Bowness Responsible Flood Mitigation Society

Title:	BRFM Hydrogeological/Geotechnical Study Scope Review
Document Number:	BRFM-200-HSR-2018
Revision:	1.0
Date Issued:	January 22, 2019
Issued To:	City of Calgary

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Revision History

Revision #	Author	Date	Description
0.1	HV	2019-01-19	First Draft
0.2	JW	2019-01-21	Updated based on internal review
0.3	JN	2019-01-22	Reviewed and updated
0.4	TD	2019-01-22	Reviewed for technical accuracy
1.0	JW	2019-01-22	Issued to the City

Glossary

Term	Description
GW	Ground Water
City	City of Calgary as a governing and administrative entity

Term	Description
cms	Cubic meters per second
AE	Associated Engineering
AE Report	Permanent Flood Barrier Protection Assessment, April 2018; prepared by AE and commissioned by the City of Calgary
BRFM	Bowness Responsible Flood Mitigation Society

References

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1. Introduction

This document provides detail of BRFM's review of the City provided scope of study for the Hydrogeological/Geotechnical ("SoS") program in support of the preliminary engineering phase of the City proposed Bowness Barrier project. The city provided information is contained in APPENDIX A. The City has also provided a map of the proposed water well locations, which was also distributed, to residents. It is located at http://www.calgary.ca/UEP/Water/Documents/Water-Documents/Groundwater-Monitoring-Study-Borehole-Drilling-Locations.pdf

BRFM has engaged Dr Tad Dabrowski, P.Eng., as our retained hydrogeological expert to review the scope of study and provide review of the adequacy of this study. The primary purpose of this review is to identify areas of concern that warrant further discussion.

1.7 Assumptions and Limitations

The City provided document in APPENDIX A appears to be an extract of a larger document. As there are parts of this document not available to BRFM, the ability to provide a full technical review is limited, and therefore the comments and feedback that are offered here are prefaced with the understanding that further discussion is needed for better understanding and conclusive technical feedback.

2. Review of City Provided Documentation

2.7 Technical Engineering Consultant

BRFM provides the following verbatim from BRFM's hydrogeological expert, Dr. Dabrowski, P.Eng

2.7.1 Response

To: Bowness Responsible Flood Mitigation Society

RE: Review of Hydrogeological Scope of Study for Bowness Barrier Project

Dear Jean and Hank,

In our discussions, you raised an issue of the extent of hydrogeologic exploration that may be required for a large-scale civil engineering project like that proposed for the Bowness Flood Mitigation Barrier. This is a very broad issue. Considering the potential impacts of flooding on a high-density residential area, no detail should be spared to gather the most important information regarding local groundwater conditions. A brief review of literature and personal knowledge of hydrogeology in Calgary area, may lead to a conclusion that there is little site-specific hydrogeological information regarding Bowness area. I would like to express support for your objective to provide responsible flood mitigation that would protect human life and prevent property damages due to Bow River flooding within Bowness and other Bow River communities.

In my opinion, in addition to literature, maps and drilling records review, addition information should be used in a design of a major water retaining structure, like Bowness Flood Barrier. This should include determination of:

1. Topography of the bedrock surface (Porcupine Hills Formation);
2. Hydraulic properties of the upper, weathered part of bedrock;
3. Distribution, thickness and continuity as well as hydraulic properties of alluvial and glacial sediments within the Bow River Valley;
4. Number of groundwater-bearing zones in a vertical profile and their hydrostatic pressures;
5. Groundwater recharge from all sources (river, lawn irrigation and from the south plateau);
6. Groundwater flow directions and velocities in various hydrogeological units;
7. Presence of hydraulic windows connecting various groundwater-bearing zones in vertical profile; and
8. Groundwater quality, that could be helpful in identification various hydrogeological units.

The Report from the Expert Management Panel on River Flood Mitigation on page 28 noted that "additional groundwater monitoring in key locations… would help inform understanding of the influence of groundwater flows during flooding…". One of the recommendations of the Panel was do develop a comprehensive groundwater computer model. To develop such a model, all the information listed above is required in addition to hydrological information (river flow rates, precipitation, surface runoff, etc.). Justification and the objective for each borehole/monitoring well shown on a Figure you provided is not given, therefore it is not possible to assess their possible value.

You provided me with part of a document, without an author, date, etc. as well as with a map entitled "Groundwater Monitoring Study – Borehole Drilling Locations". According to your email, these documents were released to BRFMS by Ms. Denise Nogueira of the City of Calgary for a review and comments. Therefore, I assume that there is no obligation on my part to follow APEGA protocol regarding review of other professionals' documents. Please verify my concerns with the source of the document. If I am breaching any ethical rules, please retain this document as confidential, until the matter is clarified.

In the document there is no indication if this is part of a multiphase study or a single exploration program. If this is part of a multiphase program, it is possible that some tasks listed below will be covered by later programs, thus some of the following comments may not apply.

Review of the document raises concern of the author's understanding of the division between geotechnical and hydrogeological studies. It should be understood that both sciences as well as other disciplines are very important components of a successful completion of the project. Please refer to Section 1.7.1, where there are eight bullets listed. The first one applies equally to both geotechnical and hydrogeological studies. Bullet two and the last one is strictly geotechnical, while all the remaining six bullets are related to hydrogeology. Further in the document near the end of subsection 1.7.1 (third paragraph from the bottom of this section) one can read -"A KCB geotechnical engineer will be present on site to log subsurface soil, rock and groundwater conditions….". Next paragraph top line includes – "A KCB representative will be present to supervise the installation and the development of the groundwater monitoring wells…". One may wonder what role in the project is assigned to each qualified and experienced hydrogeologist. In my opinion, knowledge and experience of a person conducting hydrogeological exploration is the most important part of the program. The information gathered is essential to determine correctly hydrogeological parameters. Once available these can be used in the following phases of the project development. In summary a geotechnical engineer should be responsible for geotechnical part and a hydrogeologist for hydrogeological.

Other more specific concerns include:

1. The document as provided does not identify the objectives of the program or the desired outcome that the program is supports. The document is limited in its explanation of how the information will be applied to develop the conceptual hydrogeological model, develop a comprehensive 3D groundwater model, and support the design of a flood barrier to mitigate groundwater inundation during flooding conditions.
2. The document incorporates both Hydrogeology and Geotechnical analysis and testing. These are two distinct fields of expertise and require unique specialization for both the field data acquisition program as well as for the evaluation and interpretation. Although they will utilize common information and data, the analysis should be independent. The City and BRFMS should expect that a well-qualified and experienced person will represent these unique work scopes. Can we request resumes of the geotechnical and hydrogeologists that are overseeing this work?
3. The work program does not identify how aquafers will be identified in the drilling process and how these will be isolated and tested as distinct hydraulic units. It is not clear from the work scope that the study will consider the complex hydrogeological environment that will be present in the study area. Understanding this complexity will be necessary to develop a comprehensive 3D model.
4. The program does not include geophysical surveys (ERT or shallow seismic) to locate the exploration holes. Without geophysics the proposed 19 wells would be inadequate to assess hydrogeological conditions in the very complex depositional environment within the study area. The application of these geophysical tools is necessary to interpret the well results and to integrate this into a comprehensive groundwater model
5. There is no provision for borehole geophysical logging, in order to physically identify lithological profile of the borehole. These methods will determine the presence of groundwater-bearing zones for monitoring wells installation, development and testing. In this respect geophysical tools, such as geophysical logs, are extremely valuable. The scope of work does not clearly identify how through drill cuttings logging various sediments can be identified and intervals for monitoring wells installation selected.
6. There is no information regarding how many monitoring wells are to be installed in the bedrock and various levels within the alluvial and or glacial sediments.
7. The scope of study does not include nested monitoring wells. Well nests installed at different depth will determine vertical hydraulic gradients between different groundwater bearing zones.
8. To determine groundwater flow directions, wells need to be completed in the same hydrogeologic unit at a reasonable spacing. Very complex hydrogeological conditions may be expected within the project area.

Given the lack of geophysics it is not clear how this can be achieved and assured with the proposed 14 or 19 borehole locations.

9. Without aquafer testing, hydraulic conductivity, transmissivity and storativity, as well as recharge and no recharge boundaries cannot be defined. These are important data for the comprehensive computer model development.
10. The inclusion of a river level monitoring transducers should be a requirement for this program to provide reference data. This should not be left to a question of feasibility.

Respectfully submitted,

Dr. Tad Dabrowski, P.Eng.

2.8 Request to City

2.8.1 Summary

Based on the information presented within this scope of study, it appears optimistic to consider that the proposed program will provide all the required information for a design of a barrier in such a complex hydrogeological/geotechnical environment. It is BRFM's opinion that this scope of study should be considered to be Phase 1 and would contribute to follow up hydrogeological and geotechnical work that would be required to support the design of this barrier project.

2.8.2 Details

BRFM requests the City provide responses to the following:

- Has the City has given KCB performance requirements for the study, such as expected accuracy of the study?
- Could the number of wells drilled be correlated to this accuracy such that KCB can determine in consultation with The City if more wells should be drilled to improve the study's accuracy?

The scope of hydrogeological study that is required in support of a flood mitigation barrier will be largely dictated by the degree to which this barrier is expected to control groundwater movement during flooding conditions. This should be addressed in the Terms of Reference for the barrier design. BRFM would suggest that The City adopt a performance objective (or a number of defined options for performance levels) for the barrier that defines the level of protection that the barrier will be designed to deliver. This might translate to a range of options that would then be evaluated on the basis of benefit-cost such as:

- A barrier design that will ensure that there is no accumulation of groundwater inundation that reaches surface behind the barrier;
- A barrier design that will ensure that at the design condition of 1230 m3/s river flow rate, the groundwater levels in the study area are maintained below what would be currently observed at a high river flow rate of 800 m3/s without the barrier present

In the meeting with the City on December 11th, 2018, BRFM requested that The City provide a barrier design and provide a corresponding cost and Benefit-Cost analysis for a barrier that will provide property owners mitigation from groundwater inundation such as described in the last bullet above. While this does not pre-determine the final design, it does allow the City to optimize the value of the barrier and articulate to the Province and landowners what the cost of the barrier would be if it provided protection from groundwater flooding. In the meeting the City would not commit to providing this design and cost analysis. Although the flow rate selected above of 800 m3/s is arbitrary and other values could be considered, BRFM believes this as a reasonable design specification because:

1. The value of 800 m3/s is understood to be the current threshold for when overland flooding is initiated in Bowness without the flood barrier
2. Based on residents experience with the 2005 flood at a flow rate of 791 m3/s, 800 m3/s appears to be a reasonable threshold below which there is some groundwater inundation in lower areas, but this is limited and in general at this level, the existing property level mitigation strategies with sump pumps remains effective for most residents. As flow rates exceed this level, these mitigation strategies are considered to have a risk of no longer being sufficient or practical with the risk increasing with flow rate
3. When BRFM considers other flood mitigation strategies within the FMMA, BRFM notes that through upstream storage, the Elbow River Communities peak flow rate for a 1:100 (or even 1:200) year flooding event is being attenuated to about 180-190 m3/s, which is representative of

a 1:8 year event peak flow rate based on naturalized flow.   This attenuation is providing these communities with erosion and groundwater protection for these high severity events down to this lower level of 1:8 years. If flood prone communities are to be treated equitably, then Bowness residents should expect that the mitigation strategy and infrastructure design for Bowness would also deliver erosion and groundwater protection to the 1:8 year level for the Bow River. This flow rate would be ~800 m3/s

For these reasons BRFM has advocated and will continue to advocate for upstream mitigation that will limit peak flow for at least the 100 year return period event to less than 800 m3/s or expect that the proposed mitigation infrastructure will mitigate loss due to groundwater and erosion to this same level.

3. Appendix A

1.7 Geotechnical and Hydrogeologic Field Investigations and Lab Testing

1.7.1Task 12 - Geotechnical Field Investigations and Lab Testing

In order to develop a better hydrogeological and geotechnical understanding of the existing conditions (shallow groundwater system and surficial geology) and the potential impacts of incorporating flood control barriers adjacent the Bow River, a geotechnical and hydrogeological field investigation is required. The results of this investigation will augment the data already obtained as part of the conceptual design by AE and the Calgary Rivers Morphology and Fish Habitat Study (KCB 2018). The objectives of the investigation are as follows:

- To determine the surficial geology materials and thickness;
- To assess suitability of in-situ soils for flood barrier construction;
- To determine the level, and type, of bedrock geology and determine whether permeable sandstone layers are present in the Porcupine Hills Formation;
- To determine lithology and water-bearing potential of the surficial sediments and bedrock (i.e. within any sandstone layers present);
- To determine groundwater levels and flow directions through measurement of water levels in new and existing monitoring wells;
- To undertake hydraulic (slug) testing of the monitoring wells to estimate the hydraulic conductivity of the water-bearing units;
- To assess groundwater quality through sampling of the newly installed monitoring wells and laboratory analysis for a range of typical parameters;
- To assess soil strength using Standard Penetration Testing and laboratory testing; and,
- To monitor groundwater conditions over a 12-month period (as a minimum) to assess for diurnal and seasonal groundwater level trends and responses to surface water flow changes.

Relevant reports and data will be reviewed and information gaps will be identified and discussed with The City project manager. A site reconnaissance will be conducted by the project team to identify the extent of any surveys or investigations that will be required (i.e. refine the number of exploratory holes and monitoring wells required and identify adjacent infrastructure), and determine the appropriate methods of investigation. Any changes to proposed locations due to access concerns will be communicated to the City.

During preliminary design we propose to drill 12 vertical boreholes with a track-mounted mini sonic rig to cover the extent of the flood control barriers. An additional seven (7) vertical boreholes located inland of the barrier alignment are proposed to gain an understanding of the shallow groundwater flow conditions in these areas. The geotechnical field program will be confirmed with the City after review of existing information and the project site reconnaissance. Important considerations in planning the geotechnical investigation program in Bowness will include site access, disturbance of private property, and noise. We propose to use a track-mounted mini sonic rig which we believe to be the smallest equipment available that will access tight quarters with minimal ground disturbance and provide reliable results in the gravel that is expected to be encountered. The 2.2 m wide rig should be able to access the proposed dyke alignment from the street by travelling between the houses and/or along the river bank. The tracked vehicle will minimize rutting and rig mats (wood, composite, bamboo, etc.) may also be used to further minimize disturbance. In addition to being smaller, the sonic rig is also quieter than traditional drill rigs, such as ODEX or Becker Hammer rigs. Consideration will be given to incorporating temporary, portable sound/dust barriers to minimize impacts, if required. Each hole will be drilled a minimum of 2 m into the bedrock (approximately 19 m below the ground surface). All boreholes will be completed with the installation of a 2" (0.05 m) diameter schedule 40 polyvinyl chloride (PVC) groundwater monitoring well and flush mounted cover. Any excess drill cuttings will be stored in soil bags and removed from the site on completion of drilling. Disposal costs provided assume that all soil encountered during the investigation is free from contamination.

We have allowed 11 days of drilling in our budget estimate. Prior to drilling, KCB will contact Alberta One-Call to locate buried utilities in the area. Furthermore, KCB will engage a private utility locator to identify utilities that are not registered with Alberta One-Call.

A KCB geotechnical engineer will be present on site to log subsurface soil, rock and groundwater conditions as drilling proceeds. The cost of ground disturbance mitigation measures is not included in the fee estimate.

In addition, our engineer will collect soil for subsequent laboratory testing. A KCB representative will be present to supervise the installation and development of the groundwater monitoring wells, and to undertake the necessary hydraulic testing to estimate the conductivity of water-bearing units. At this stage, it is assumed that the hydraulic conductivity of the sand and gravel aquifer can be adequately determined using short duration slug tests.

Following drilling, a suite of geotechnical laboratory index testing, including moisture content, organic contents, Atterberg limits, maximum dry densities and optimum moisture contents, soil permeability, and particle size distributions, will be undertaken to characterize the foundation soils. Borehole logs will be prepared based on visual classifications in the field in addition to laboratory test results. Based on the collected information, geotechnical parameters to be used in the hydrotechnical and civil designs will be recommended.

1.7.2 Task 13 - Geotechnical Assessment and Report

KCB will undertake a geotechnical assessment for the preliminary design using the outcomes of the drilling investigation and lab testing described in the previous section. The assessment will cover:

- Assessment of historic slope instability sites relevant to the Bowness flood control barrier;
- Assessment of surficial geology to provide recommendations for barrier foundation designs;
- Slope stability assessments;
- Barrier and foundation seepage assessments;
- Material suitability and specifications;
- Settlement potential assessments; and,

- A description of materials for barrier construction.

Slope stability and seepage assessments will be conducted using the Slope/W and Seep/W computer software programs.

Consideration of dam safety requirements, given the size and capacity of the structure, will also be reviewed.

A geotechnical assessment report will be prepared that:

- Summarizes our review of existing data;
- Summarizes observations from site reconnaissance;
- Summarizes the ground investigation and lab testing;
- Discusses the results of the geotechnical assessment; and,
- Provides our recommendations, including suitable materials for barrier construction.

We will combine the geotechnical report with the hydrogeological report. Draft and final reports will be issued as electronic copies (PDF).

A meeting will be held with The City following submission of the draft report to discuss the outcomes of the report. Meeting notes will be prepared and circulated by KCB. Comments received from The City during the meeting will be incorporated into the final report.

1.7.3Task 14 – Hydrogeological Assessments and Report

In support of the preliminary flood barrier design, hydrogeological assessment and groundwater modelling is required to understand the current groundwater conditions along the alignment and inland of the proposed barrier alignment, potential impacts of groundwater inundation during flood events on the proposed barrier (and visa versa) and nearby buildings, and to assess whether groundwater flood mitigation measures are effective and required. The assessment will include:

- A review of relevant reports and available data, and information gaps will be identified and discussed with the City;
- Site reconnaissance and hydrogeological field investigation which includes the installation and testing of 19 groundwater monitoring wells;
- Implementation of a groundwater monitoring program;
- Data analysis and conceptual hydrogeological model (CHM) development that includes characterization of local hydrostratigraphy, aquifer hydraulic properties, groundwater flow conditions and recharge (including the hydraulic relationship between the shallow aquifer system and the Bow River);
- Development of a numerical flow model to evaluate potential impacts of the proposed flood barrier on the groundwater system during normal flows and flood events;
- Groundwater inundation risk mapping for specific river flood events both with and without the proposed flood barrier in place to assess potential impacts to residential buildings and infrastructure;
- Assessment of the need for groundwater mitigation measures; and,

- If required, their subsequent preliminary design.

The key components of the proposed hydrogeological assessment are described in the following sections.

Field Data Collection

In the RFP, the City indicates that there is limited groundwater data available for the Bowness project area. The drilling and hydraulic testing of 19 boreholes is therefore proposed which will be coordinated with the geotechnical drilling program described in Section 3.7.1. Twelve (12) of the boreholes will be located along the proposed flood barrier alignment, while the remaining seven (7) boreholes will be sited at suitable locations inland of the river. Three (3) pairs of the 12 monitoring wells will be located to enable the assessment of seepage under the flood barrier. For each pair, one well will be placed on the river side of the proposed barrier and one well will be placed on the inland side of the structure. The actual number of monitoring wells required will be confirmed following completion of the data review and site reconnaissance.

All the boreholes will be completed as 2” PVC monitoring wells with screens installed in the anticipated shallow sand and gravel aquifer. At this stage, it is assumed that the bedrock does not host a significant aquifer that is in hydraulic connection with the shallow groundwater system. The aquifer potential of the bedrock will be visually assessed during drilling based on the material type and degree of fracturing, and if this assumption is shown to be incorrect, additional bedrock monitoring wells will need to be considered.

Following installation, KCB will develop the wells and then the following monitoring activities will be undertaken at each monitoring well:

- Measure water level;
- Complete hydraulic testing (slug tests); and,
- Collect groundwater sample.

The groundwater samples will be submitted to an accredited laboratory for analysis of routine potable parameters following standard chain of custody protocols. The wells will be capped and locked following the monitoring activities. When, and if, the wells are to be decommissioned this will be discussed with the City based on the needs of the project.

Groundwater Monitoring Program

A groundwater monitoring program (GMP) is proposed for the project area that will include the following components:

- Continuous recording of groundwater levels in 10 monitoring wells using pressure-transducer data-loggers (PTDLs). In addition, level-temperature-conductivity (LTC) data-loggers will be installed in three (3) of the monitoring wells located along the proposed flood barrier (i.e. 13 data-loggers in total).

For this proposal, it has been assumed that the GMP will be continued for a period of 12 months. It is proposed that the dataloggers are downloaded and the data reviewed on a quarterly basis, at which time manual water levels will be recorded. KCB will provide The City with all the data collected during GMP.

The feasibility of installing temporary pressure transducers in the Bow River to continuously measure river levels will be assessed. If deemed feasible, a budget for the supply, installation, monthly water level surveys and monitoring of river level pressure transducers will be prepared and submitted to the City.

The monitoring results will be used to assess diurnal and seasonal variations in groundwater levels in the project area associated with precipitation recharge and river discharge /recharge to the shallow aquifer system. The groundwater chemistry and conductivity time-series data will provide additional information required to assess the hydraulic interaction between the shallow sand-gravel aquifer and the Bow River.

Groundwater Conceptualization

A conceptual hydrogeological model (CHM) will be compiled for the project area based on the data review and results of the hydrogeological site investigation. As part of the CHM, three (3) representative cross-sections will be developed to include the installed groundwater monitoring well pairs. Basic analytical calculations will be completed to assess the radius of influence and groundwater flow at various river flow stages (normal flows and flood events).

The CHM will form the basis for the construction and parameterization of the groundwater flow model discussed below.

Groundwater Modelling

Three-dimensional (3-D) groundwater flow modelling is proposed to assess the impact of the proposed flood barrier on the shallow groundwater system, potential for groundwater inundation associated with various river flood events both with and without the flood barrier in place, and the efficiency /requirement for groundwater mitigation measures. KCB proposes to use FEFLOW 6.2 to complete the modelling. It is anticipated that the model domain will extend along the Bow River from downstream of the Bowness Railway Bridge to upstream of the 16th Avenue SW bridge, and extend inland to include the Trans-Canada highway and slopes of Paskapoo Hill (i.e. includes the Bowness residential area).

A 3-D modelling approach is proposed to take into account the complex three-dimensional groundwater flow regime anticipated along this stretch of the Bow River. However, if the hydrogeological investigation, groundwater monitoring and CHM show that 2-D transect (cross-sectional) modelling would be sufficient to address the project requirements, then a revised modelling scope will be prepared after discussion with the City.

The model will be constructed based on the CHM and will be calibrated to current (steady-state) groundwater conditions based on the water level data collected during the hydrogeological field investigation. The normal river stage derived from the 2-D HEC-RAS model (Section 3.10) will be used to establish the hydraulic boundary conditions along the Bow River. The steady-state model calibration will be undertaken initially using the manual method, followed by a bounded PEST (Parameter ESTimation) calibration. Although not ideal, it is assumed that transient calibration of the model will not be completed at this stage due to a lack of groundwater monitoring data for the project area. Based on the proposed project schedule, insufficient groundwater level time-series data (approximately 1 to 2 months) will be available from the proposed monitoring network for adequate transient calibration but will be revisited during final design if the results of the groundwater level monitoring deem it worthwhile.

It is proposed that a limited sensitivity analysis be completed on the calibrated steady-state model, where the following key input parameters will be varied:

- Horizontal hydraulic conductivity of the sand-gravel aquifer; and,
- The hydraulic conductance of the Bow River bed.

The following range of multipliers will be used to vary the hydraulic conductivity and streambed conductance in the model: 0.1, 0.5, 2 and 10.

After completion of the steady-state model calibration and sensitivity analysis, the following transient prediction simulations will run:

- Without flood barrier:
  - Normal (seasonal) river levels;
  - 1:20 and 1:50 flood events; and,
  - June 2013 flood.
- With flood barrier:
  - 1:20 and 1:50 flood events.
- Flood barrier with groundwater cut-off wall:
  - 1:20 and 1:50 flood events.

Allowance has been made for the simulation of up to three (3) groundwater cut-off wall designs with the preferred flood barrier alignment in place. The steady-state base (current conditions) model will be used to establish the initial conditions for the transient prediction models. The groundwater flow model will use river stage time-series derived from the HEC-RAS model to simulate the 1:20 and 1:50 year flood events, as well as the June 2013 flood. The predictive model runs will simulate the groundwater level rise and recession associated with the various flood events. Groundwater recharge from precipitation and lateral groundwater inflows (recharge) from the upstream catchment (Paskapoo Hill) will be simulated. The predictive modelling will not take into account flooding due to overland flows from upstream portions of the watershed, as it is assumed that these flows will be effectively handled by the stormwater drainage system.

Groundwater Inundation Mapping and Impact Assessment

An assessment of the groundwater inundation (at surface) and flooding (sub-surface, e.g. basements) potential around the proposed flood barrier and inland areas will be undertaken for the various flood events modelled by comparing the predicted maximum groundwater elevation surface to the topography. ArcGIS geospatial analysis techniques will be used to compile the following series of groundwater inundation and flood risk maps for the project area:

- Groundwater inundation and flooding both with and without the preferred flood barrier alignment in place for the 1:20 and 1:50 year flood events, as well as the June 2013 flood for the without barrier case.
- Groundwater inundation and flooding with the preferred flood barrier alignment and groundwater cut-off wall in place for the 1:20 and 1:50 year flood event.

The predicted timing and duration of the groundwater inundation and flooding will also be considered as part of the impact assessment. The impact assessment will inform the evaluation of the requirement for groundwater mitigation measures. If required, groundwater mitigation measures would subsequently be incorporated into the design of the flood control system.

Reporting

The hydrogeological site investigation and groundwater modelling results will be summarised in a *Geotechnical and Hydrogeological Assessment* report (refer to Section 3.7.2). The hydrogeological component of the report will include:

- Review of existing data and gap analysis;
- A description of all the hydrogeological field work undertaken, including detailed borehole logs and monitoring well installations;
- Analysis and interpretation of hydraulic testing and available groundwater monitoring results;
- Description of the conceptual hydrogeological model developed for the project area;
- Summary of the groundwater model design and build, model calibration and sensitivity analysis, model prediction scenarios and interpretation of results;
- Groundwater flood mitigation assessment results;
- Groundwater inundation / flood risk mapping and impact assessment results; and,
- Conclusions and recommendations.