation at the existing building grades, raising the structures and critical utilities (e.g., electrical/mechanical) above the design flood level may be a measure. These types of flood resiliency measures could be achieved by: (1) use stilts or columns to jack up houses; or (2) raise up the local grade to the design flood level (i.e., an earthen mound) and relocate the house and critical utilities to this level. It is important to note that these types of measures to raise structures (i.e., stilts or columns) are still susceptible to damage during flood events. These types of measures are not feasible with respect to public and first responder safety, costs, accessibility and zoning/bylaw changes and are not fundable based on the grant criteria for the funding that the Town has received.

5.0 Non-Structural Flood Mitigation Measures

5.1 Buyouts

Buyouts and removal of existing properties from the floodway was implemented by the Government of Alberta in certain locations in Southern Alberta following the 2013 flood. If it is not feasible to protect the property by flood mitigation measures, the dwelling/building is typically demolished as part of the buyout. Further discussions could be undertaken with the landowners to discuss this measure and with provincial/federal governments to determine funding availability.

Another potential measure that could be reviewed further with the landowners is relocation in an area that is outside the Town's flood hazard zone.

5.2 Land Zoning

Land zoning and planning policies are used to direct development away from flood hazard areas. As previously noted, Lehigh is located in the floodway, which includes the main channel of a stream and a portion of the adjacent overbank area. New development is typically discouraged in the floodway (https://floods.alberta.ca/) by AEP, and not permitted in the Flood Conveyance Zone under the Town of Drumheller Land Use Bylaw.

Land zoning changes in addition to raising existing structures was discussed previously in **Section 4.4**.

5.3 Status Quo

The current Lehigh flood management model has significant drawbacks. In addition to the properties being subject to frequent flooding, the community is zoned as floodway by AEP and Flood Conveyance Zone under the Town of Drumheller Land Use Bylaw, which does not allow for new development. Additionally, the Province of Alberta has revised rules for the Disaster Recovery Program (DRP) funding such that there will only be one DRP claim allowed for each property. Damages resulting from subsequent DRP claims would not be allowed and this applies in perpetuity for the future owners as well as current owners. This could result in a liability to the property owner and possibly the Town if future owners are unable to make a DRP claim because it had been applied previously. Additionally, DRP funding is only available for "extraordinary" events, which are typically defined as those equal to or greater than the 1:100-year return period flood.

Funding would not be available for lesser magnitude events (e.g., 2005, 2013). Under the status quo condition, the Town is also required to plan for and provide emergency response for Lehigh as per the Alberta Emergency Management Act, on an on-going basis.

In considering the status quo measure, it is important to note that not only is there a high risk of flood damages to property, but it also poses a risk to public and first responder safety. This includes the potential for injuries and fatalities.

6.0 Future Steps

At this time, based on the Comprehensive Flood Mitigation Analysis study, a full buyout of the community of Lehigh was deemed to be the best solution to mitigate future flood impacts to people and property. It is recommended that the Flood Mitigation Office meets with Lehigh residents to discuss next steps in the buyout process and determine what supports will be needed.

7.0 Closure

This report has been prepared for the exclusive use of the Drumheller Resiliency & Flood Mitigation Office. This report is based on, and limited by, the interpretation of data, circumstances, and conditions available at the time of completion of the work as referenced throughout the report. It has been prepared in accordance with generally accepted engineering practices. No other warranty, expressed or implied, is made.

Sincerely,

Wood Environment and Infrastructure Solutions
a Division of Wood Canada Limited

Prepared by:

APEGA ID: 51544
PROFESSIONAL ENGINEER ALBERTA
LIVLEEN HUNDAL
31 January 2022

L.S. Hundal, M.Eng., P.Eng.
Senior Associate Engineer

Reviewed by:

Josh Strukoff, P.Eng.
Senior Water Resources Engineer

PERMIT TO PRACTICE
WOOD ENVIRONMENT & INFRASTRUCTURE SOLUTIONS
RM SIGNATURE:
RM APEGA ID #: 165082
DATE: 2022-01-31
PERMIT NUMBER: P004546
The Association of Professional Engineers and Geoscientists of Alberta (APEGA)

8.0 References

NHC (2020a). Drumheller River Hazard Study – Open Water Hydrology Assessment Report. Prepared for Alberta Environment and Parks. Northwest Hydraulics Consultants Ltd. March 2020.

NHC (2020b). Drumheller River Hazard Study – Hydraulic Modelling and Flood Inundation Mapping Report. Report prepared for Alberta Environment and Parks. Northwest Hydraulic Consultants Ltd. April 2020.

NHC (2020c). Drumheller River Hazard Study – Channel Stability Investigation Report. Report prepared for Alberta Environment and Parks. Northwest Hydraulic Consultants Ltd. April 2020.

Wood Environment & Infrastructure Solutions (March 2021). Package B and Nacmine Conceptual Design and Feasibility Study. Prepared for DRFMO, March 2021.

Wood, January 2021. Aquatic Environment Assessment Rosedale, Cambria, Lehigh and East Coulee.

Wood, January 2021. Terrestrial Assessment Cambria, Lehigh and East Coulee – Drumheller Flood Mitigation.

Appendix A – List of Properties and Survey Information

TABLE A1
LEHIGH SUMMARY OF PROPERTY INFORMATION

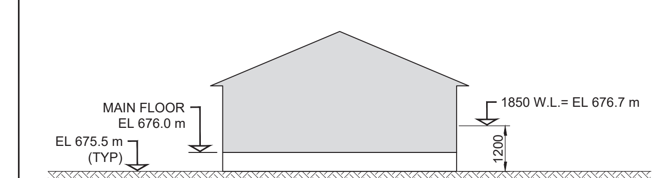
PID	Civic Location	Property Owner	Legal Address	Site Area (Sq.Ft.)	Site Area (Acres)	Type of Residence	Estimated Elevations (m)				Approx. Discharge Start of Flood (cms)
							Main Floor	Grade at House	Basement	1850 Flood	
851,514.00	102/106 - 2nd Street West	DeSmety/Kazmar	Portion of Lot 3, Block 1, Plan 881 0626	625,552.58	14.36	Manufactured Home	677.0	675.5	No	676.81	869
851,513.00	244 - 3rd Street West	Lumsden	Portion of Lot 1, Block 1, Plan 881 0626	114,609.86	2.63	House	676.1	675.5	No	676.71	869
851,433.00	215 - 2nd Street West	Town Drumheller		82,024.88	1.88	Vacant Land	n/a	675.5	n/a	676.71	869
851,507.00	220 - 2nd Street West	Roach	Portion of Lot 1, Block 2, Plan 881 0626	34,264.79	0.79	Manufactured Home	677.2	676.0	No	676.71	800
851,508.00	224 - 2nd Avenue West	Kaczmar	Portion of Lot 2, Block 2, Plan 881 0626	34,289.44	0.79	House	676.2	675.5	674.8	676.71	800
851,509.00	312 - 2nd Street West	Dahm/Grabner	Portion of Lot 3, Block 2, Plan 881 0626	34,208.71	0.79	Vacant Land	n/a	675.6	n/a	676.71	800
855,544.00	112 - 4th Street West (Joint Address)	Steward	Portion of Lot 10, Block 2, Plan 816 8FS	21,081.99	0.48	Manufactured Home	676.7	675.5	No	676.71	800
855,545.00	112 - 4th Street West (Joint Address)	Steward	Portion of Lot 10, Block 2, Plan 816 8FS	6,540.34	0.15	Vacant Land	n/a	675.6	n/a	676.71	800
855,548.00	330 - 2nd Street West (Joint Address)	Carls	Portion of Lot 15, Block 2, Plan 816 8ES	13,076.38	0.3	Manufactured Home	676.7	675.5	No	676.71	800
855,546.00	330 - 2nd Street West (Joint Address)		Portion of Lot 14, Block 2, Plan 816 8ES	6,539.99	0.15	Garage/Shop	675.5	675.5	No	676.71	800
852,953.00	333 - 2nd Avenue West	Bittner	Portion of Lot 1, Block 5, Plan 816 8FS	20,988.50	0.48	Demolished	n/a	675.5	n/a	676.71	800
852,895.00	337 - 2nd Avenue West	Dragan/DeHaan	Portion of Lot 1, Block 5, Plan 816 8FS	13,970.26	0.32	Vacant Land	n/a	675.6	n/a	676.71	800
852,901.00	245 - 3rd Street West (Joint Address)	McDonald	Portion of Lot 14, Block 5, Plan 816 8FS	26,805.97	0.62	Manufactured Home	676.2	675.2	No	676.71	750
852,897.00	245 - 3rd Street West (Joint Address)		Portion of Lot 12, Block 5, Plan 816 8FS	15,669.75	0.36	House	675.9	675.3	n/a	676.71	750
852,145.00	222 - 4th Street West	James	Portion of Lot 6, Block 5, Plan 816 8FS	19,844.55	0.46	Former mobile home	n/a	675.0	n/a	676.71	750
851,376.00	228 - 4th Street West	Justinick	Portion of Lot 10, Block 5, Plan 816 8FS	21,376.82	0.49	House w. crawlspace	676.2	675.0	675.0	676.71	750
720.00	225 - 4th Street West	Head	Portion of Lot 5, Block 4, Plan 816 8FS	31,543.31	0.72	House	676.4	675.0	674.6	676.71	720
851,402.00	215 - 4th Street West	Head	Portion of Lot 5, Block 4, Plan 816 8FS	28,701.27	0.66	Vacant Land	n/a	675.0	n/a	676.71	720
851,553.00	115 - 4th Street West	878947 Alberta	Portion of Lot 10, Block 3, Plan 816 8FS	36,037.87	0.83	Vacant Land	n/a	675.0	n/a	676.55	720
855,472.00	109 - 4th Street West	878947 Alberta	Portion of Block 11, Plan 961 1501	33,328.13	0.77	Bi-level House	676.6	675.2	674.6	676.55	720
855,473.00	105 - 4th Street West	Ginger	Portion of Block 12, Plan 961 1501	58,125.45	1.33	House w. crawlspace	676.4	676.4	675.4	676.39	720

NOTES: The properties start to flood at discharges that range from 720 to 869 m3/s, which corresponds to between a 1:10 and 1:20-year regulated return period flood event.

DRUMHELLER VALLEY

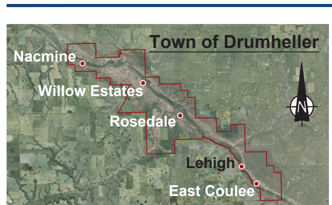
LEHIGH PROPERTIES AND SURVEY INFORMATION PLAN

SUMMARY DETAILS OF IMPACTED PROPERTIES								
PROPERTY NO.	CIVIC LOCATION	LEGAL ADDRESS	ESTIMATED ELEVATIONS (M)				APPROX. DISCHARGE START OF FLOOD (CMS) SEE NOTE 2
			MAIN FLOOR	GRADE AT HOUSE	BASEMENT	1850 FLOOD	
1	102/106 - 2ND STREET WEST	LOT 3, BLOCK 1, PLAN 881 0626	677.32	675.87	NO	676.81	869
2	244 - 3RD STREET WEST	LOT 1, BLOCK 1, PLAN 881 0626	676.10	675.50	NO	676.71	869
3	215 - 2ND STREET WEST	LOT 2, BLOCK 1, PLAN 8810626	N/A	675.50	N/A	676.71	869
4	220 - 2ND STREET WEST	LOT 1, BLOCK 2, PLAN 881 0626	677.26	676.00	ON CONCRETE PILES	676.71	800
5	224 - 2ND AVENUE WEST	LOT 2, BLOCK 2, PLAN 881 0626	676.24	675.00	674.72	676.71	800
6	312 - 2ND STREET WEST	LOT 3, BLOCK 2, PLAN 881 0626	N/A	675.00	N/A	676.71	800
7	112 - 4TH STREET WEST (JOINT ADDRESS)	LOTS 9-12, BLOCK 2, PLAN 816 8FS	676.85	675.70	NO	676.71	800
8	330 - 2ND STREET WEST (JOINT ADDRESS)	LOT 15-16, BLOCK 2, PLAN 816 8ES	676.46	675.50	NO	676.71	800
9	330 - 2ND STREET WEST (JOINT ADDRESS)	LOT 14, BLOCK 2, PLAN 816 8ES	675.97	675.97	NO	676.71	800
10	112 - 4TH STREET WEST (JOINT ADDRESS)	LOT 13, BLOCK 2, PLAN 816 8FS	N/A	675.60	N/A	676.71	800
11	333 - 2ND AVENUE WEST	LOTS 1-3, BLOCK 5, PLAN 816 8FS	677.08	675.50	NO	676.71	800
12	337 - 2ND AVENUE WEST	LOTS 4-5, BLOCK 5, PLAN 816 8FS	N/A	675.60	N/A	676.71	800
13	245 - 3RD STREET WEST (JOINT ADDRESS)	LOT 14-17, BLOCK 5, PLAN 816 8FS	676.00	675.30	NO	676.71	750
14	245 - 3RD STREET WEST (JOINT ADDRESS)	LOTS 12-13, BLOCK 5, PLAN 816 8FS	675.80	675.70	N/A	676.71	750
15	222 - 4TH STREET WEST	LOTS 6-8, BLOCK 5, PLAN 816 8FS	N/A	675.00	N/A	676.71	750
16	228 - 4TH STREET WEST	LOTS 9-11, BLOCK 5, PLAN 816 8FS	676.33 ADDITION 675.53 ORIGINAL	675.00	675.00	676.71	750
17	225 - 4TH STREET WEST	LOTS 5-7, BLOCK 4, PLAN 816 8FS	676.1 EST.	675.00	674.60	676.71	720
18	215 - 4TH STREET WEST	LOTS 1-4, BLOCK 4, PLAN 8168 F.S.				676.71	720
19	115 - 4TH STREET WEST	LOTS 6-10, BLOCK 3, PLAN 816 8FS	N/A	675.00	N/A	676.55	720
20	109 - 4TH STREET WEST	BLOCK 11, PLAN 961 1501	677.03	675.10	674.60	676.55	720
21	105 - 4TH STREET WEST	BLOCK 12, PLAN 961 1501	676.45	676.25	675.90	676.39	720



TYPICAL SECTION AT RESIDENCE SHOWING GROUND AND FLOOR LEVEL RELATIVE TO FLOOD LEVEL

Scale 1:100



NOTES:

1. ELEVATIONS ARE GEODETIC IN METRES AND WERE DERIVED FROM ALBERTA SURVEY CONTROL MARKERS, USING GPS SURVEYS AND PROVIDED BY HUNTER SURVEYS (SEPT 2021).
2. THE PROPERTIES START TO FLOOD AT DISCHARGES THAT RANGE FROM 720 TO 869 m^3/s, WHICH CORRESPONDS TO BETWEEN A 1:10 AND 1:20-YEAR REGULATED RETURN PERIOD FLOOD EVENT.

LEGEND:

- PROPERTY NO. (FROM TABLE) — ①
- EXISTING GRADE — ×
- FINISHED GRADE — +
- ALBERTA SURVEY CONTROL MARKER
- BOREHOLE
- GARAGE FLOOR — G
- FINISHED FLOOR HOUSE — H
- SHED — S

Project Number: CW238408

Date: OCTOBER, 2021

wood.

DRUMHELLER RESILIENCY AND FLOOD MITIGATION PROGRAM

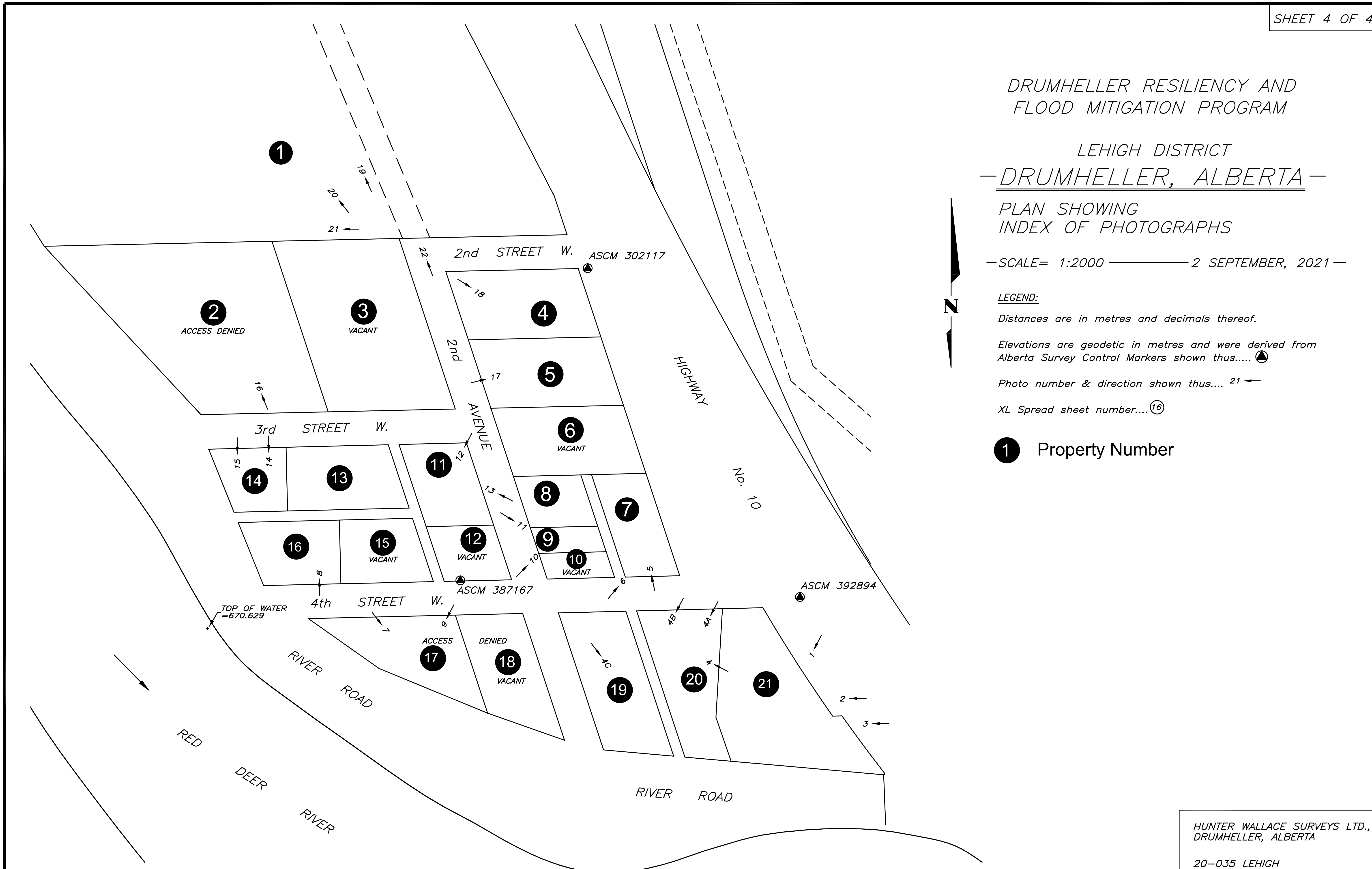
LEHIGH COMPREHENSIVE FLOOD MITIGATION ANALYSIS REPORT

Figure A.1

Appendix B – Site Photos

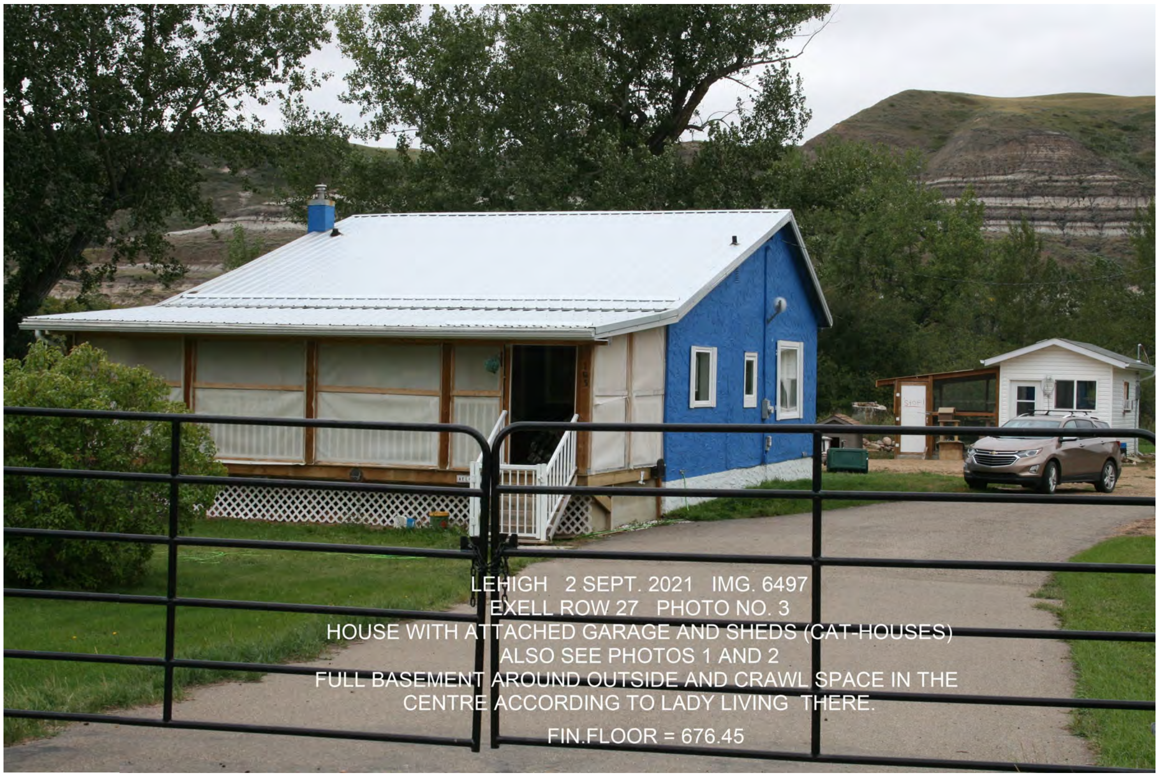
wood.

Property Number	LEGAL..... LEHIGH, ALBERTA. 2 SEPTEMBER 2021.	PICTURE NO.ON INDEX
1	LOT 3, BLOCK 1, PLAN 881 0626	19, 20, 21, 22
2	LOT 1, BLOCK 2, PLAN 881 0626 SITE PERMISSION DENIED VIA MARK.DID NOT MEET OWNER.	16
3	LOT 2, BLOCK 1, PLAN 881 0626	NIL
4	LOT 1, BLOCK 2, PLAN 881 0626	18
5	LOT 2, BLOCK 2, PLAN 881 0626	17
6	LOT 3, BLOCK 2, PLAN 881 0626	NIL
7	LOTS 9-12, BLOCK 2, PLAN 8168 F.S. ALSO OWNS ROW 16 (LOT 13) ON SAME TITLE. VACANT-GARDEN ... NO PICTURE OF GARDEN	5, 6
8 & 9	LOTS 14-16, BLOCK 2, PLAN 8168 F.S.	10, 11
10	LOT 13, BLOCK 2, PLAN 8168 F.S. THIS IS ON SAME TITLE AS ROW 16 (LOTS 9- 12) VACANT- GARDEN	GARDE NNIL
11	LOTS1-3, BLOCK 5, PLAN 8168 F.S.	12. 13
12	LOTS 4 & 5, BLOCK 5, PLAN 8168 F.S.	NIL
13	LOTS 14-17, BLOCK 5, PLAN 8168 F.S.	NIL
14	LOTS 12-13, BLOCK , PLAN 8168 F.S.	14, 15
15	LOT 6-8, BLOCK 5, PLAN 8168 F.S.	NIL
16	LOTS 9-11, BLOCK 5, PLAN 8168 F.S.	8
17	LOTS 5-7, BLOCK 4, PLAN 8168 F.S. SITE PERMISSION DENIED. TALKED TOMRS. WOOD AT GATE.	7 , 9
18	LOTS 1-4, BLOCK 4, PLAN 8168 F.S.	NIL
19	LOTS 6-10, BLOCK 3, PLAN 8168 F.S. BUNKHOUSE OR SUMMER KITCHEN	4C
20	BLOCK 11, PLAN 961 1501	4, 4A & 4B
21	BLOCK 12, PLAN 961 1501	1, 2, & 3


SHEET 4 OF 4
DRUMHELLER RESILIENCY AND
FLOOD MITIGATION PROGRAM
LEHIGH DISTRICT
DRUMHELLER, ALBERTA
PLAN SHOWING
INDEX OF PHOTOGRAPHS
SCALE= 1:2000
2 SEPTEMBER, 2021
LEGEND:
Distances are in metres and decimals thereof.
Elevations are geodetic in metres and were derived from Alberta Survey Control Markers shown thus.....
Photo number & direction shown thus.... 21
XL Spread sheet number.... 16
1 Property Number
N
2nd STREET W.
3rd STREET W.
4th STREET W.
2nd AVENUE
HIGHWAY No. 10
RIVER ROAD
RIVER ROAD
RED DEER RIVER
ASCM 302117
ASCM 387167
ASCM 392894
TOP OF WATER =670.629
ACCESS DENIED
VACANT
ACCESS DENIED
VACANT
HUNTER WALLACE SURVEYS LTD.,
DRUMHELLER, ALBERTA
20-035 LEHIGH


LEHIGH 2 SEPT. 2021 IMG 6497
EXCEL ROW 27 PHOTO 1
GARAGE AND SHEDS ALSO SEE PHOTOS 1-3
GARAGE FIN. FLOOR = 675.55


LEHIGH 2 SEPT. 2021 6498
EXEL ROW 27, PHOTO 1
GARAGE FIN. FLOOR = 675.55



LEHIGH 2 SEPT. 2021 IMG. 6497
EXELL ROW 27 PHOTO NO. 3
HOUSE WITH ATTACHED GARAGE AND SHEDS (CAT-HOUSES)
ALSO SEE PHOTOS 1 AND 2
FULL BASEMENT AROUND OUTSIDE AND CRAWL SPACE IN THE CENTRE ACCORDING TO LADY LIVING THERE.
FIN.FLOOR = 676.45

LEHIGH 2 SEPT. 2021 IMG. 6500
EXEL ROW 26 PHOTO 4
SINGLE HOUSE WITH FLL CONC. BASEMENT.DETACHED GARAGE (LOOKS LIKE OLD EL-RAY DRIVE IN). ALSO SEE PHOTOS 4A AND 4B.
THIS HOUSE IS HOOKED UP TO DRUM. WATER LINE
FIN. FLOOR = 677.03


LEHIGH 2 SEPT. 2021 IMG. 6499
EXCEL ROW 26 PHOTO 4A
HOUSE WITH FULL CONC. BASEMENT
AND DETACHED GARAGE (LOOKS LIKE THE OLD EL-RAY DRIVE IN
BUILDING ALSO SEE PHOTO 4B OF OLD MINER'S HOUSE AT N.W.
COR. OF THIS PROPERTY.
FIN. FLOOR = 677.03


LEHIGH 2 SEPT. 2021 IMG 6493
EXEL ROW 26, PHOTO NO. 4B
ABANDONED OLD COAL MINER'S HOUSE


LEHIGH 6501 2 SEPT. 2021
EXEL ROW 25 PHOTO 4C
BUNKHOUSE OR SUMMER KITCHEN


LEHIGH 2 SEPT. 2021 IMG. 6494
EXEL ROW 13 PHOTO NO.5
GAR. FIN. FLOOR = 675.65


LEHIGH 2 SEPT. 2021 IMAGE 6493
PHOTO NO.6
FIN. FLOOR = 676.85


LEHIGH 2 SEPT. 2021 IMG. 6492
EXCEL ROW 23 & 23 PHOTO. 7
ALSO SEE PHOTO NO. 9 FOR GARAGE
ACCESS DENIED. MET MRS. HEAD AT LOCKED GATE. FULL CONC. BASEMENT AND


i-GO
LEHIGH 2 SEPT. 2021 IMG.6491
EXCEL ROW 22 PHOTO NO. 8
JIM? JUSINICK
HOUSE WITH CONC. CRAWL SPACE (TO BE CONFIRMED)
FIN.FLOORS = LOWER = 675.53 UPPER = 676.33


LEHIGH 2 SEPT. 2021 IMG. 6490
EXEL ROW 20 PHOTO 9
ACESS DENIED
FIN. FLOOR APPROX. 675.1

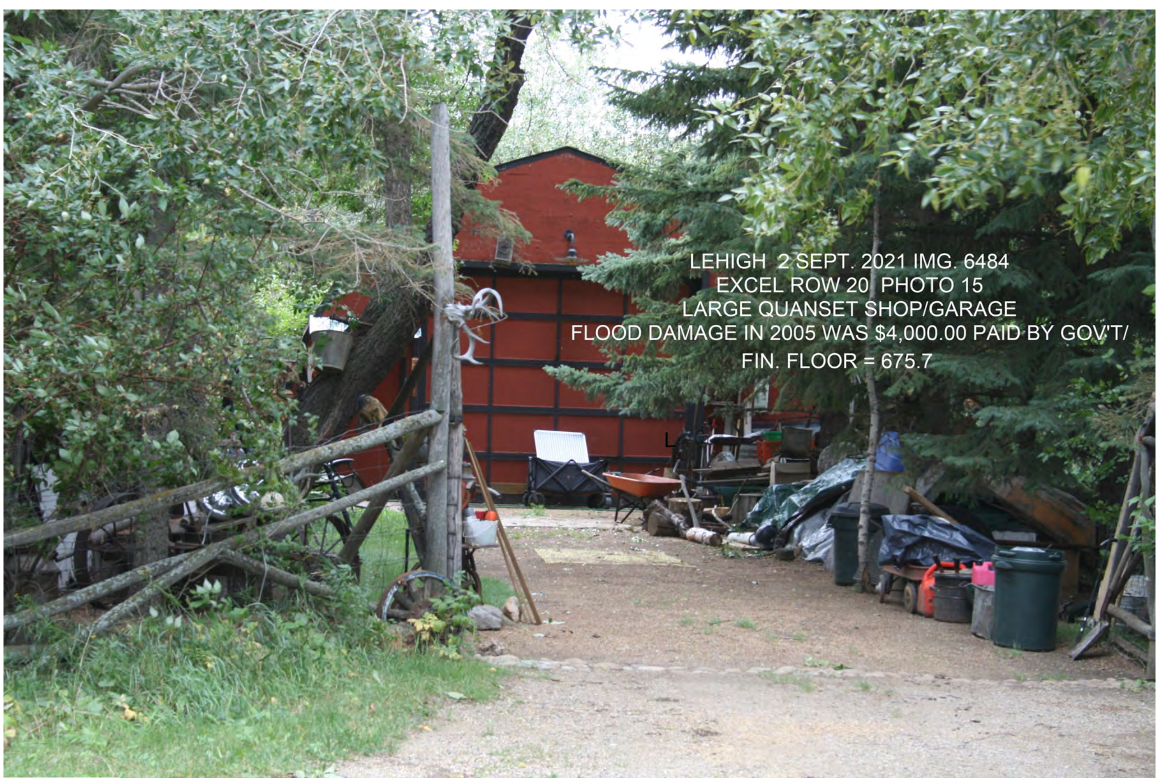
LEHIGH 2 SEPT. 2021 IMG. 6488
EXCEL ROW 14 PHOTO NO,. 11
.... CARLS . HE SAID THE 2005 FLOOD CAME UP TO THE SECOND STEP. THE 2013 DID NOT COME INSIDE HIS PROPERTY. HE ALSO OWNS EXCEL ROW 15
FIN. FLOOR = 676.46

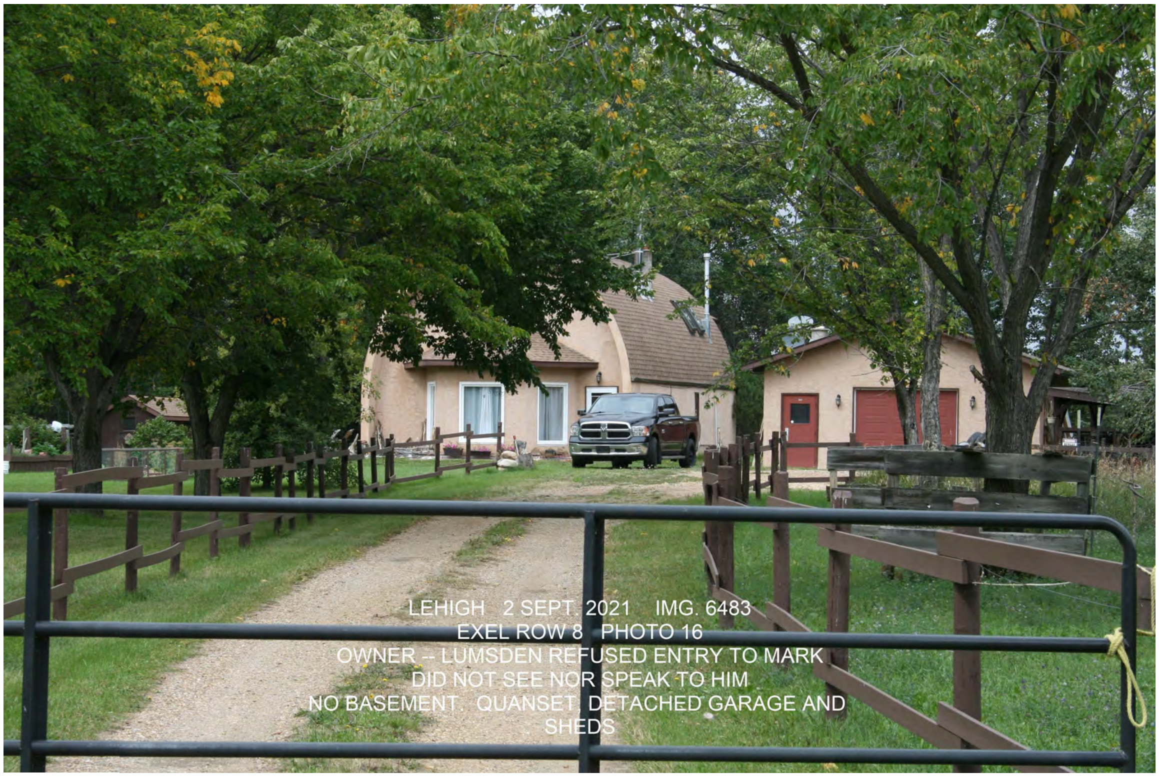
LEHIGH 2 SEPT. 2021. IMG. 6689
EXCEL ROW 15 PHOTO. 10
....CARL. HE ALSO OWNS NEXT DOOR BEING EXCEL ROW 14, PHOTO. 44
EXEL. ROW 16 IS VACANT LOT TO SOUTH OWNED BY DON STEWARD AND IS USED FOR A GARDEN.
FIN. FLOOR = 675.97


3 ST
2 AVE
LEHIGH 2 SEPT. 2021 IMG.6487
EXEL ROM 17 PHOTO 12
RECENT MANUFACTURED HOME. PROPOSED GRAGE NOT BUILT YET.
NO BASEMENT. BUILDING ON SCREW PILES.
FIN. FLOOR = 677.08


LEHIGH 2 SEPT. 2021 IMG. 6487
EXEL ROW 17. PHOTO.
NEW MANUFACTURED HOME ON SCREW PILES
NO BASEMENT. PROPOSED GARAGE -- NOT BUILT YET
FIN. FLOOR =677.08


LEHIGH 2 SEPT. 2021 IMG. 6485
EXEL ROW 20 PHOTO 14
NO BASEMENT. CLAIMS 2005 FLOOD CAME CLOSE TO
FIN. FLOOR OF HOUSE, QUANSET GOT FLOODED:
$400.00 TO REPLACE GYPROC WITH PLYWOOD.
INTERESTING DEVELOPMENT
EDWIN MacDONALD
FIN. FLOOR = 676.10


LEHIGH 2 SEPT. 2021 IMG. 6484
EXCEL ROW 20 PHOTO 15
LARGE QUANSET SHOP/GARAGE
FLOOD DAMAGE IN 2005 WAS $4,000.00 PAID BY GOV'T/
FIN. FLOOR = 675.7


LEHIGH 2 SEPT. 2021 IMG. 6483
EXEL ROW 8 PHOTO 16
OWNER -- LUMSDEN REFUSED ENTRY TO MARK
DID NOT SEE NOR SPEAK TO HIM
NO BASEMENT. QUANSET, DETACHED GARAGE AND
SHEDS


LEHIGH 2 SEPT.3 2021 IMG 6481
EXEL ROW 11, PHOTO 17
CHECK BASEMENT WITH DAVE
FIN. FLOOR: = 686.24.

LEHIGH 2 SEPT. 2021 IMG 6480
EXEL ROW 10, PHOTO 18
MODULAR HOME ON CONCRETE PILES
DETACHED GARAGE FIN. FLOOR =676.20
FIN. FLOOR HOUSE = 677.26

LEHIGH 2 SEPT. 2021. IMG 6479
EXEL ROW 7. PHOTO 19
DeSMET NEW SHOP STOP WORK ORDER
TOWN WILL NOT ISSUE PERMITS TO FINISH
FIN. FLOOR = 676.59

LEHIGH 2 SEPT. 2021 IMG6478
EXEL ROW 7, PHOTO 20
DeSMET HOUSE NO FOUNDAION FIN. FLOOR = 677.32

LEHIGH, 2 SEPT. 2021, IMG 6777
EXEL ROW 7, PHOTO 21
DeSMET GARAGE FIN.FLOOR 676.35


LEHIGH 2 SEPT. 2021 IMG.6726
EXEL ROW 7, PHOTO 22
DAVE DeSMET NEW SHOP

Appendix C – Hydrotechnical Report

9819 12 Avenue SW | Edmonton, AB T6X 0E3 | 780.436.5868 | www.nhcweb.com

nhc
northwest hydraulic consultants ltd

NHC Ref. No. 1005694

31 January 2022

Drumheller Resiliency and Flood Mitigation Program
Town of Drumheller
Box 1179
Drumheller, AB T0J 0Y0

Attention: **Drumheller Resiliency and Flood Mitigation Office**

Re: **Hydrotechnical Assessment of Channel Widening and Dredging as Flood Mitigation Neighbourhood of Lehigh, Drumheller**

1 INTRODUCTION

Northwest Hydraulic Consultants Ltd. (NHC) was retained by the Drumheller Resiliency and Flood Mitigation Program (DRFM Program) to assess the hydrotechnical performance of several suggested flood mitigation alternatives for the neighbourhood of Lehigh within the Town of Drumheller. The assessment considered channel widening and dredging of the Red Deer River within and downstream of Lehigh in an effort to locally lower water surface levels during a design flood event.

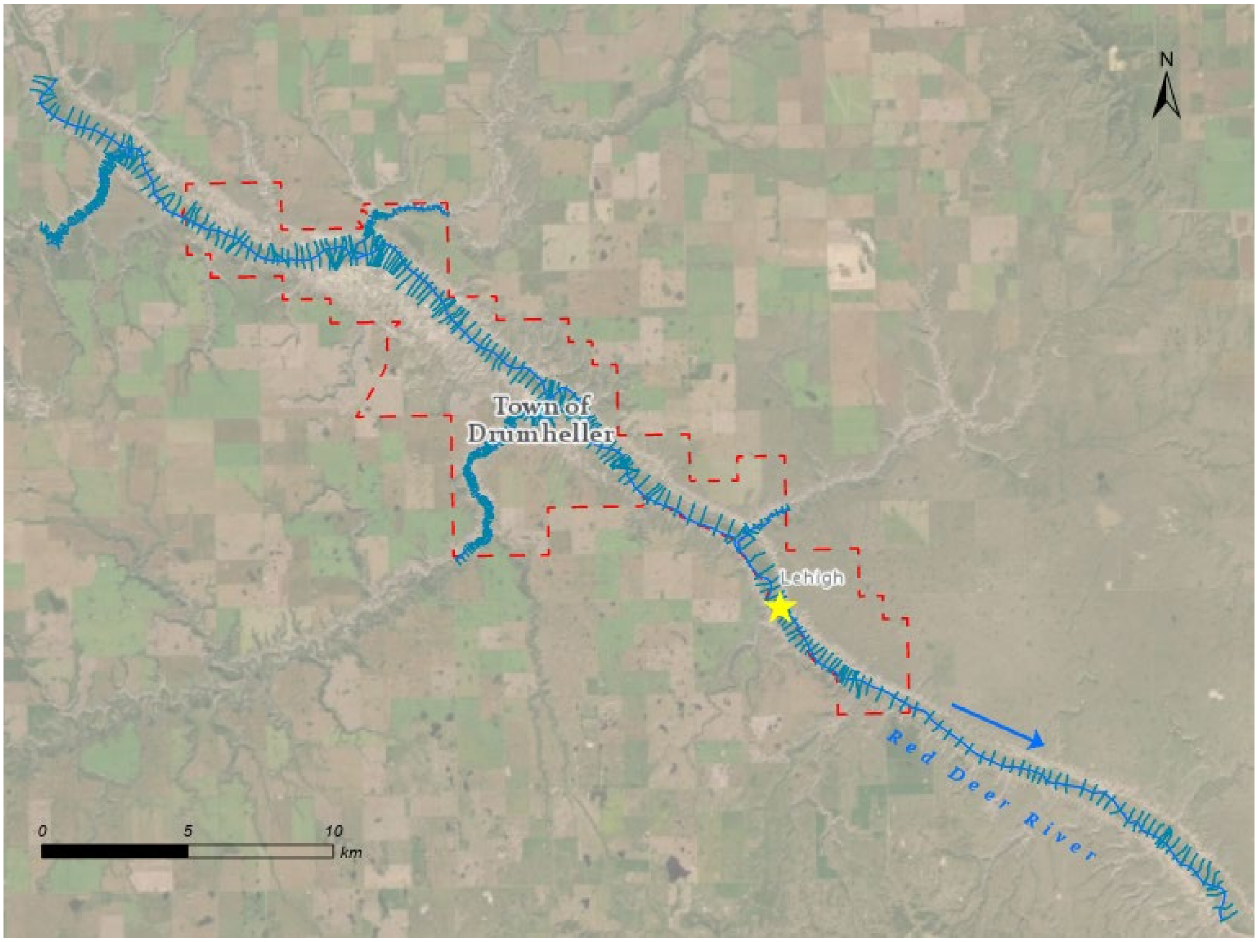
2 BACKGROUND

NHC previously completed a river hazard study for Alberta Environment and Parks (AEP). That study assessed river hydraulics and flood hazards along the Red Deer River, Kneehills Creek, Michichi Creek, Rosebud River, and Willow Creek within the Town of Drumheller (NHC, 2020a). The study included the development of a one dimensional hydraulic model, which was used to determine water levels for various flood scenarios. Flows used for this study were determined as part of a hydrology assessment (NHC, 2020b).

2.1 Study Area

Lehigh is located on the left bank of the Red Deer River, approximately 20 kilometres downstream of Central Drumheller. The area consists of low-lying floodplain that is presently vulnerable to inundation at flow rates of about 800 m^3/s, which corresponds to between a 10- and 20-year regulated return period flood event. **Figure 1** depicts the location of Lehigh along with the extents of the hydraulic model used to determine flood inundation extents as part of the 2020 Flood Hazard Study (NHC, 2020a). The lines perpendicular to the river are surveyed cross sections used for one dimensional hydraulic modelling.

Figure 1: Project Location and Extent of Flood Hazard Study Model



Beginning at the headwaters in the Rocky Mountains, the contributing watershed of the Red Deer River basin at Drumheller has an area of approximately 24,900 km^2 as based on Water Survey of Canada (WSC) gauge station 05CE001. Floods along the Red Deer River in Drumheller are typically derived from rapid spring snowmelt augmented by heavy rainfall events and usually occur in June (NHC 2020b).

Flows in the Red Deer River have been regulated since 1983 by Dickson Dam, which is located about 50 km upstream of the city of Red Deer. The drainage area upstream of the reservoir (5,590 km^2) accounts for only 22% of the total drainage area upstream of Drumheller (NHC, 2020b).

2.2 Flood History

The Red Deer River at Drumheller (05CE001) gauge station was established by WSC in November 1915. Prior to systematic recording, the flood events which occurred in 1901 and 1915 are the two largest known events on the Red Deer River (NHC, 2020b). While no definite indication of magnitude could be found for the 1901 flood, the 1915 flood had an estimated instantaneous discharge of 2,020 m^3/s (NHC, 2020b). Two other flood events were observed in 1952 and 1954 while the gauge station was not in operation and their instantaneous discharge values were estimated as 1,360 m^3/s and 1,530 m^3/s, respectively (NHC, 2020a). More recently, two significant recorded open water flood events occurred in

2005 and 2013, with instantaneous discharge values estimated at 1,450 m^3/s and 1,270 m^3/s, respectively (NHC, 2020a). Both the 2005 and 2013 floods caused property damage within Lehigh.

2.3 Channel Stability

The results of a channel stability investigation (NHC, 2020c) undertaken for the 2020 river hazard study indicate that the Red Deer River active channel width has generally decreased through the study reach (**Figure 1**) since 1950 largely as a result of lateral deposition and vegetation encroachment along the river. At Lehigh, the width was reduced by a maximum of 45 m between 1950 and 2019, which is consistent with the average throughout the entire study reach. The river bed elevation profile through Drumheller has not changed significantly since the earliest available data for comparison were obtained in 1984. However, some general lowering of the river bed was noted in the area of Lehigh (NHC, 2020c).

It is worth noting that a series of spurs were constructed in 1992 along the left bank of the river between Lehigh and East Coulee to prevent bank erosion and protect the highway embankment. These structures appear to have functioned as designed, stabilizing the river bank and promoting bed scour near the tips of each structure. Upstream water levels are not expected to be affected by the spurs during a flood event.

2.4 Channel Widening and Dredging

Channel widening and dredging both involve the excavation of material from the channel bed and banks to increase the cross sectional area available for conveyance. Channel widening increases the bankfull width of the channel, which is the distance between the banks at an elevation just below the point when water begins to spill out into the floodplain. Widening is accomplished by excavating material along the river bank. Dredging is the removal of material below the normal water level, which increases the average depth of the channel. Increasing channel capacity can sometimes reduce water levels locally; however, accompanying changes in river flow velocity may limit the effectiveness of widening and dredging.

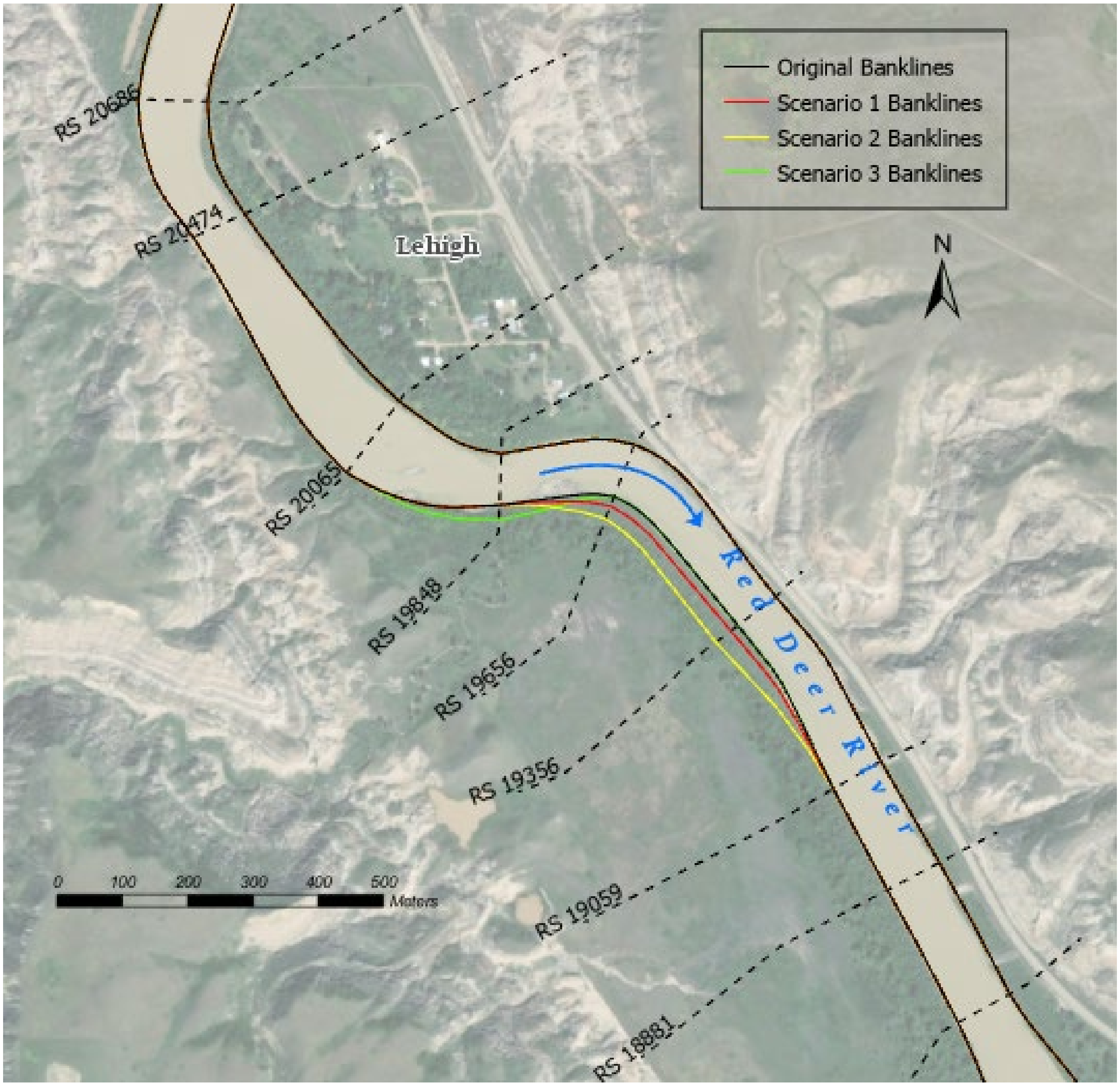
The model previously developed for AEP as part of the Drumheller River Hazard Study (NHC, 2020a) was modified to evaluate the effects of channel widening and dredging as flood mitigation alternatives for Lehigh. Model results and practical considerations for the suggested flood mitigation measures are provided below.

3 METHODOLOGY

The one-dimensional HEC-RAS model from the river hazard study was developed to assess flood risk for the Town of Drumheller and includes a 56 km reach of the Red Deer River as well as Kneehills Creek, Michichi Creek, Rosebud River, and Willow Creek (NHC, 2020a). The model includes surveyed cross sections along the study reaches, which are numbered according to river station ("RS"), or the distance in metres from the downstream end of the reach. This assessment used the 100-year regulated flood (1,850 m^3/s), as reported in the hydrology component of the river hazard study (NHC, 2020b). This is the design flood adopted for new flood mitigation works within the Town of Drumheller as approved by AEP and represents the flow which has a one percent chance of being equalled or exceeded each year.

By modifying the original model base geometry, three scenarios were established to assess the potential effects of channel widening and dredging on water levels in Lehigh. These three scenarios included: (1) 10% channel widening over 290 m, (2) 30% channel widening over 290 m, and (3) dredging of the channel bottom over 240 m. The existing natural bank slope was retained along cross sections for both of the channel widening scenarios. A plan view of the three channel modification scenarios can be seen in **Figure 2,** with Lehigh situated between RS 20 686 and RS 19 848**.** Channel widening modifications were applied on the right bank downstream of Lehigh (between RS 19 656 and RS 19 356) where there is available space outside the river banks for such works, while dredging modifications were applied along the downstream portion of Lehigh (RS 20 065 and RS 19 848) where sand and gravel bar formations are evident from aerial photos. Channel widening is not possible on the left bank of the river, as it would impact the highway and existing properties in Lehigh. These scenarios represent modifications which are within the upper limit of feasibility (i.e., more drastic changes to the channel would not likely be feasible due to the potential for bank instability, likelihood for increased deposition of sediment, construction challenges and associated costs, as well as environmental concerns and difficulty in obtaining permitting approvals to carry out the work). The channel widening scenarios focused on extending channel width along the cross section, while the dredging scenario simulated removal of point bars attached to the banks and mid-channel bars without altering the deepest point of the channel.

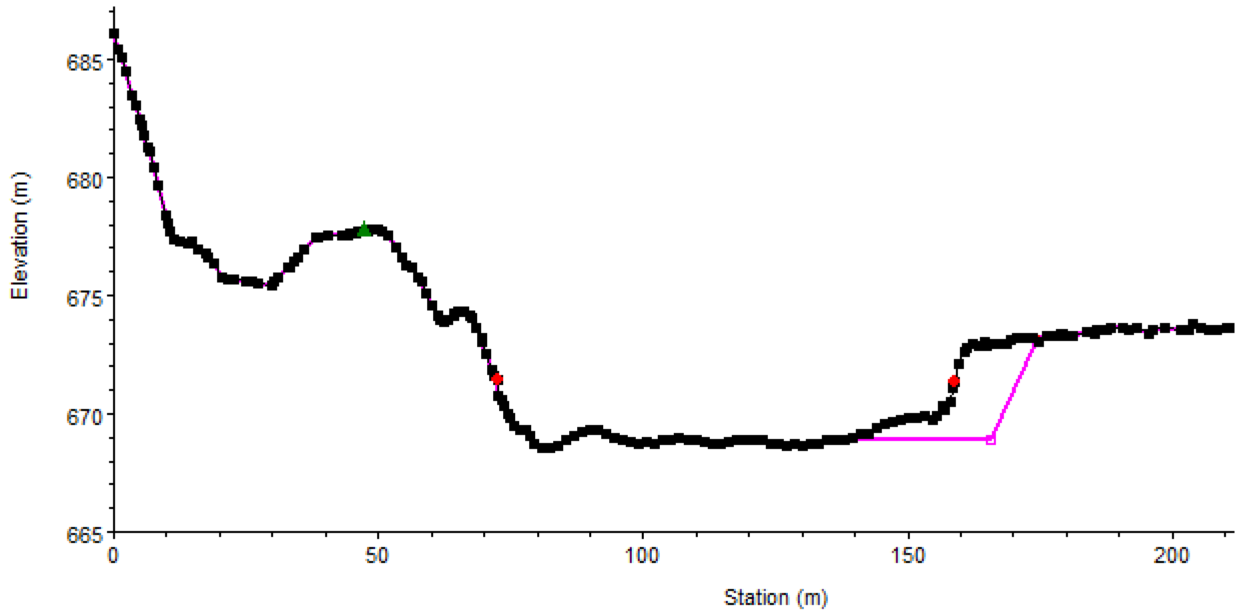
Figure 2: Plan View of Channel Modification Scenarios



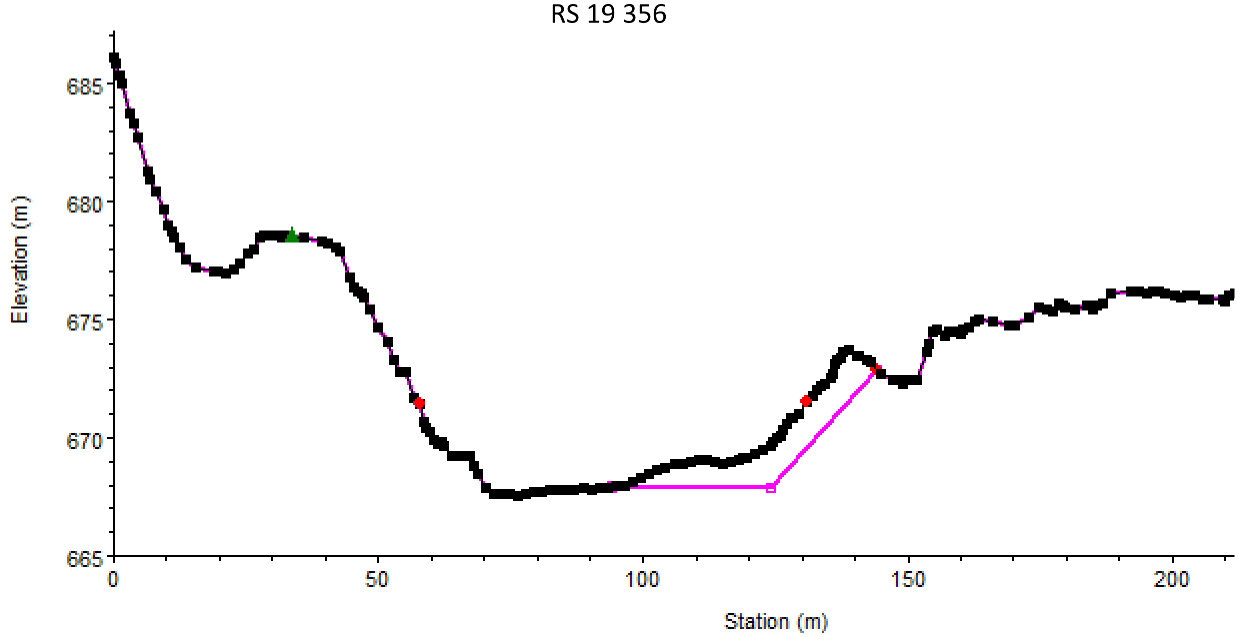
Scenario 1 included channel widening by approximately 10% of the bankfull channel width over 290 m between RS 19 656 and RS 19 356, downstream of Lehigh. The modifications applied at each cross section can be seen in **Figure 3.** This scenario requires the removal of approximately 30,800 m^3 of material.

Figure 3: Scenario 1 – 10% Channel Widening over 290 m

RS 19 656

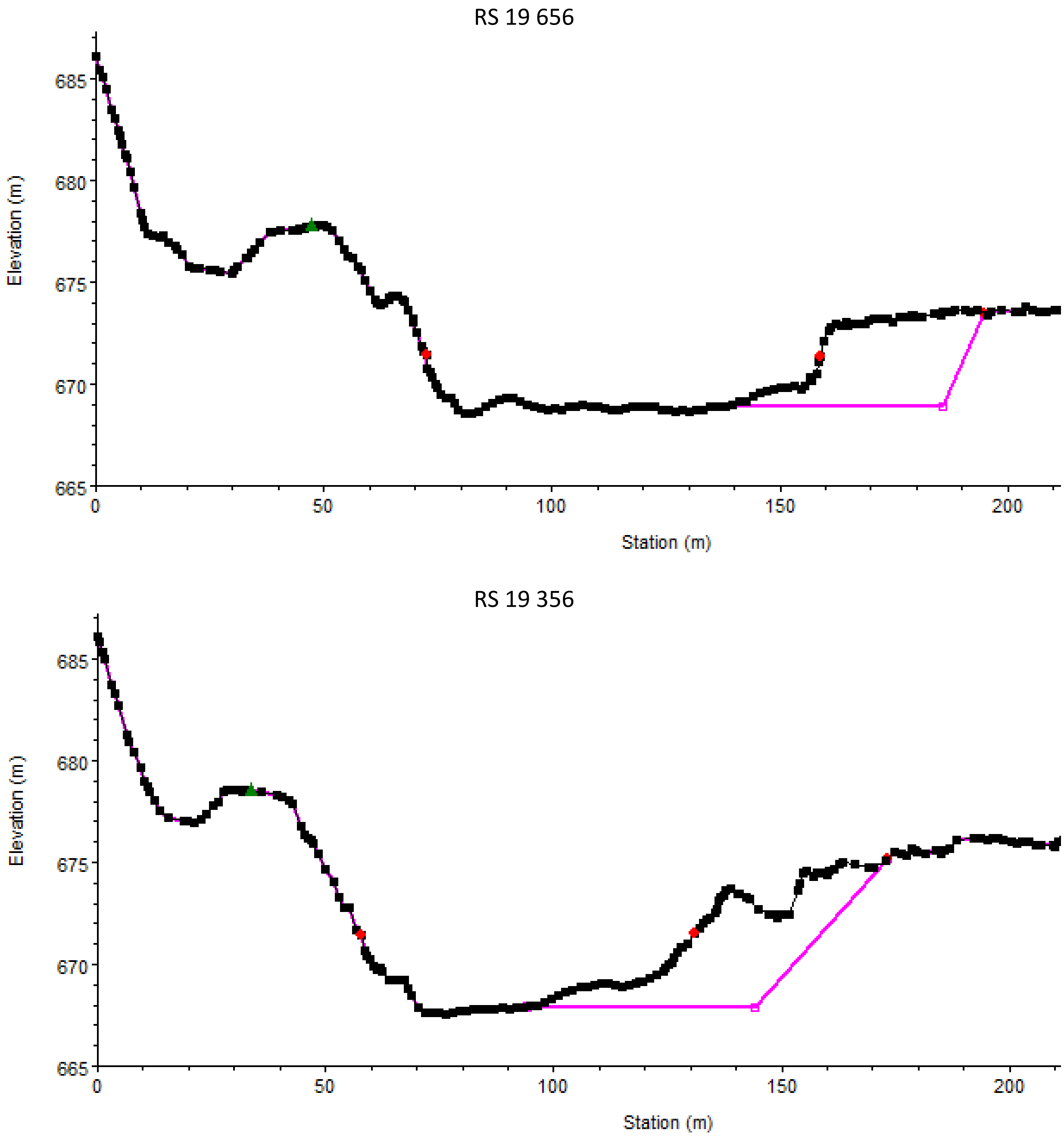


RS 19 356



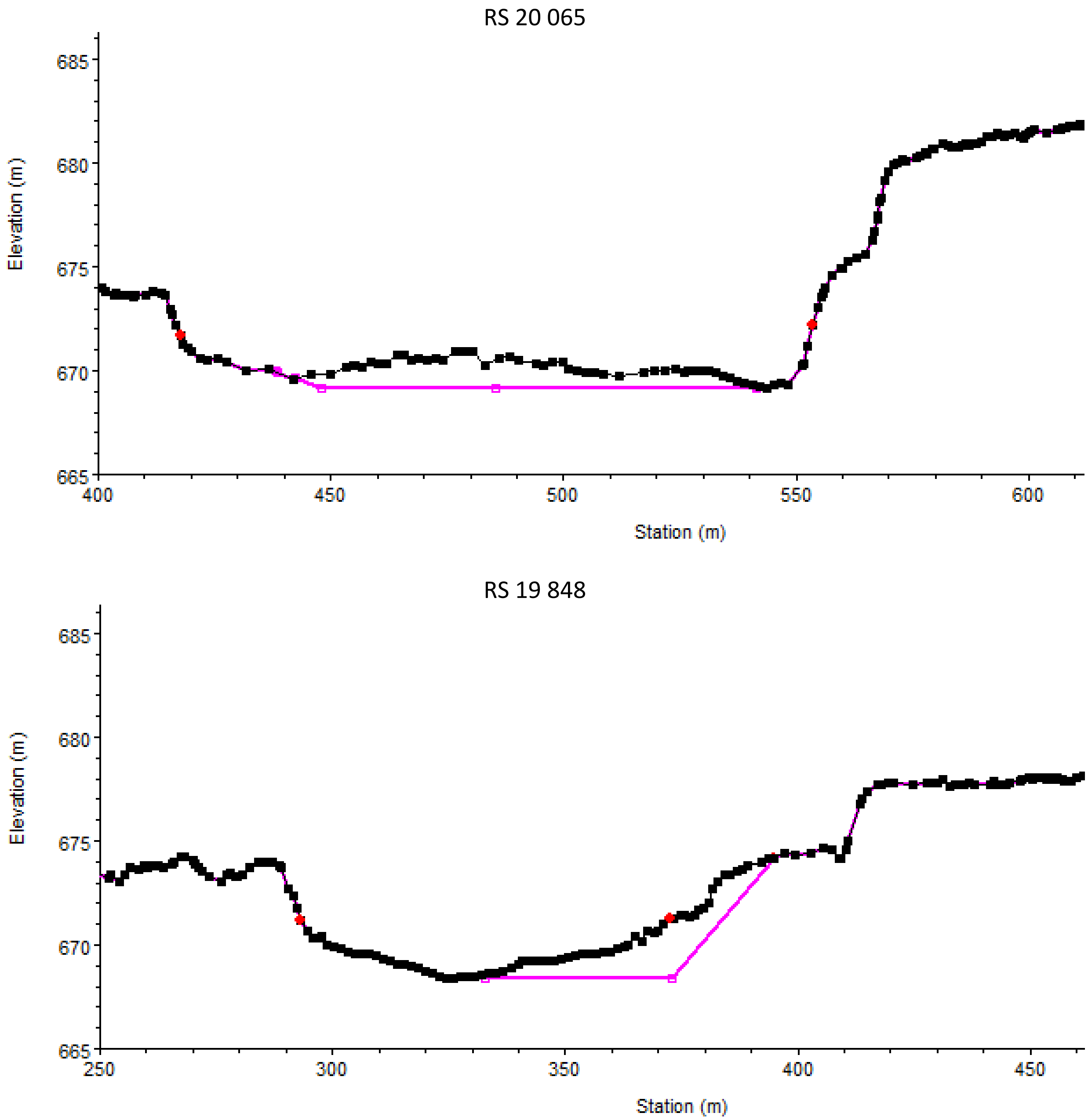
Scenario 2 included channel widening by approximately 30% of the bankfull channel width over 290 m between RS 19 656 and 19 356. The modifications applied at each cross section can be seen in **Figure 4.** This scenario requires the removal of approximately 81,800 m^3 of material.

Figure 4: Scenario 2 – 30% Channel Widening over 290 m



Scenario 3 included channel dredging over 240 m between RS 19 848 and RS 20 065, where sediment deposition was visible in the aerial photos. The modifications applied at each cross section can be seen in **Figure 5**. This scenario requires the removal of approximately 42,300 m^3 of material.

Figure 5: Scenario 3 – Channel Dredging over 240 m



4 RESULTS

The three scenarios described in the section above were modelled for design flood conditions (1,850 m^3/s), and the results are presented in the following section. Results include comparisons of flow area at modified cross sections in an effort to illustrate the scale of changes, as well as comparisons of water levels and velocities at Lehigh under design flood conditions to demonstrate the impact of the changes.

A summary of the modelled flow areas at each of the modified cross sections under design flood conditions are presented for all scenarios in **Table 1**. Scenario 2, which represents a 30% increase in bank width, had the greatest increase in channel capacity (approximately 13-35%) of each scenario. Scenario 3, channel dredging, had the lowest increase in channel capacity (approximately 6-12%).

Table 1: Summary of Excavation Amounts and Flow Area Changes under Design Flood Conditions

Channel Modification Scenario	Approximate excavation volume (m^3)	Flow area (m^2) at RS 20 065 (% change)	Flow area (m^2) at RS 19 848 (% change)	Flow area (m^2) at RS 19 656 (% change)	Flow area (m^2) at RS 19 356 (% change)
Baseline – Existing Conditions	0	1390.76	1017.52	899.26	663.28
Scenario 1 – 10% Channel Widening	30,800	No change	No change	961.70 (+6.9%)	747.15 (+12.6%)
Scenario 2 – 30% Channel Widening	81,800	No change	No change	1056.45 (+17.5%)	892.5 (+34.6%)
Scenario 3 – Channel Dredging	42,300	1477.86 (+6.3%)	1134.49 (+11.5%)	No change	No change

A summary of water levels under design flood conditions at the cross sections through Lehigh (RS 20 686, RS 20 474, RS 20 065 and RS 19 848) are presented for all scenarios in **Table 2**. The largest changes in water level were found for Scenario 2 (30% increase in bank width) with a reduction in levels throughout Lehigh of 0.09 to 0.12 m. Channel dredging (Scenario 3) was least effective at lowering water levels and even slightly increased water levels at the downstream end of Lehigh.

Table 2: Summary of Water Levels at Lehigh under Flood Mitigation Scenarios

Channel Modification Scenario	Water surface elevation (m) at RS 20 686 (change)	Water surface elevation (m) at RS 20 474 (change)	Water surface elevation (m) at RS 20 065 (change)	Water surface elevation (m) at RS 19 848 (change)
Baseline – Existing Conditions	676.87	676.70	676.71	676.41
Scenario 1 – 10% Channel Widening	676.82 (-0.05)	676.65 (-0.05)	676.65 (-0.06)	676.34 (-0.07)
Scenario 2 – 30% Channel Widening	676.78 (-0.09)	676.60 (-0.10)	676.61 (-0.10)	676.29 (-0.12)
Scenario 3 – Channel Dredging	676.81 (-0.06)	676.64 (-0.06)	676.68 (-0.03)	676.52 (+0.11)

Table 3 includes a summary of water velocities under design flood conditions in Lehigh for all scenarios. A reduction in water level for a given flow can result in an increase in velocities, potentially increasing the hazard during floods. Within Lehigh, this velocity increase does not appear to be significant. Scenario 2 has the greatest decrease in water levels (see **Table 2**), and it produces the greatest increase in velocities (up to 0.08 m/s). The decrease in velocity at the two downstream cross sections under Scenario 3 is a result of channel modifications carried out at those sections.

Table 3: Summary of Water Velocities at Lehigh under Flood Mitigation Scenarios

Channel Modification Scenario	Velocity (m/s) at RS 20 686 (change)	Velocity (m/s) at RS 20 474 (change)	Velocity (m/s) at RS 20 065 (change)	Velocity (m/s) at RS 19 848 (change)
Baseline – Existing Conditions	2.27	2.73	1.92	2.94
Scenario 1 – 10% Channel Widening	2.29 (+0.02)	2.76 (+0.03)	1.94 (+0.02)	2.98 (+0.04)
Scenario 2 – 30% Channel Widening	2.31 (+0.04)	2.79 (+0.06)	1.96 (+0.04)	3.02 (+0.08)
Scenario 3 – Channel Dredging	2.30 (+0.03)	2.77 (+0.04)	1.76 (-0.16)	2.35 (-0.59)

5 SUMMARY AND CONCLUSIONS

The hydraulic model from the recently completed Drumheller River Hazard Study for AEP (NHC, 2020a) was modified to determine the effects of channel widening and river dredging as possible flood mitigation measures. Three scenarios were developed to quantify changes in water levels through Lehigh: (1) 10% channel widening over 290 m, (2) 30% channel widening over 290 m, and (3) dredging of the channel bottom over 240 m. The second scenario resulted in the largest reduction in water levels of between 0.09 and 0.12 m throughout Lehigh for the design flood, as compared with an average expected flood depth of 1.2 m under these conditions. This scenario involved increasing the channel capacity by 12-35% through the removal of an estimated 81,800 m^3 of material. As channel capacity modifications were made to downstream cross sections and not those within Lehigh under this scenario, related effects also included a slight increase in water velocity throughout Lehigh of 0.04-0.08 m/s.

The model results for all mitigation scenarios show relatively small decreases in water surface elevation (or flood level) throughout Lehigh despite relatively sizable increases in channel capacity. A decrease in water level of approximately 0.1 m would not significantly reduce the flood risk or need for other structural mitigation measures given the expected depth of flooding of 1.1 to 1.7 m in the community of Lehigh.

There are also practical issues to consider with channel widening or dredging in this area. The area of potential channel widening is located within Wheatland County and outside of the Town of Drumheller so coordination with the County would be required. Additionally, access to this area is difficult as there is no road access and steep valley walls along the floodplain. Removing sediment from a watercourse would have adverse impacts to aquatic habitat over a relatively large instream footprint, such as disturbances to fish resting and spawning areas and increased suspended sediment loads in the water during instream work. Therefore, there are likely to be significant difficulties in obtaining regulatory approvals under the Alberta *Water Act* and Canada *Fisheries Act* for this type of work. There is also the challenge of finding a place to dispose of the 81,800 m^3 of excavated and dredged material that is not suitable for other flood mitigation construction purposes. Finally, it should be noted that the effects of dredging are often short lived, as sediment deposition will continue to occur and routine maintenance dredging would be required. Given the challenges of carrying out such work and the limited impact on water levels at Lehigh, neither channel widening nor dredging are considered effective flood mitigation measures for the area.

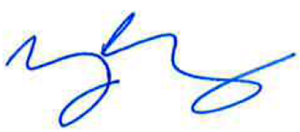
6 CLOSURE

The information provided in this document was prepared for the Drumheller Resiliency and Flood Mitigation Program office to support upcoming flood mitigation projects within the Town of Drumheller. Please feel free to contact Robyn Andrishak by email (randrishak@nhcweb.com) or phone (587-759-7517) if any additional information or clarification are required.

Sincerely,

Northwest Hydraulic Consultants Ltd.

Prepared by:



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Associate

Reviewed by:

Robyn Andrishak, M.Sc., P.Eng.
Principal

7 REFERENCES

NHC (2020a). *Drumheller River Hazard Study: Hydraulic Modelling and Flood Inundation Mapping Report*. Northwest Hydraulic Consultants Ltd. for Alberta Environment and Parks.

NHC (2020b). *Drumheller River Hazard Study: Open Water Hydrology Assessment Report*. Northwest Hydraulic Consultants Ltd. for Alberta Environment and Parks.

NHC (2020c). *Drumheller River Hazard Study: Channel Stability Investigation Report*. Northwest Hydraulic Consultants Ltd. for Alberta Environment and Parks.

Appendix D – Hydrogeology Report

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Memo

To:	Deighen Blakely Drumheller Resiliency and Flood Management Office		
From:	David Parsons	**Reviewer:**	Sukru Sumer
cc:	Liv Hundal	**Wood File No.:**	CW238408
Date:	28 January 2022		
Re:	**Groundwater Seepage Assessment for Flood Control Structures – Lehigh**		

1.0 Introduction and Background

The following memo summarizes the results of our assessment and theoretical calculations of groundwater seepage beneath a conceptual flood barrier dike in the community of Lehigh in Drumheller. The quantities of seepage and magnitude of change of the water table elevation behind the dikes at critical time steps were determined to assess potential risks of flooding to nearby residential properties.

Background information for the seepage analyses was obtained from the following sources:

- Drumheller Flood Mitigation Geotechnical Data Report (Parkland Geo, 2020);
- Drumheller Resiliency and Flood Mitigation Conceptual Design Report (Wood, 2021);
- Borehole drilling logs and laboratory data from the recent geotechnical drilling programs;
- Representative cross-sections showing dike geometry, topography, and river/flood levels;
- Elevation survey data collected in September 2021 by Hunter Survey Systems Ltd.; and
- Alberta Water Well Information System and Alberta River Basins web application (AEP, 2021a, b).

The locations of affected properties, relevant boreholes/installations and other features are indicated on **Figure 1**. Based on the available information, the surficial geology in the Lehigh area are predominantly sand deposits that consist of silty sand near the surface and gravelly sand below. The surficial deposits range from 7 to 14 m thick in the area and lie atop weathered shale bedrock.

According to the conceptual design report, the tops of the dikes would lie at elevations between 677.10 and 677.80 masl across the area of Lehigh, designed to such elevations to provide 0.75 m freeboard under flood conditions. The dike would be 6.00 m wide at the top to allow for maintenance vehicle access and have 2:1 H:V or similar side-slopes. The natural ground level in the area behind the conceptual dike is relatively flat and ranges in elevation between 674.00 and 676.00 masl. Average river water level is assumed to be 670.70 masl, and the design flood level is understood to be 676.80 masl.

2.0 Methodology

2.1 Estimation of Hydraulic Parameters

Estimates of hydraulic conductivity of the subsurface materials were obtained from in-situ hydraulic response (slug) tests performed in two water table monitoring standpipes installed in boreholes located in the central and southeastern portions of the Lehigh area (BH20-27 and -28). Tests were initiated by quickly bailing a volume of water from the standpipe and monitoring the recovery of the displaced water column back to the static condition. Two tests were conducted at each location. The response data was analyzed using the Hvorslev (1951) solution, and the analyses were performed using AQTESOLV aquifer test analysis software (HydroSolve, 2007).

Hydraulic conductivity of the surficial sand deposits was estimated using this method to be as low as 1.5 x 10^{-7} m/s at standpipe BH20-27, up to 2.0 x 10^{-5} m/s at BH20-28.

Water Well drilling reports for two water wells installed in the vicinity of Property no. 4 on **Figure 1** (closest to the intersection of 2nd Street West and Highway 10) indicate completion in shallow sand and gravel deposits and include short duration pumping test data (**Attachment A**). Well ID# 1305518 (owner at time of installation was Dan Belliveau) was pumped at a rate of 22.7 L/min for 2 hours on 30 August 2013. The water level was drawn down only 0.16m before the pump was stopped. Well ID#1305546 (owner Don Steward) was pumped at 9.1 L/min for 2 hours on 6 June 2014, and drawdown reached 0.31m.

The pumping test drawdown and recovery data was analyzed using the Neuman (1974) solution for an unconfined aquifer. Aquifer transmissivities of 1.8 x 10^{-3} and 1.7 x 10^{-4} m/s were obtained for the "Belliveau" well and "Steward" well respectively. These values equate to hydraulic conductivities of 4.3 x 10^{-4} m/s and 3.9 x 10^{-5} m/s for an aquifer saturated thickness of approximately 4.3m as estimated from the lithological information on the drilling records.

Slug test and pumping test analytical results are shown in **Attachment B**.

Hydraulic conductivity estimates were also obtained from limited grain size distribution data from borehole drilling samples, using the method of Shepard (1989) for natural graded sediments:

$$K = 100 * d_{50}^{1.5} \qquad (1)$$

Where:

K = hydraulic conductivity (ft/d)

d_{50} = sieve size through which 50% of sample passes (mm)

Using equation 1, a hydraulic conductivity of 3.5 x 10^{-4} m/s was estimated for the sand deposits based on grain size analysis of sample G3 from borehole BH21-B08 (**Attachment C**).

A summary of all hydraulic conductivity estimates is shown in **Table 1**.

Table 1 – Hydraulic Conductivity Estimates - Lehigh

Location	Test Type	Analysis	Hydraulic Conductivity (m/s)	Comment
BH21-B08	Grain Size Distribution	Shepard (1989)	3.5×10^{-4}	Drilling sample G3 from borehole BH21-B08.
BH20-27	Slug Test	Hvorslev (1951) Test 1	1.5×10^{-7}	Bail-down tests in 1-inch diameter standpipe, partially silted.
	Slug Test	Hvorslev (1951) Test 2	3.5×10^{-7}	
BH20-28	Slug Test	Hvorslev (1951) Test 1	1.7×10^{-5}	Bail-down tests in 2-inch diameter standpipe.
	Slug Test	Hvorslev (1951) Test 2	2.0×10^{-5}	
"Belliveau" Well	Pumping Test	Neuman (1974)	4.3×10^{-4}	Short duration pumping test, data from water well drilling report.
"Steward" Well	Pumping Test	Neuman (1974)	3.9×10^{-5}	Short duration pumping test, data from water well drilling report.

The results in **Table 1** generally fall within the range of values determined from other sites in the area but are quite variable and may reflect a highly heterogeneous subsurface geology in Lehigh. The various methods for obtaining hydraulic parameter estimates each have inherent limitations. Slug tests generally provide a "lower-bound" estimate of hydraulic conductivity for formation materials in the immediate vicinity of the piezometer intake and can be highly impacted by well construction and drilling disturbances (Butler, 1998). Incongruently slow recovery of the water column during slug tests and an apparent build-up of silt in the screened interval was noted in standpipe BH20-27.

Drilling samples for grain size analyses are obtained from discrete subsurface intervals and can be prone to sampling biases. Pumping tests, because of their longer duration as compared to slug tests, yield response data that is generally more reflective of the bulk properties of a large aquifer volume. However, due to the short test durations and small amounts of drawdown observed in Lehigh, it is likely that the response in the pumping wells is only representative of the formation materials to a radial distance of 10 to 20 m.

2.2 Estimation of Seepage

The quantity of seepage and potential extent of flooding was evaluated based on hydraulic head changes produced by a rise in the river level to the peak flood condition. The water table head changes were determined based on calculations of unsteady one-dimensional flow in a homogeneous, unconfined aquifer by Edelman (doctoral thesis, Delft, 1947) as described by Huisman and Olsthoorn (1983, pp.47-48). The calculations are as follows:

$$u = 0.5*\sqrt{(S_y/Kb)}*(x/\sqrt{t}) \qquad (2a)$$

$$s_x = s_o*\text{erfc}(u) \qquad (2b)$$

$$q_o = (s_o/\sqrt{(\pi)}) * (\sqrt{(Sy*K*b)})*(1/\sqrt{(t)}) \qquad (2c)$$

$$E_2 = e^{-uu} \qquad (2d)$$

$$q_x = q_o * E_2 \qquad (2e)$$

where:

S_y = specific yield
K = hydraulic conductivity (L/t)
b = aquifer thickness (L).
x = distance from flood-dike interface (L)
t = time (t)
s_o = river level rise, and s_x = head change at distance x from the interface (L)
q_o = seepage rate at the interface, and q_x = seepage rate at distance x (L^3/t)

Some assumptions were made to simplify the calculations:

- The transition to the flood condition is instantaneous and the peak flood persists for up to three days.
- The surficial geology is assumed to be represented by a single homogeneous layer of material.
- The surficial deposits are approximately 9.0m thick in the areas considered, based on available drilling information.
- Hydraulic conductivity of the surficial materials has an assumed value of 4.3×10^{-4} m/s in all areas, based on the pumping test data, and is considered a reliable estimate and most representative of the overall behaviour of the bulk aquifer.
- Specific yield of 0.2 is assumed for all areas.
- Flow is largely controlled by the gravelly sand deposits, while underlying bedrock and overlying dike material are considered effectively impermeable.
- Distances (x) at which water table rise and seepage are calculated are relative to the flood/dike interface, which is located at the river-side toe of the dike.
- The initial water table is assumed to be flat and corresponds to the average river level. Recent measurement of water levels from the standpipe piezometers supports this assumption.
- Groundwater recharge and confining effects of surface material such as road pavement were neglected.

The calculations were automated to produce multiple estimates of seepage flux and water table displacement from adjusted input parameters using a spreadsheet. The results were calculated at the one-, two- and three-day time steps, which are within the range of time that peak flooding would be expected to persist. Sensitivity of the hydraulic head change and seepage rate to uncertainty in hydraulic conductivity and specific yield were assessed as well.

Water levels in the standpipes BH20-27 and BH2-28 were monitored through the month of September 2021 with the intent of verifying the parameter estimates and comparing observed to theoretical behaviour. A plot of the hydrographs along with river levels obtained from the Red Deer River at Drumheller hydrometric station #05CE001 (AEP, 2021b) showed some small fluctuations related to rain events between 11 and 15 September (**Figure 2**). Peak levels in the standpipes appear to correspond to similar peaks approximately 24 hours previous in the river.

wood.

3.0 Results

3.1 Theoretical Calculations

Table 2 shows the estimated groundwater seepage rates and water table displacements at various distances behind the dike after periods of two and three days. The table also demonstrates the sensitivity of the results to variations in hydraulic conductivity and specific yield.

Table 2: Estimated Hydraulic Head Changes Under Flood Condition – Lehigh Typical Section

Time (d)	Distance From Dike (m)	Results, Base Case, $K=4.3 \times 10^{-4}$ m/s, $S_y=0.2$		Sensitivity Analysis $K=1 \times 10^{-3}$ m/s		Sensitivity Analysis $K=1 \times 10^{-4}$ m/s		Sensitivity Analysis $S_y=0.1$	
		Hydraulic Head Change, Δs (m)	Seepage Rate, q_x (m^3/d/m)	Hydraulic Head Change, Δs (m)	Seepage Rate, q_x (m^3/d/m)	Hydraulic Head Change, Δs (m)	Seepage Rate, q_x (m^3/d/m)	Hydraulic Head Change Δs (m)	Seepage Rate, q_x (m^3/d/m)
1	20	4.45***	26.51	-	-	-	-	-	-
	40	2.98***	22.16	-	-	-	-	-	-
	60	1.83**	16.43	-	-	-	-	-	-
	80	1.02*	10.81	-	-	-	-	-	-
	100	0.51	6.31	-	-	-	-	-	-
2	20	4.92***	19.31	-	-	-	-	-	-
	40	3.81***	17.66	-	-	-	-	-	-
	60	2.83***	15.20	-	-	-	-	-	-
	80	2.00**	12.33	-	-	-	-	-	-
	100	1.35*	9.42	-	-	-	-	-	-
3	20	5.13***	15.93	5.46***	24.57	4.14***	7.19	5.42***	11.38
	40	4.21***	15.00	4.84***	23.94	2.49**	5.56	4.74***	11.04
	60	3.35***	13.58	4.24***	22.94	1.31*	3.62	4.10***	10.50
	80	2.59**	11.81	3.66***	21.60	0.60	1.99	3.49***	9.80
	100	1.94**	9.87	3.13***	20.00	0.23	0.92	2.93***	8.96

*****indicates possible seepage impacting residences, for areas with ground surface elevation at or below 674 masl.
**possible impacts where g.s. at or below 675 masl.
***possible impacts where g.s. at or below 676 masl.

The map in **Figure 1** indicates the potential extents of basement flooding and surface seepage in the areas considered when hydraulic head changes (water table rise) along the flow path are assessed relative to ground surface elevation. Impacts to subsurface structures such as basements are possible if the theoretical water table rise reaches within a typical basement depth of 2.5 m below ground surface. **Figure 1** shows basement flooding would most likely be expected to occur within 105 m from the dike interface, and within 75 m of the dike in the higher elevation areas to the north. In a worse case, accounting for uncertainties in the hydraulic conductivity and specific yield, subsurface impacts could potentially extend as far as 150m from the interface at locations where ground surface is near or below 675 masl.

Figure 1 shows four properties with basements that are situated within the more vulnerable areas to the south and southeast, and two of these also occur close to the areas of potential surface seepage.

Table 2, above, includes calculated groundwater seepage fluxes in addition to hydraulic head changes due to flooding. The seepage flux is presented as a volumetric flow rate (m^3/d) through the entire thickness of surficial materials per m lateral length of dike. The rate of seepage occurring at the locations of subsurface structures would be a portion of that, depending on the bottom elevation of the structure relative to the flood induced

wood.

water table elevation at the location of the structure. In addition, the integrity and permeability of construction materials (eg. concrete) can be variable. The quantity of seepage into basement structures is not estimated here.

A detailed summary of the theoretical calculations for the Lehigh area are shown in **Attachment D**.

3.2 SEEP/W Model

A parallel seepage analysis by computer simulation was undertaken using SEEP/W 2-D cross-sectional modeling application (GEOSLOPE, 2016), as part of the slope stability assessment and was revised for the assessment documented herein. This analysis accounts for some of the geological complexity of the area and can simulate groundwater seepage under a more realistic flood timing scenario. The SEEP/W model base-case configuration conceptualized the surficial sand deposits as two layers – silty sand on top of gravelly sand. The silty sand was assigned a hydraulic conductivity of 5 x 10^{-6} m/s and a hydraulic conductivity of 5 x 10^{-4} m/s was assumed for the underlying gravelly sand. This is consistent with similar analyses completed for other sites in the Drumheller area, but is slightly different from the theoretical calculations, for which a value of 4.3 x 10^{-4} m/s is assigned for a single layer representing the full thickness of the surficial deposits.

Surface seepage has been reported in low-lying areas during periods of past high river levels possibly owing to variability of the near-surface materials, so a separate analysis was run assigning the upper sand layer the same hydraulic conductivity as the gravelly layer (5 x 10^{-4} m/s). The SEEP/W model analyses were performed as transient analyses that simulated head changes and seepage as a flood advanced to a peak level within 36 hours and persisted for an additional 24 hours.

The seepage flux through the surficial materials beneath the landward toe of the dike, after 24 hours of peak flood (60 hours from onset of flooding), is 22.3 m^3/d/m, as determined using the computer model for the typical 2-D section. Under the scenario assuming a high-K surface layer, the estimated seepage was 27.8 m^3/d/m. In comparison, a seepage flux of 15.9 m^3/d/m was determined, as shown in Table 1 above, by applying equation 2(a to e) for x = 20m from the flood/dike interface, and t = 72 hours after instantaneous flooding. The differences in the estimates of seepage flux are largely owing to the minor differences in hydraulic conductivities assigned to the geological materials, as well as the different flood timing assumptions used in the two approaches.

The computer models showed similar water table rise with distance at the latter stages of peak flooding – with potential for basement impacts to distances of 70 to 80 m. The results indicate possible surface daylighting of seepage to a distance of 25 m beyond the flood/dike interface (high K surface sand scenario only). This is a smaller distance than estimates obtained using equation 2 (a to e) which indicate that surface seepage may occur up to 60m behind the dike. Neither approach considered the application of a toe drain or ditch on the landward side of the dike. The model geometry and outputs from the SEEP/W analyses are shown in **Figure 3**.

4.0 Summary/Conclusions

The assessment of extent of groundwater seepage and potential impacts to properties in the community of Lehigh drew the following conclusions:

- Additional data collected from recent slug tests in standpipe piezometers and historical short duration pumping tests was analyzed to refine the representative hydraulic conductivity for the surficial deposits in the area to be used in calculations. These estimates were variable, ranging from 1.5 x 10^{-7} to 4.3 x 10^{-4} m/s. The higher values obtained from pumping tests are considered to be more reliable, are similar to previous estimates based on limited borehole grain size data and are in better agreement with observed timing of river-induced water level fluctuations in standpipe piezometers.

- Theoretical calculations of groundwater seepage and hydraulic head changes relative to ground surface under flood conditions show that impact to residential basement structures within a distance of 105 m from the flood-dike interface can occur within two to three days of peak flooding.
- Groundwater seepage to basement structures could likely impact 10 properties (lots indicated on **Figure 1**) located at the south and west extents of the area, including four current residential buildings understood to include basements.
- Daylighting of seepage at ground surface could be observed within approximately 60 m of the dike.
- Seepage of groundwater to surface may occur on the eight properties (lots indicated on **Figure 1**) that are closest to the river along the west and south extents of the community, and surface seepage could likely occur close to three residential buildings currently located among these properties.
- Minimal to no impacts would be expected in areas to the north and northeast which are sparsely developed, and/or where ground surface elevations are higher (close to 676 masl).
- Estimated distances of observed impacts are sensitive to uncertainty in hydraulic parameters such as hydraulic conductivity and specific yield.
- Computer simulations using SEEP/W produce comparable results to the theoretical calculations.

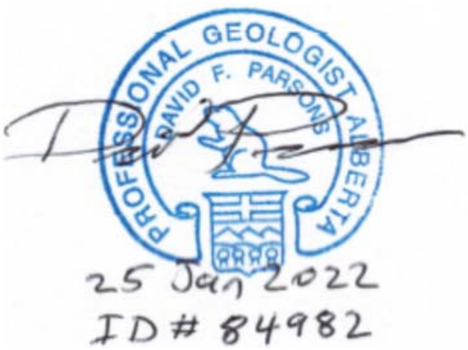
5.0 Closure

This memorandum has been prepared for the exclusive use of Wood and The Town of Drumheller. The groundwater seepage evaluation was conducted in accordance with generally accepted industry practices. Any use which a third-party makes of this document, or any reliance on or decisions to be made based upon it, are the responsibility of such third parties. Wood accepts no responsibility for damages, if any, suffered by any third-party as a result of decisions made or actions based on this report.

Wood trusts the above memorandum is satisfactory to your needs and expectations. We appreciate the opportunity to be of service to the Town of Drumheller. Should you wish to discuss any aspect of this memorandum, please do not hesitate to contact David Parsons at 403-540-5320 or david.parsons@woodplc.com.

Sincerely,
Wood Environment & Infrastructure Solutions
a Division of Wood Canada Limited

Prepared by:



David Parsons, M.Sc., P.Geol.
Senior Hydrogeologist

Reviewed by:

Sukru Sumer, PhD., P.Eng.
Senior Associate Hydrogeologist

6.0 References

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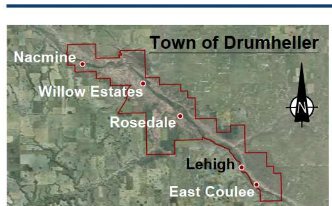
Figures

Figure 1: Location Plan – Lehigh
Figure 2: Hydrograph – Sept 2021
Figure 3: SEEP/W Output

LEHIGH SITE PLAN

LEHIGH PROPERTIES		
PROPERTY NO.	CIVIC LOCATION	LEGAL ADDRESS
1	102/106 - 2ND STREET WEST	LOT 3, BLOCK 1, PLAN 881 0626
2	244 - 3RD STREET WEST	LOT 1, BLOCK 1, PLAN 881 0626
3	215 - 2ND STREET WEST	LOT 2, BLOCK 1, PLAN 8810626
4	220 - 2ND STREET WEST	LOT 1, BLOCK 2, PLAN 881 0626
5	224 - 2ND AVENUE WEST	LOT 2, BLOCK 2, PLAN 881 0626
6	312 - 2ND STREET WEST	LOT 3, BLOCK 2, PLAN 881 0626
7	112 - 4TH STREET WEST (JOINT ADDRESS)	LOTS 9-12, BLOCK 2, PLAN 816 8FS
8	330 - 2ND STREET WEST (JOINT ADDRESS)	LOT 15-16, BLOCK 2, PLAN 816 8ES
9	330 - 2ND STREET WEST (JOINT ADDRESS)	LOT 14, BLOCK 2, PLAN 816 8ES
10	112 - 4TH STREET WEST (JOINT ADDRESS)	LOT 13, BLOCK 2, PLAN 816 8FS
11	333 - 2ND AVENUE WEST	LOTS 1-3, BLOCK 5, PLAN 816 8FS
12	337 - 2ND AVENUE WEST	LOTS 4-5, BLOCK 5, PLAN 816 8FS
13	245 - 3RD STREET WEST (JOINT ADDRESS)	LOT 14-17, BLOCK 5, PLAN 816 8FS
14	245 - 3RD STREET WEST (JOINT ADDRESS)	LOTS 12-13, BLOCK 5, PLAN 816 8FS
15	222 - 4TH STREET WEST	LOTS 6-8, BLOCK 5, PLAN 816 8FS
16	228 - 4TH STREET WEST	LOTS 9-11, BLOCK 5, PLAN 816 8FS
17	225 - 4TH STREET WEST	LOTS 5-7, BLOCK 4, PLAN 816 8FS
18	215 - 4TH STREET WEST	LOTS 1-4, BLOCK 4, PLAN 8168 F.S.
19	115 - 4TH STREET WEST	LOTS 6-10, BLOCK 3, PLAN 816 8FS
20	109 - 4TH STREET WEST	BLOCK 11, PLAN 961 1501
21	105 - 4TH STREET WEST	BLOCK 12, PLAN 961 1501



LEGEND:

- FINISHED GRADE
- ALBERTA SURVEY CONTROL MARKER
- BOREHOLE
- WATER WELL
- HOUSE WITH BASEMENT (B)
- GARAGE FLOOR (G)
- FINISHED FLOOR HOUSE (H)
- SHED (S)
- POTENTIAL IMPACT TO PROPERTIES
- POTENTIAL GROUNDWATER SEEPAGE AT SURFACE
- POTENTIAL DIKE AND SWALE EXTENTS
- FLOW BOUNDARY 1850 cms
- PROPERTY NO. (FROM TABLE)

Project Number: CW238408

Date: NOVEMBER, 2021

DRUMHELLER RESILIENCY AND FLOOD MITIGATION PROGRAM

LEHIGH COMPREHENSIVE FLOOD MITIGATION ANALYSIS REPORT

Figure 1

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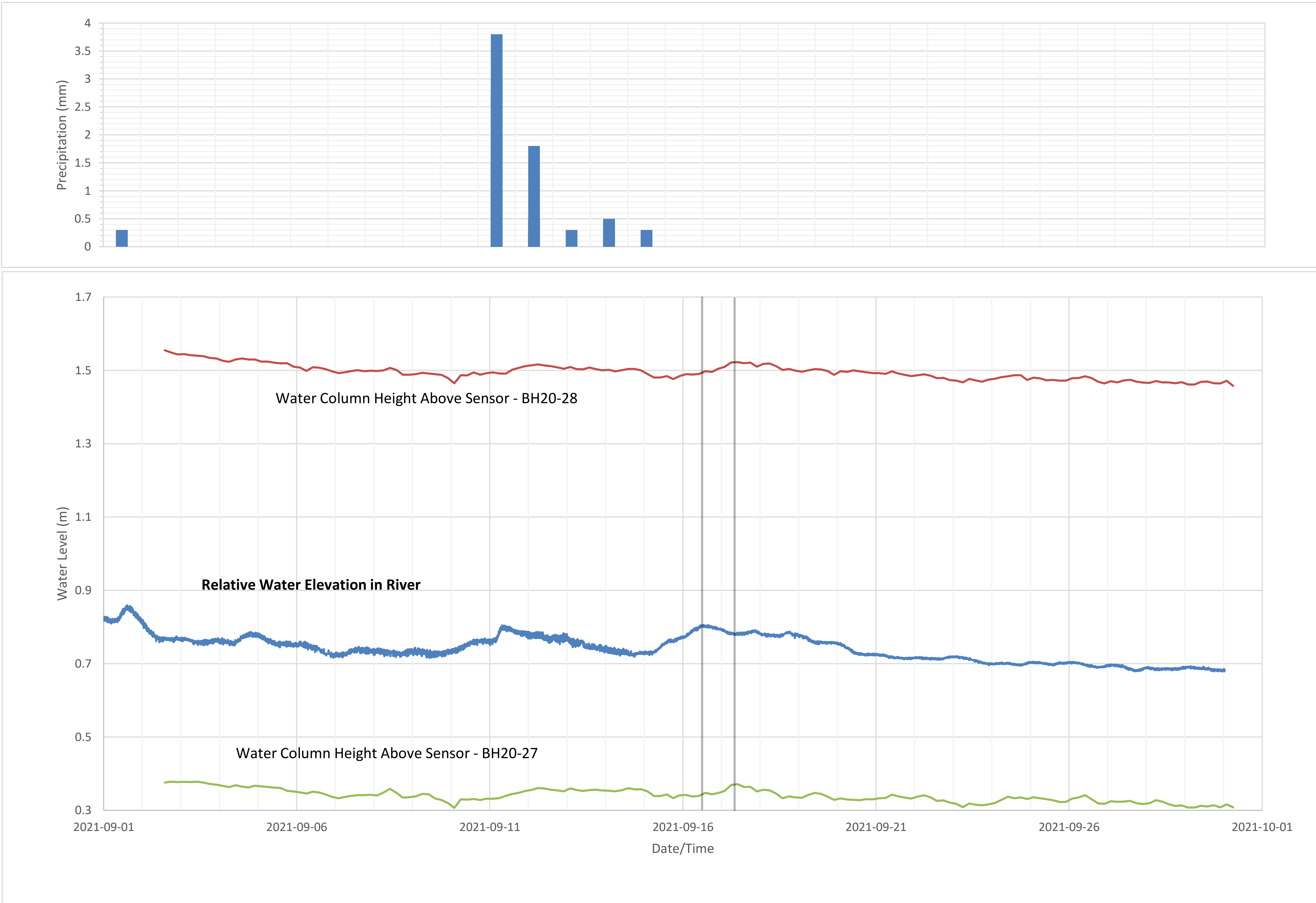


wood.

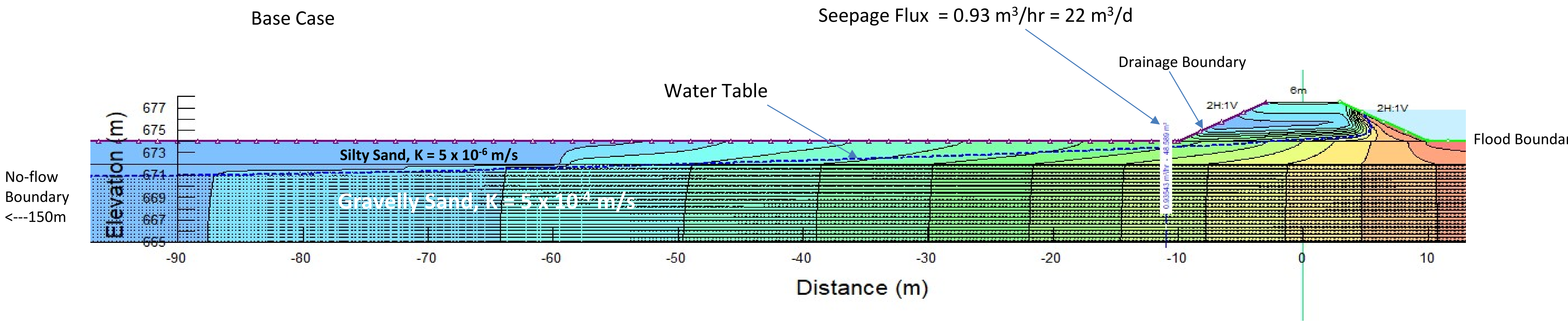
DRUMHELLER VALLEY

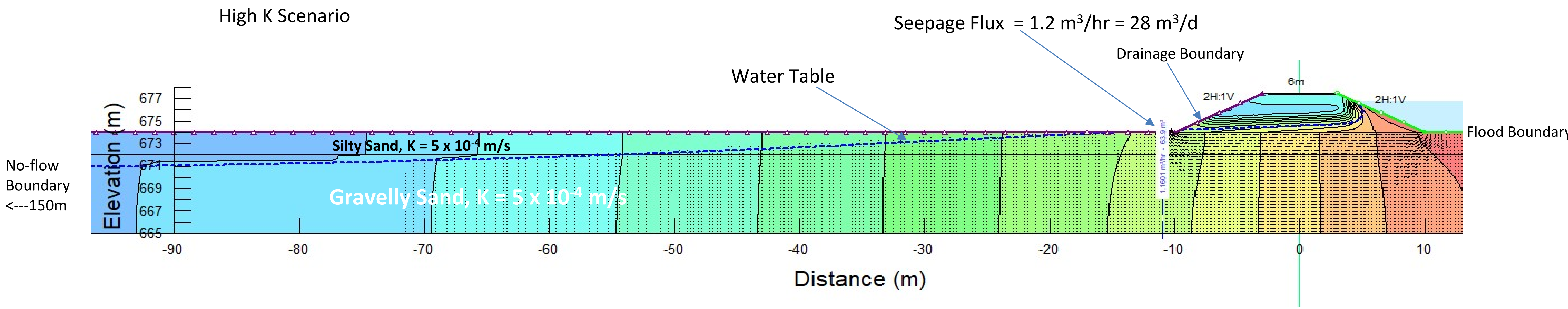
CLIENT: Town of Drumheller

PROJECT:	Drumheller Flood Mitigation Structures
TITLE:	Water Level Hydrograph

DATE:	JOB No.:	FILE:	FIGURE No.:	REV.
November 2021	CW238408	Hydrograph_rev2.xlsx	D.2	A

P:\Projects\Calgary Water\CW2384 - Drumheller -\CW238408 - Lehigh\Hydrograph_rev2.xlsx|FIGURE D.2





wood.

DRUMHELLER VALLEY

CLIENT: Town of Drumheller	PROJECT: Drumheller Flood Mitigation Structures
	TITLE: SEEP/W Results, Peak Flood @ 60h - LeHigh

DATE:	JOB No.:	FILE:	FIGURE No.:	REV.
November 2021	CW238408	Figure3_SEEP_LeHigh_rev_1121.xlsx	D.3	A

Attachment A

Water Well Reports

Water Well Drilling Report

View in Imperial | Export to Excel

The driller supplies the data contained in this report. The Province disclaims responsibility for its accuracy. The information on this report will be retained in a public database.

GOWN ID

GIC Well ID 1305518
GoA Well Tag No.
Drilling Company Well ID
Date Report Received 2013/11/04

Well Identification and Location

Measurement in Metric

Owner Name	Address	Town	Province	Country	Postal Code
BELLVEAU, DAN	P.O. BOX 1121	DRUMHELLER	ALBERTA	CANADA	T0J 0Y0

Location	1/4 or LSD	SEC	TWP	RGE	W of MER	Lot	Block	Plan	Additional Description
	16	31	27	18	4				

Measured from Boundary of
m from
m from

GPS Coordinates in Decimal Degrees (NAD 83)
Latitude 51.355906 Longitude -112.516457
How Location Obtained
Hand held autonomous GPS 20-30m

Elevation m
How Elevation Obtained
Not Obtained

Drilling Information

Method of Drilling
Rotary - Mud

Type of Work
New Well

Proposed Well Use
Domestic

Formation Log

Measurement in Metric

Depth from ground level (m)	Water Bearing	Lithology Description
7.01		Brown Clay
7.92		Gravel
8.23	Yes	Coal

Yield Test Summary

Measurement in Metric

Recommended Pump Rate 22.73 L/min

Test Date	Water Removal Rate (L/min)	Static Water Level (m)
2013/08/30	22.73	5.06

Well Completion

Measurement in Metric

Total Depth Drilled	Finished Well Depth	Start Date	End Date
8.23 m	8.23 m	2013/08/30	2013/08/30

Borehole

Diameter (cm)	From (m)	To (m)
20.02	0.00	5.79
14.92	5.79	6.71
13.02	6.71	8.23

Surface Casing (if applicable)
Plastic
Size OD : 15.24 cm
Wall Thickness : 0.965 cm
Bottom at : 6.71 m

Well Casing/Liner
Size OD : cm
Wall Thickness : cm
Top at : m
Bottom at : m

Perforations

From (m)	To (m)	Diameter or Slot Width (cm)	Slot Length (cm)	Hole or Slot Interval(cm)

Perforated by

Annular Seal Bentonite Slurry
Placed from 0.00 m to 6.71 m
Amount 26.00 Gallons

Other Seals

Type	At (m)

Screen Type Stainless Steel
Size OD : 11.43 cm

From (m)	To (m)	Slot Size (cm)
6.71	8.23	0.076

Attachment Attached To Casing
Top Fittings Threaded Bottom Fittings Plug

Pack
Type Frac Sand Grain Size 10-30
Amount 7.00 Bags

Contractor Certification

Name of Journeyman responsible for drilling/construction of well
MICHAEL PHILLIPS

Certification No
136572A

Company Name
GERRITSEN DRILLING

Copy of Well report provided to owner
Yes

Date approval holder signed
2013/11/04

Water Well Drilling Report

View in Imperial **Export to Excel**

The driller supplies the data contained in this report. The Province disclaims responsibility for its accuracy. The information on this report will be retained in a public database.

GOWN ID

GIC Well ID: 1305518
GoA Well Tag No.:
Drilling Company Well ID:
Date Report Received: 2013/11/04

Well Identification and Location

Measurement in Metric

Owner Name	Address	Town	Province	Country	Postal Code
BELLVEAU, DAN	P.O. BOX 1121	DRUMHELLER	ALBERTA	CANADA	T0J 0Y0

Location	1/4 or LSD	SEC	TWP	RGE	W of MER	Lot	Block	Plan	Additional Description
	16	31	27	18	4				

Measured from Boundary of
m from
m from

GPS Coordinates in Decimal Degrees (NAD 83)
Latitude 51.355906 Longitude -112.516457
How Location Obtained
Hand held autonomous GPS 20-30m

Elevation m
How Elevation Obtained
Not Obtained

Additional Information

Measurement in Metric

Distance From Top of Casing to Ground Level 53.34 cm
Is Artesian Flow
Rate L/min
Is Flow Control Installed
Describe

Recommended Pump Rate 22.73 L/min
Recommended Pump Intake Depth (From TOC) 6.10 m
Pump Installed
Depth m
Type
Make
H.P.
Model (Output Rating)

Did you Encounter Saline Water (>4000 ppm TDS)
Depth m
Gas
Depth m
Well Disinfected Upon Completion Yes
Geophysical Log Taken
Submitted to ESRD
Sample Collected for Potability
Submitted to ESRD

Additional Comments on Well

Yield Test

Taken From Top of Casing — Measurement in Metric

Test Date	Start Time	Static Water Level
2013/08/30	3:00 PM	5.06 m

Method of Water Removal

Type Pump
Removal Rate 22.73 L/min
Depth Withdrawn From 6.10 m

If water removal period was < 2 hours, explain why

Depth to water level

Pumping (m)	Elapsed Time Minutes:Sec	Recovery (m)
5.06	0:00	5.22
5.35	2:00	5.00
5.29	4:00	5.06
5.21	6:00	5.06
5.22	10:00	5.07
5.21	20:00	5.07
5.22	30:00	5.08
5.22	40:00	5.08
5.22	60:00	5.09
5.22	80:00	5.09
5.22	100:00	5.09
5.22	128:00	5.09

Water Diverted for Drilling

Water Source	Amount Taken	Diversion Date & Time
VILLAGE OF ROCKFORD	9092.18 L	2013/08/30 9:00 AM

Contractor Certification

Name of Journeyman responsible for drilling/construction of well
MICHAEL PHILLIPS

Certification No
136572A

Company Name
GERRITSEN DRILLING

Copy of Well report provided to owner
Yes

Date approval holder signed
2013/11/04

Water Well Drilling Report

View in Imperial **Export to Excel**

The driller supplies the data contained in this report. The Province disclaims responsibility for its accuracy. The information on this report will be retained in a public database.

GIC Well ID	1305546
GoA Well Tag No.	
Drilling Company Well ID	
Date Report Received	2014/06/14

GOWN ID

Well Identification and Location

Measurement in Metric

Owner Name	Address	Town	Province	Country	Postal Code
STEWARD, DON	P.O. BOX 218	DRUMHELLER	ALBERTA	CANADA	T0J 0Y0

Location	1/4 or LSD	SEC	TWP	RGE	W of MER	Lot	Block	Plan	Additional Description
	16	31	27	18	4				

Measured from Boundary of
m from
m from

GPS Coordinates in Decimal Degrees (NAD 83)
Latitude 51.355999 Longitude -112.515932
How Location Obtained
Not Verified

Elevation m
How Elevation Obtained
Not Obtained

Drilling Information

Method of Drilling
Rotary - Mud

Proposed Well Use
Domestic

Type of Work
New Well

Formation Log

Measurement in Metric

Depth from ground level (m)	Water Bearing	Lithology Description
4.57		Brown Sandy Clay
5.79		Sand
7.62		Gravel

Yield Test Summary

Measurement in Metric

Recommended Pump Rate 9.09 L/min

Test Date	Water Removal Rate (L/min)	Static Water Level (m)
2014/06/06	9.09	4.39

Well Completion

Measurement in Metric

Total Depth Drilled	Finished Well Depth	Start Date	End Date
7.62 m	7.62 m	2014/06/06	2014/06/06

Borehole

Diameter (cm)	From (m)	To (m)
20.02	0.00	7.62

Surface Casing (if applicable)
Size OD : cm
Wall Thickness : cm
Bottom at : m

Well Casing/Liner
Plastic
Size OD : 15.24 cm
Wall Thickness : 0.965 cm
Top at : m
Bottom at : 4.57 m

Perforations

From (m)	To (m)	Diameter or Slot Width (cm)	Slot Length (cm)	Hole or Slot Interval(cm)

Perforated by

Annular Seal Bentonite Chips/Tablets
Placed from 0.00 m to 4.57 m
Amount 8.00 Bags

Other Seals

Type	At (m)

Screen Type Stainless Steel
Size OD : 11.43 cm

From (m)	To (m)	Slot Size (cm)
4.57	7.62	0.076

Attachment Attached To Casing
Top Fittings Threaded Bottom Fittings Plug

Pack
Type Frac Sand Grain Size 10-20
Amount 13.00 Bags

Contractor Certification

Name of Journeyman responsible for drilling/construction of well
MILES O'KEEFE

Certification No
145068A

Company Name
GERRITSEN DRILLING

Copy of Well report provided to owner
Yes

Date approval holder signed
2014/06/14

Water Well Drilling Report

View in Imperial | Export to Excel

The driller supplies the data contained in this report. The Province disclaims responsibility for its accuracy. The information on this report will be retained in a public database.

GOWN ID

GIC Well ID: 1305546
GoA Well Tag No.:
Drilling Company Well ID:
Date Report Received: 2014/06/14

Well Identification and Location

Measurement in Metric

Owner Name	Address	Town	Province	Country	Postal Code
STEWARD, DON	P.O. BOX 218	DRUMHELLER	ALBERTA	CANADA	T0J 0Y0

Location	1/4 or LSD	SEC	TWP	RGE	W of MER	Lot	Block	Plan	Additional Description
	16	31	27	18	4				

Measured from Boundary of
m from
m from

GPS Coordinates in Decimal Degrees (NAD 83)
Latitude 51.355999 Longitude -112.515932
How Location Obtained: Not Verified

Elevation m
How Elevation Obtained: Not Obtained

Additional Information

Measurement in Metric

Distance From Top of Casing to Ground Level cm
Is Artesian Flow
Rate L/min
Is Flow Control Installed
Describe

Recommended Pump Rate 9.09 L/min
Recommended Pump Intake Depth (From TOC) 6.10 m
Pump Installed
Depth m
Type
Make
H.P.
Model (Output Rating)

Did you Encounter Saline Water (>4000 ppm TDS) Depth m
Gas Depth m
Well Disinfected Upon Completion Yes
Geophysical Log Taken
Submitted to ESRD
Sample Collected for Potability
Submitted to ESRD

Additional Comments on Well

Yield Test

Taken From Top of Casing — Measurement in Metric

Test Date	Start Time	Static Water Level
2014/06/06	3:00 PM	4.39 m

Method of Water Removal

Type PUMP
Removal Rate 9.09 L/min
Depth Withdrawn From 6.10 m

If water removal period was < 2 hours, explain why

Depth to water level

Pumping (m)	Elapsed Time Minutes:Sec	Recovery (m)
4.39	0:00	4.70
4.49	2:00	4.61
4.49	4:00	4.61
4.50	6:00	4.61
4.51	8:00	4.61
4.52	10:00	4.61
4.53	16:00	4.62
4.54	20:00	4.62
4.57	30:00	4.63
4.59	40:00	4.62
4.61	50:00	4.62
4.63	60:00	4.62
4.65	80:00	4.62
4.68	100:00	4.62
4.70	124:00	4.62

Water Diverted for Drilling

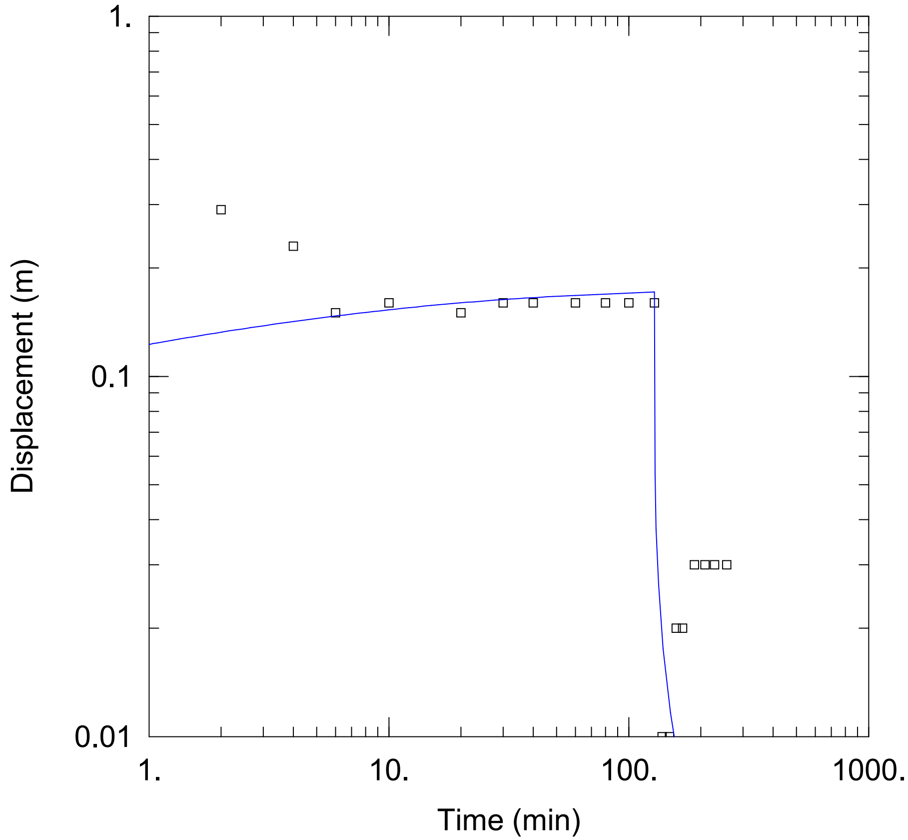
Water Source	Amount Taken	Diversion Date & Time
TOWN OF STRATHMORE	9092.18 L	2014/06/06 9:00 AM

Contractor Certification

Name of Journeyman responsible for drilling/construction of well: MILES O'KEEFE
Certification No: 145068A
Company Name: GERRITSEN DRILLING
Copy of Well report provided to owner: Yes
Date approval holder signed: 2014/06/14

Attachment B

Pumping Test and Slug Test Analyses



WELL TEST ANALYSIS

Data Set: C:\...\Belliveau_PumpTest_Neu.aqt
Date: 10/20/21 Time: 13:26:58

PROJECT INFORMATION

Company: Wood.
Client: Town of Drumheller
Project: CW238408
Location: BH20-28
Test Well: BH20-28
Test Date: 2 Sep.2021

SOLUTION

Aquifer Model: Unconfined
Solution Method: Neuman

$T = 0.001826\ m^2/sec$
$S = 0.0116$
$Sy = 0.3236$
$ß = 1.073E-5$

AQUIFER DATA

Saturated Thickness: 4.285 m

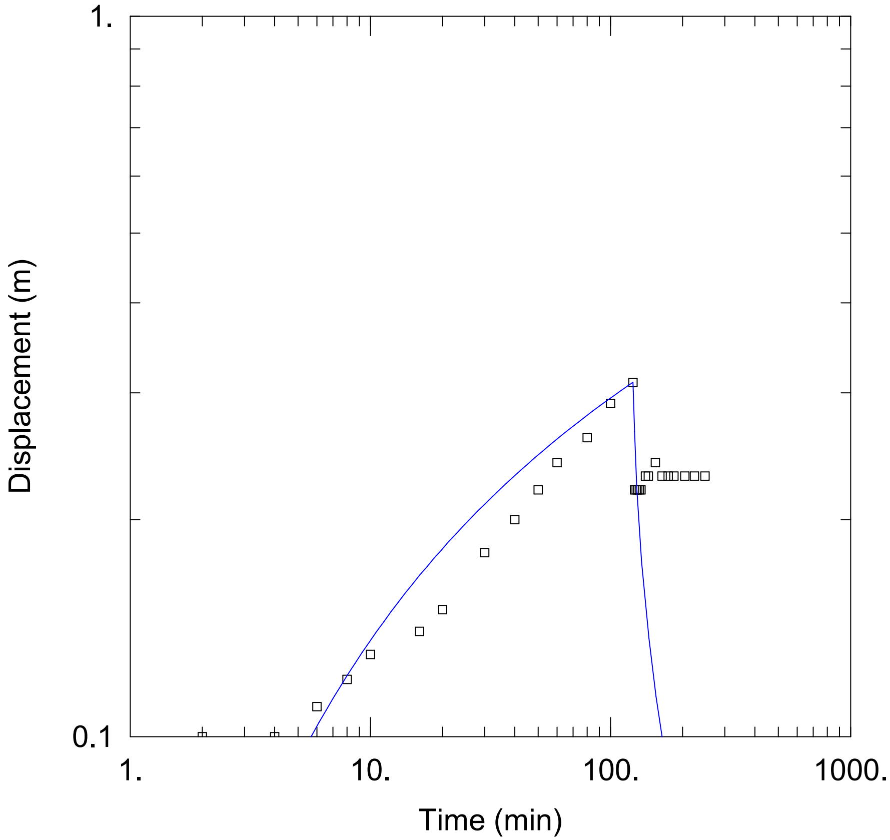
WELL DATA

Pumping Wells

Well Name	X (m)	Y (m)
Belliveau	0	0

Observation Wells

Well Name	X (m)	Y (m)
□ Belliveau	0	0



WELL TEST ANALYSIS

Data Set: C:\...\Steward_PumpTest_Neu.aqt
Date: 10/20/21 Time: 13:28:42

PROJECT INFORMATION

Company: Wood.
Client: Town of Drumheller
Project: CW238408
Location: BH20-28
Test Well: BH20-28
Test Date: 2 Sep.2021

SOLUTION

Aquifer Model: Unconfined
Solution Method: Neuman

T = 0.0001684 m^2/sec
S = 3.421
Sy = 0.3
ß = 6.747

AQUIFER DATA

Saturated Thickness: 4.285 m

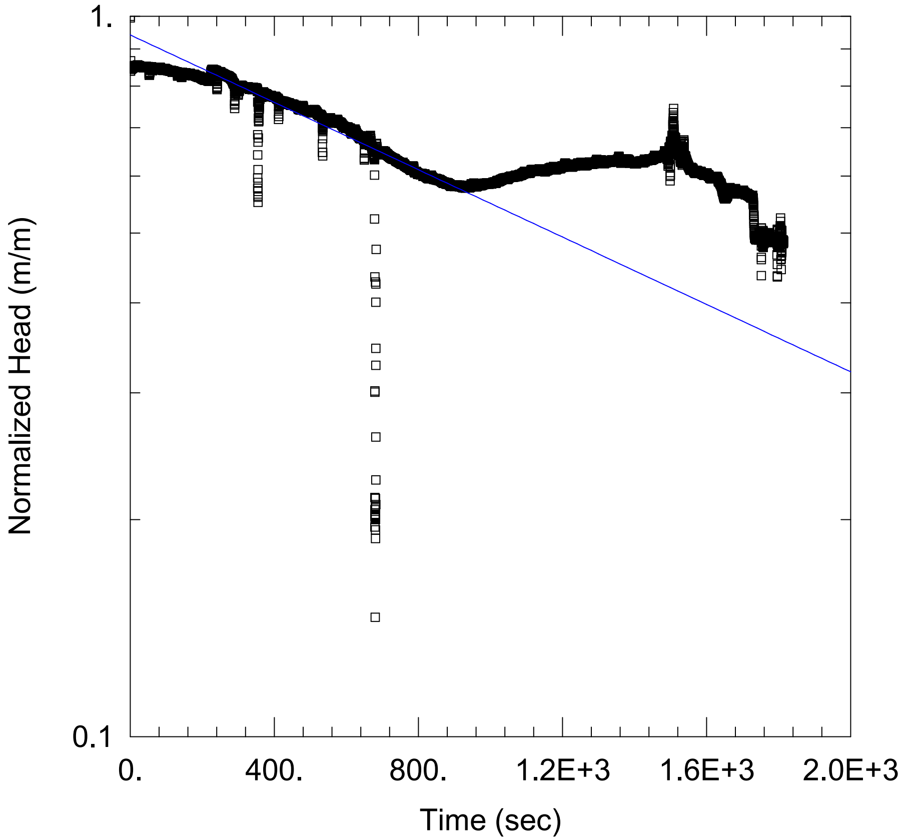
WELL DATA

Pumping Wells

Well Name	X (m)	Y (m)
Steward	0	0

Observation Wells

Well Name	X (m)	Y (m)
□ Steward	0	0



WELL TEST ANALYSIS

Data Set: C:\...\BH27_test1.aqt
Date: 10/20/21 Time: 13:29:53

PROJECT INFORMATION

Company: Wood.
Client: Town of Drumheller
Project: CW238408
Location: BH20-28
Test Well: BH20-28
Test Date: 2 Sep.2021

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev

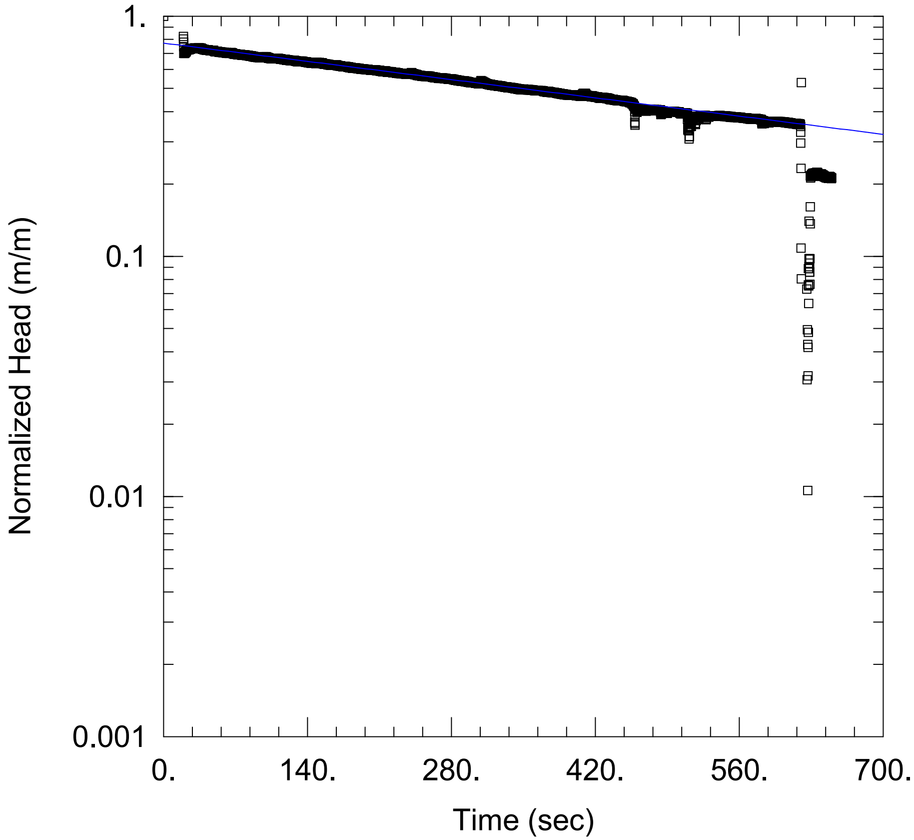
K = 1.505E-7 m/sec
y0 = 0.1601 m

AQUIFER DATA

Saturated Thickness: 4.285 m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (BH20-27)

Initial Displacement: 0.17 m
Total Well Penetration Depth: 0.6 m
Casing Radius: 0.0127 m
Static Water Column Height: 4.285 m
Screen Length: 0.6 m
Well Radius: 0.0762 m



WELL TEST ANALYSIS

Data Set: C:\...\BH27_test2.aqt
Date: 10/20/21 Time: 13:31:01

PROJECT INFORMATION

Company: Wood.
Client: Town of Drumheller
Project: CW238408
Location: BH20-28
Test Well: BH20-28
Test Date: 2 Sep.2021

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev

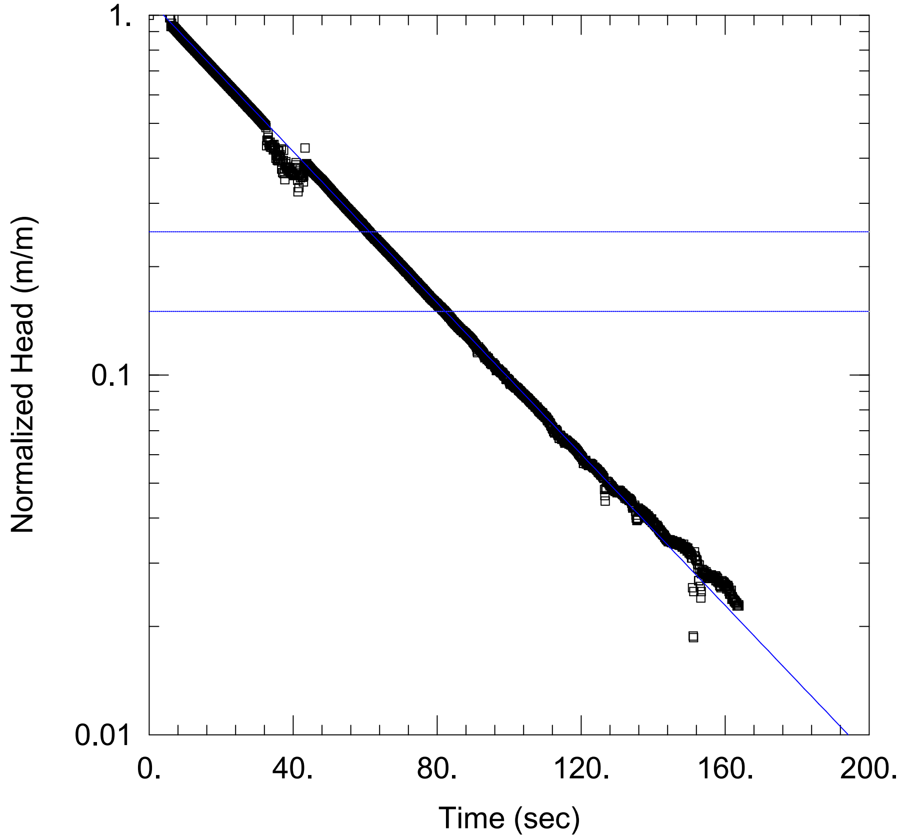
K = 3.493E-7 m/sec
y0 = 0.1313 m

AQUIFER DATA

Saturated Thickness: 4.285 m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (BH20-27)

Initial Displacement: 0.17 m
Total Well Penetration Depth: 0.6 m
Casing Radius: 0.0127 m
Static Water Column Height: 4.285 m
Screen Length: 0.6 m
Well Radius: 0.0762 m



WELL TEST ANALYSIS

Data Set: C:\...\BH28_test1.aqt
Date: 10/20/21 Time: 13:31:58

PROJECT INFORMATION

Company: Wood.
Client: Town of Drumheller
Project: CW238408
Location: BH20-28
Test Well: BH20-28
Test Date: 2 Sep.2021

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev

K = 1.719E-5 m/sec
y0 = 0.5505 m

AQUIFER DATA

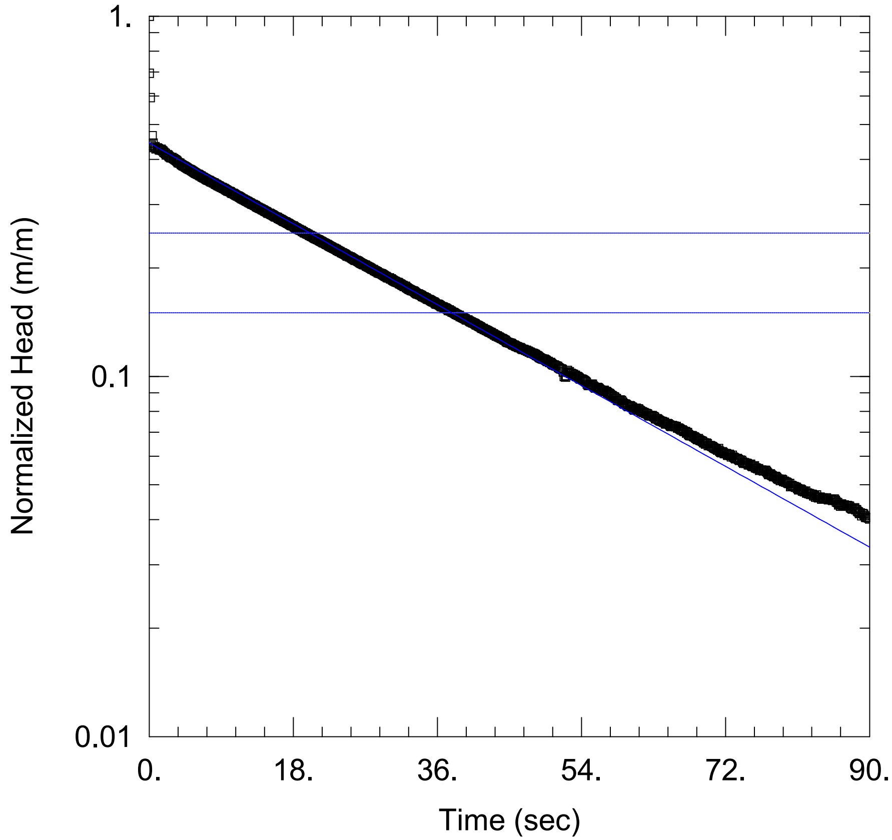
Saturated Thickness: 4.285 m

Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (BH20-28)

Initial Displacement: 0.5 m
Total Well Penetration Depth: 1.285 m
Casing Radius: 0.0254 m

Static Water Column Height: 4.285 m
Screen Length: 1.285 m
Well Radius: 0.0762 m



WELL TEST ANALYSIS

Data Set: C:\...\BH28_test2.aqt
Date: 10/20/21 Time: 13:32:41

PROJECT INFORMATION

Company: Wood.
Client: Town of Drumheller
Project: CW238408
Location: BH20-28
Test Well: BH20-28
Test Date: 2 Sep.2021

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev

K = 2.039E-5 m/sec
y0 = 0.2224 m

AQUIFER DATA

Saturated Thickness: 4.285 m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (BH20-28)

Initial Displacement: 0.5 m
Total Well Penetration Depth: 1.285 m
Casing Radius: 0.0254 m
Static Water Column Height: 4.285 m
Screen Length: 1.285 m
Well Radius: 0.0762 m

Attachment C

Particle Size Data

SIEVE ANALYSIS REPORT (ASTM C136 / ATT 25/26)

Wood Environment & Infrastructure Solutions
A Division of Wood Canada Limited

To: Town of Drumheller

Office: Wood Calgary Materials
Project No: CW238404
Client: Town of Drumheller
Copies to:

Attn: Sattar Khan

Project: Drumheller Resiliency and Flood Mitigation

Sample ID:

Sample Type: Grab

Sampled By: Naeem A.

Date Sampled: March, 2021

Date Received: March, 2021

Date Tested: 30-Mar-21

Sieve Size	% Passing
150.0	
125.0	
100.0	
80.0	
50.0	
40.0	
28.0	
25.0	100
20.0	85
16.0	81
14.0	
12.5	77
10.0	75
5.0	67
2.5	63
1.250	54
0.630	43
0.315	33
0.160	25.2
0.080	16.0

Source: BH21-B08 G3 @ 3.9-4.2 m
Sample Description: Gravelly sand, some fines
Comments :

Wood Environment & Infrastructure Solutions
A Division of Wood Canada Limited

Reviewed By: HM

Reporting of these test results constitutes a testing service only. Engineering interpretation or evaluation of the test results will be provided only upon written request. If you are not the Intended recipient please notify us by telephone as soon as possible and either return the message by post or destroy it. If you are not the intended recipient, any use by you of its contents is prohibited.

Attachment D

Seepage Calculations

Project: Drumheller Flood Mitigation
Location: LeHigh

Scenario 1: T = 1d

Parameters		**Distance**	
K(m/s)=	4.30E-04	x_1(m)=	20
b(m)=	9	x_2(m)=	40
S_y=	0.2	x_3(m)=	60
S_o(m)=	6.1	x_4(m)=	80
t(day)=	1	x_5(m)=	100

q_o = 0.00032574 m^3/s 28.1438 m^3/d

Unsteady one-dimensional flow

u = 0.5*(sqrt(S_y/Kb))*(x/sqrt(t))

q_o = (s_o/sqrt(π)) * (sqrt(S_y*K*b))*(1/sqrt(t))

E_1 = erfc(u) $E_2 = e^{-u^2}$

s = S_o*E_1 q = q_o*E_2

				Head Change (s_n at distance x_n)				**Seepage rate per metre** m^3/s	m^3/d	L/min
u_1=	0.244569696	E_1=	0.729438	s_1= 4.449569	E_2=	0.941939	q_1=	0.000306826	26.50972724	18.40953
u_2=	0.489139392	E_1=	0.489096	s_2= 2.983485	E_2=	0.787212	q_2=	0.000256425	22.15512224	15.3855
u_3=	0.733709089	E_1=	0.299446	s_3= 1.826623	E_2=	0.583723	q_3=	0.000190141	16.42816173	11.40845
u_4=	0.978278785	E_1=	0.166513	**s_4= 1.01573**	E_2=	0.384032	q_4=	0.000125094	10.80810901	**7.505631**
u_5=	1.222848481	E_1=	0.083743	s_5= 0.510833	E_2=	0.224168	q_5=	7.30201E-05	6.308939904	4.381208

Scenario 2: T = 2d

Parameters		**Distance**	
K(m/s)=	4.30E-04	x_1(m)=	20
b(m)=	9	x_2(m)=	40
S_y=	0.2	x_3(m)=	60
S_o(m)=	6.1	x_4(m)=	80
t(day)=	2	x_5(m)=	100

q_o = 0.00023033 19.9007 m^3/d

				Head Change (s_n at distance x_n)				**Seepage rate per metre** m^3/s	m^3/d	L/min
u_1=	0.172936891	E_1=	0.80679	s_1= 4.921417	E_2=	0.970536	q_1=	0.000223545	19.3142914	13.4127
u_2=	0.345873781	E_1=	0.624743	s_2= 3.810932	E_2=	0.88725	q_2=	0.000204362	17.6568499	12.2617
u_3=	0.518810672	E_1=	0.463126	s_3= 2.825069	E_2=	0.764018	q_3=	0.000175977	15.2044472	10.55864
u_4=	0.691747563	E_1=	0.327936	s_4= 2.000412	E_2=	0.619703	q_4=	0.000142737	12.3324967	8.564234
u_5=	0.864684453	E_1=	0.221387	s_5= 1.35046	E_2=	0.473464	q_5=	0.000109054	9.422243969	6.543225

Project: Drumheller Flood Mitigation
Location: LeHigh

Scenario 3: T = 3d

Parameters		Distance	
K(m/s)=	4.30E-04	x_1(m)=	20
b(m)=	9	x_2(m)=	40
S_y=	0.2	x_3(m)=	60
S_o(m)=	6.1	x_4(m)=	80
t(day)=	3	x_5(m)=	100
q_o =	**0.00018806** m^3/s		**16.2488** m^3/d

Unsteady one-dimensional flow

u = 0.5*(sqrt(S_y/Kb))*(x/sqrt(t))
q_o = (s_o/sqrt(π)) * (sqrt(S_y*K*b))*(1/sqrt(t))
E_1 = erfc(u) $E_2 = e^{-u^2}$
s = S_o*E_1 q = q_o*E_2

		Head Change (s_n at distance x_n)		Seepage rate per metre m³/s	m³/d	L/min
u_1= 0.14120238	E_1= 0.841723	s_1= 5.134509	E_2= 0.980259	q_1= 0.000184352	15.92805168	11.06115
u_2= 0.28240476	E_1= 0.689613	s_2= 4.206638	E_2= 0.923345	q_2= 0.000173649	15.00325946	10.41893
u_3= 0.42360714	E_1= 0.549126	s_3= 3.349666	E_2= 0.835736	q_3= 0.000157173	13.579712	9.430356
u_4= 0.56480952	E_1= 0.424429	**s_4= 2.589016**	E_2= 0.726868	q_4= 0.000136698	11.81074995	**8.20191**
u_5= 0.7060119	E_1= 0.31806	s_5= 1.940169	E_2= 0.60747	q_5= 0.000114244	9.87066395	6.854628

Scenario 4: Sy = 0.1

Parameters		Distance	
K(m/s)=	4.30E-04	x_1(m)=	20
b(m)=	9	x_2(m)=	40
S_y=	0.1	x_3(m)=	60
S_o(m)=	6.1	x_4(m)=	80
t(day)=	3	x_5(m)=	100
q_o =	**0.00013298**		**11.4896** m^3/d

		Head Change (s_n at distance x_n)		Seepage rate per metre m³/s	m³/d	L/min
u_1= 0.09984516	E_1= 0.88771	s_1= 5.415031	E_2= 0.99008	q_1= 0.000131663	11.37567469	7.899774
u_2= 0.199690321	E_1= 0.777633	s_2= 4.743562	E_2= 0.960908	q_2= 0.000127784	11.04049756	7.667012
u_3= 0.299535481	E_1= 0.671852	s_3= 4.098299	E_2= 0.914186	q_3= 0.00012157	10.50367114	7.294216
u_4= 0.399380641	E_1= 0.572203	s_4= 3.49044	E_2= 0.852566	q_4= 0.000113376	9.795679646	6.802555
u_5= 0.499225802	E_1= 0.480181	s_5= 2.929102	E_2= 0.779403	q_5= 0.000103647	8.95507071	6.218799

Project: Drumheller Flood Mitigation
Location: LeHigh

Scenario 5: K = 1 x 10-3

Parameters		Distance	
K(m/s)=	1.00E-03	x_1(m)=	20
b(m)=	9	x_2(m)=	40
S_y=	0.2	x_3(m)=	60
S_o(m)=	6.1	x_4(m)=	80
t(day)=	3	x_5(m)=	100

q_o = 0.0002868 m^3/s 24.7792 m^3/d

Unsteady one-dimensional flow

u = 0.5*(sqrt(S_y/Kb))*(x/sqrt(t))
q_o = (s_o/sqrt(π)) * (sqrt(S_y*K*b))*(1/sqrt(t))
E_1 = erfc(u) $E_2 = e^{-u^2}$
s = S_o*E_1 q = q_o*E_2

				Head Change (s_n at distance x_n)				**Seepage rate per metre** m^3/s	m^3/d	L/min
u_1=	0.092592593	E_1=	0.895818	s_1= 5.464491	E_2=	0.991463	q_1=	0.000284348	24.56767538	17.06089
u_2=	0.185185185	E_1=	0.793405	s_2= 4.839772	E_2=	0.966288	q_2=	0.000277128	23.9438476	16.62767
u_3=	0.277777778	E_1=	0.69444	s_3= 4.236083	E_2=	0.925741	q_3=	0.000265499	22.93913639	15.92996
u_4=	0.37037037	E_1=	0.60043	s_4= 3.662621	E_2=	0.871818	q_4=	0.000250034	21.60296874	15.00206
u_5=	0.462962963	E_1=	0.512643	s_5= 3.12712	E_2=	0.807078	q_5=	0.000231467	19.99875963	13.88803

Scenario 6: K = 1 x 10-4

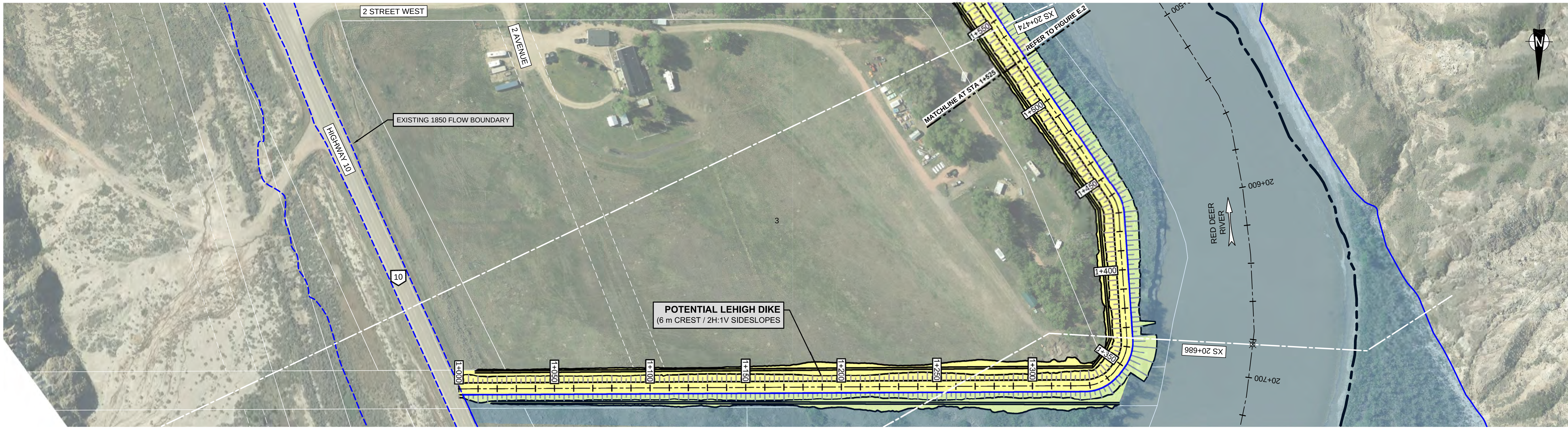
Parameters		Distance	
K(m/s)=	1.00E-04	x_1(m)=	20
b(m)=	9	x_2(m)=	40
S_y=	0.2	x_3(m)=	60
S_o(m)=	6.1	x_4(m)=	80
t(day)=	3	x_5(m)=	100

q_o = 9.0693E-05 7.83587 m^3/d

				Head Change (s_n at distance x_n)				**Seepage rate per metre** m^3/s	m^3/d	L/min
u_1=	0.292803487	E_1=	0.678811	s_1= 4.140745	E_2=	0.917838	q_1=	8.32415E-05	7.192066401	4.994491
u_2=	0.585606974	E_1=	0.407572	s_2= 2.486191	E_2=	0.709684	q_2=	6.43634E-05	5.56099408	3.861801
u_3=	0.878410461	E_1=	0.214141	s_3= 1.306258	E_2=	0.462271	q_3=	4.19247E-05	3.622293807	2.515482
u_4=	1.171213948	E_1=	0.097652	s_4= 0.595675	E_2=	0.253665	q_4=	2.30056E-05	1.987684313	1.380336
u_5=	1.464017435	E_1=	0.038412	s_5= 0.234312	E_2=	0.117262	q_5=	1.06348E-05	0.918847934	0.638089

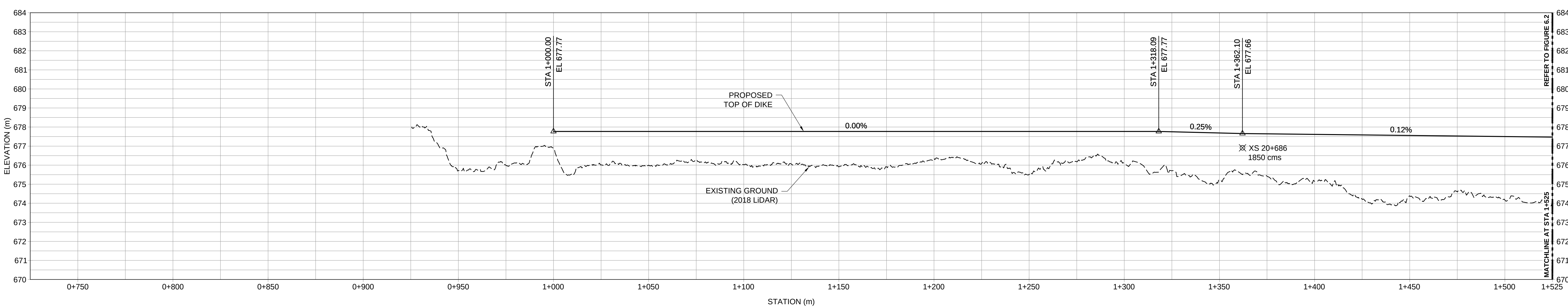
Appendix E – Dike Plan, Profile and Cross Sections

LEHIGH
PLAN AND PROFILE (1 of 2)



PLAN - LEHIGH DIKE CENTERLINE

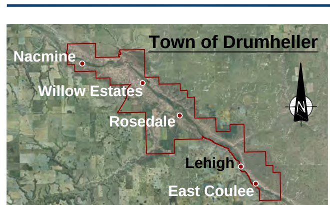
Scale 1:1000



0 25 50
1:1000 Meters

PROFILE - LEHIGH DIKE CENTERLINE

Scale H 1:1000 \ V 1:100



NOTES:

1. EXISTING GROUND CONTOURS INFORMATION WAS DERIVED FROM LIDAR (2018) AND PROVIDED BY DRFMO.
2. HIGH RESOLUTION AERIAL PHOTO FROM 2019 AND PROVIDED BY DRFMO.
3. FOR DIKE CROSS SECTIONS SEE APPENDIX E, FIG E.3.

LEGEND:

- POTENTIAL DIKE AND SWALE EXTENTS
- FLOW BOUNDARY 1850 cms
- RIVER CROSS SECTION STATION LABEL — XS XX+XXX
- BOREHOLE
- WATER WELL

Project Number: CW238408

Date: OCTOBER, 2021

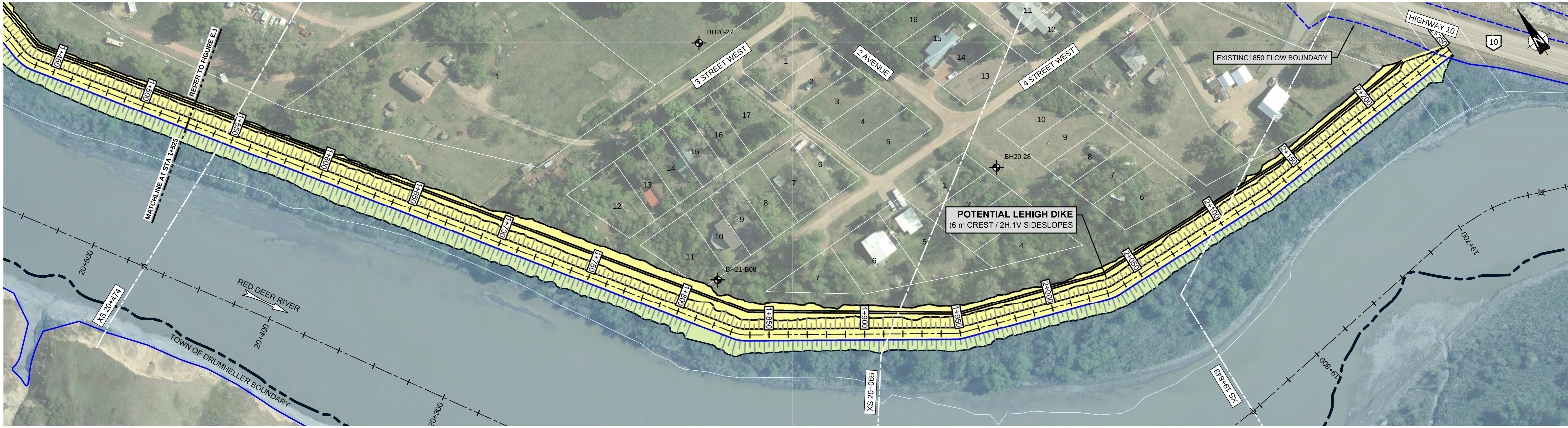
wood.

DRUMHELLER RESILIENCY AND FLOOD MITIGATION PROGRAM

LEHIGH COMPREHENSIVE FLOOD MITIGATION ANALYSIS REPORT

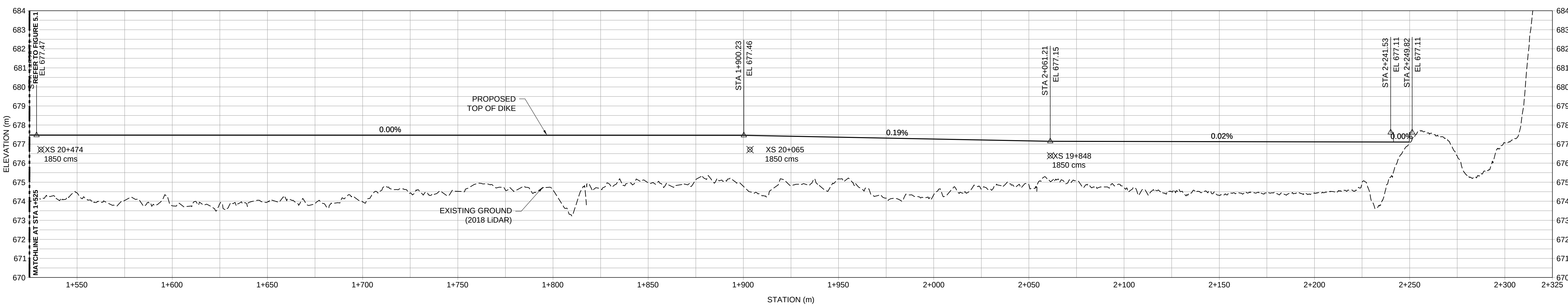
Figure E.1

LEHIGH
PLAN AND PROFILE (2 of 2)



PLAN - LEHIGH DIKE CENTERLINE

Scale 1:1000

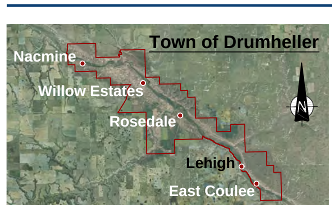


0 25 50

1:1000 Meters

PROFILE - LEHIGH DIKE CENTERLINE

Scale H 1:1000 \ V 1:100



NOTES:

1. EXISTING GROUND CONTOURS INFORMATION WAS DERIVED FROM LIDAR (2018) AND PROVIDED BY DRFMO.
2. HIGH RESOLUTION AERIAL PHOTO FROM 2019 AND PROVIDED BY DRFMO.
3. FOR DIKE CROSS SECTIONS SEE APPENDIX E, FIG E.3.

LEGEND:

- POTENTIAL DIKE AND SWALE EXTENTS
- FLOW BOUNDARY 1850 cms
- RIVER CROSS SECTION STATION LABEL — XS XX+XXX
- BOREHOLE
- WATER WELL

Project Number: CW238408

Date: OCTOBER, 2021

wood.

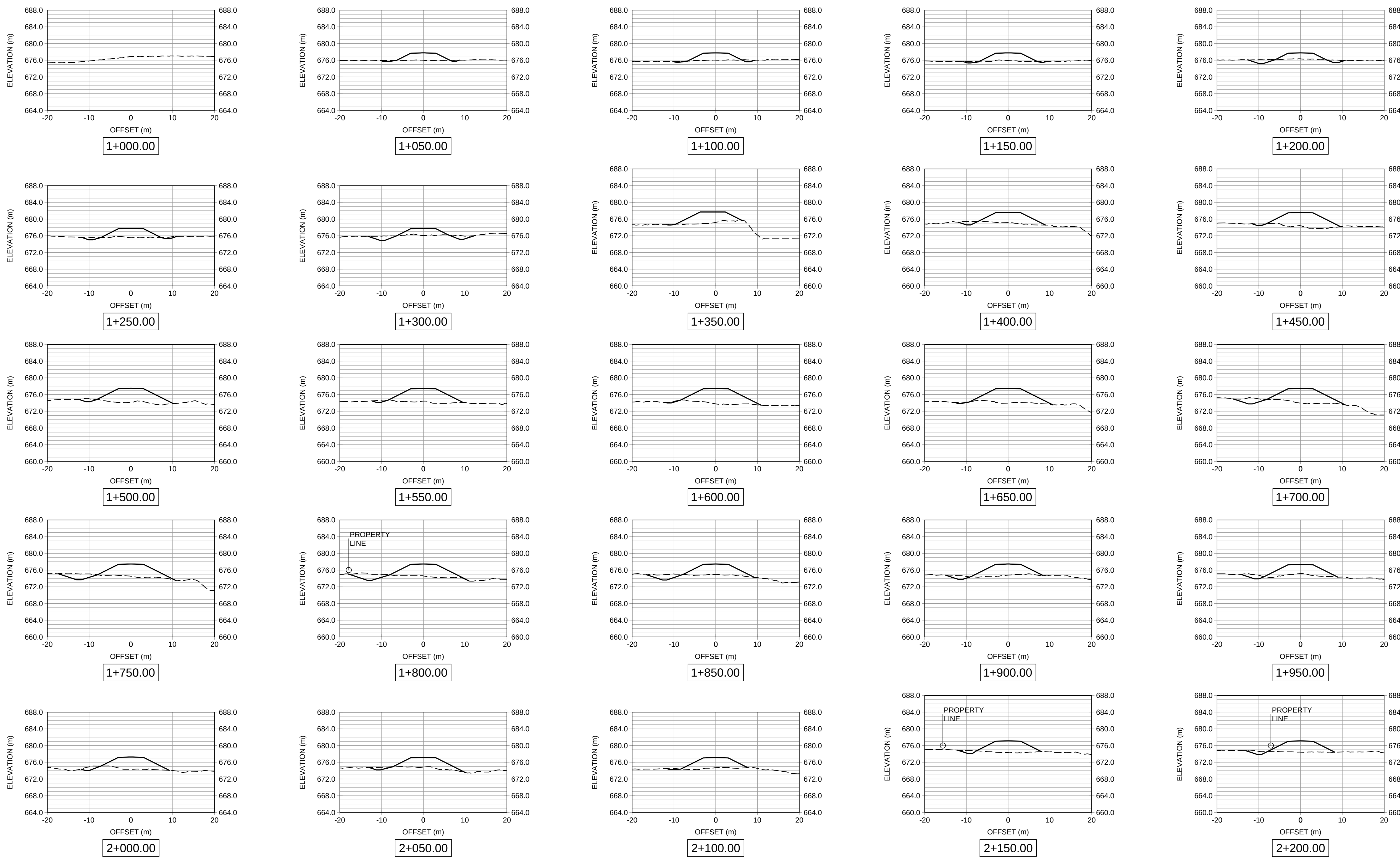
DRUMHELLER RESILIENCY AND FLOOD MITIGATION PROGRAM

LEHIGH COMPREHENSIVE FLOOD MITIGATION ANALYSIS REPORT

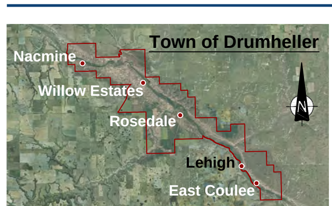
Figure E.2

DRUMHELLER VALLEY

LEHIGH DIKE CROSS SECTIONS



0 12.5 25
1:500 Meters



Project Number: CW238408

Date: OCTOBER, 2021

wood.

DRUMHELLER RESILIENCY AND FLOOD MITIGATION PROGRAM
LEHIGH COMPREHENSIVE FLOOD MITIGATION ANALYSIS REPORT

Figure E.3

Appendix F – Construction Cost Estimate

Table F1: Lehigh Dike Construction Cost Estimate

Item	Description	Qty.	Unit	Unit Price	Price
Construction					
Allowances					
1.01	Road Reclamation	1	LS	$50,000	$50,000
1.02	Demolition and Removal	1	LS	$50,000	$50,000
Temporary					
1.03	Mobilization / Demobilization	1	LS	$220,000	$220,000
1.04	Site Security - Fencing	1	LS	$30,000	$30,000
1.05	Stockpile Access	1	LS	$50,000	$50,000
1.06	Stockpile Reclamation	1	LS	$20,000	$20,000
1.07	Traffic Accomodation	1	LS	$10,000	$10,000
Site Preparation					
1.08	Clear and Grub	2.87	ha	$50,000	$143,343
1.09	Care of Water	1	LS	$27,000	$27,000
1.10	Erosion and Sediment Control	1	LS	$50,000	$50,000
1.11	Environmental Monitoring	1	LS	$85,000	$85,000
Excavation & Fill Placement					
1.12	Common Excavation	6,687	m^3	$8	$53,493
1.13	Borrow Excavation	34,086	m^3	$25	$852,158
1.14	Supply and Place Topsoil	132	m^3	$65	$8,576
1.15	Access Roads	2	Ea.	$10,000	$20,000
1.16	Over Excavation	8,747	m^3	$18	$157,437
1.17	Impervious Fill	174	m^3	$60	$10,415
Surface Protection					
1.18	Bedding Gravel	206	m^3	$60	$12,355
1.19	Class 1M Riprap	569	m^3	$225	$127,917
Ancillary					
1.20	Corrugated Steel Pipe - 450 mm Diameter	30	m	$400	$12,000
1.21	Concrete Pipe - 600 mm Diameter	60	m	$550	$33,000
1.22	Concrete Pipe - 900 mm Diameter	40	m	$1,100	$44,000
1.23	Precast Concrete Pipe Flared End - 600 mm Diameter	3	Ea.	$5,000	$15,000
1.24	Precast Concrete Pipe Flared End - 900 mm Diameter	2	Ea.	$10,000	$20,000
1.25	Precast Concrete Pipe Headwall - 600 mm Diameter	3	Ea.	$6,000	$18,000
1.26	Precast Concrete Pipe Headwall - 900 mm Diameter	2	Ea.	$12,000	$24,000
1.27	1220 x 1220 Precast Concrete Gatewell Structure with MSU Access Hatch and Ladder Rungs	3	Ea.	$30,000	$90,000
1.28	2800 x 1220 Precast Concrete Gatewell Structure with MSU Access Hatch and Ladder Rungs	1	Ea.	$60,000	$60,000
1.29	Non-rising Stem Sluice Gate - 610 mm	3	Ea.	$5,000	$15,000
1.30	Non-rising Stem Sluice Gate - 910 mm	2	Ea.	$8,000	$16,000
1.31	Cast Iron Double Hinged Flap Gate - 610 mm	3	Ea.	$5,000	$15,000
1.32	Cast Iron Double Hinged Flap Gate - 910 mm	2	Ea.	$8,000	$16,000
Landscape					
1.33	Chain Link Fence	400	m	$135	$54,000
1.34	Chain Link Fence - Gate	7	Ea.	$1,500	$10,500
1.35	Boulder Steps	4	Ea.	$1,100	$4,400
1.36	Topsoil Placement	24,990	m^2	$2	$49,980
1.37	Hydro-seeding	24,990	m^2	$4	$99,960
1.38	Addition Landscaping (Plantings)	1	LS	$85,000	$85,000
1.39	Landscape Warranty Maintenance	2	year	$50,000	$100,000
				Subtotal (rounded)	**$2,760,000**
Contingency (30%)					**$828,000**
				Total (rounded)	**$3,590,000**

Appendix G – Lifecycle Operation & Maintenance Cost

Lifecycle Cost for Operation Maintenance Based on Net Present Value Analysis

MAINT. OPTION	Inflation Rate	3%	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14
		SUM	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Scenario Annual Cost of $10,770 (2021 dollars) spread over 50 yrs.	Project	$538,500	$0	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770
	Project NPV	$1,251,267	$0	$11,093	$11,426	$11,769	$12,122	$12,485	$12,860	$13,246	$13,643	$14,052	$14,474	$14,908	$15,355	$15,816	$16,291
	Annual NPV Cost	$25,025															

Lifecycle Cost for Operation Maintenance Based on Net Present Value Analysis

MAINT. OPTION	Inflation Rate	3%	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24	Year 25	Year 26	Year 27
		SUM	15	16	17	18	19	20	21	22	23	24	25	26	27
Scenario Annual Cost of $10,770 (2021 dollars) spread over 50 yrs.	Project	$538,500	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770
	Project NPV	$1,251,267	$16,779	$17,283	$17,801	$18,335	$18,885	$19,452	$20,035	$20,636	$21,256	$21,893	$22,550	$23,226	$23,923
	Annual NPV Cost	$25,025													

Lifecycle Cost for Operation Maintenance Based on Net Present Value Analysis

MAINT. OPTION	Inflation Rate	3%	Year 28	Year 29	Year 30	Year 31	Year 32	Year 33	Year 34	Year 35	Year 36	Year 37	Year 38	Year 39	Year 40
		SUM	28	29	30	31	32	33	34	35	36	37	38	39	40
Scenario Annual Cost of $10,770 (2021 dollars) spread over 50 yrs.	Project	$538,500	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770
	Project NPV	$1,251,267	$24,641	$25,380	$26,142	$26,926	$27,734	$28,566	$29,423	$30,305	$31,214	$32,151	$33,115	$34,109	$35,132
	Annual NPV Cost	$25,025													

Lifecycle Cost for Operation Maintenance Based on Net Present Value Analysis

MAINT. OPTION	Inflation Rate	3%	Year 41	Year 42	Year 43	Year 44	Year 45	Year 46	Year 47	Year 48	Year 49	Year 50
		SUM	41	42	43	44	45	46	47	48	49	50
Scenario Annual Cost of $10,770 (2021 dollars) spread over 50 yrs.	Project	$538,500	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770	$10,770
	Project NPV	$1,251,267	$36,186	$37,272	$38,390	$39,542	$40,728	$41,950	$43,208	$44,504	$45,839	$47,215
	Annual NPV Cost	$25,025										