Toronto and Region Conservation Authority Flood Protection Land Forming Technical Design Considerations

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1. Introduction

1.1 Background

The Toronto and Region Conservation Authority (TRCA) is responsible for the development, implementation, and maintenance of a number of flood control measures in their jurisdiction, including conveyance measures like engineered channels, as well as flow control facilities like dams, dykes (also known as levees or berms) and landforms that direct flow away from flood vulnerable areas. While the majority of such measures have been widely applied globally and are well understood as a result, this is not necessarily the case with respect to land forming. Flood protection through land forming is a relatively new concept that reshapes the land to provide passive flood protection, which subject to Ministry of Natural Resources and Forestry (MNRF) review and approval, may be considered permanent flood protection. Consequently, this concept requires a significant level of detail to be addressed at the Environmental Assessment (EA) and detailed design stages, including but not limited to planning justification, cost benefit analysis, field investigations, desktop analyses and operational and maintenance requirements.

To date (2018), only one flood protection landform (also referred to as a landform or FPL in this document) has been constructed in TRCA's jurisdiction, which is located within the West Don Lands in the City of Toronto. The planning and design of the West Don Lands Landform was completed as a partnership between the Waterfront Toronto, TRCA and municipal and provincial government. The design process included comprehensive consultations under the Conservation Ontario Class Environmental Assessment for Remedial Flood and Erosion Control Projects. The technical assessment required input from a number of disciplines, including civil engineering, water resources, geotechnical, hydrogeology, structural and landscape architecture. While this allowed for successful implementation of the West Don Lands Landform, no formal documentation was completed after the construction to define the specific considerations and scope of technical studies to be used for future applications.

Regardless, TRCA has identified other opportunities where the application of landform is considered to be preferred from the risk management and cost effectiveness perspective and there are currently a number of high profile flood remediation studies being planned or are underway within TRCA, which may consider landforms as part of a comprehensive flood remediation plan.

In turn, this document addresses the need for more comprehensive design considerations to cover a range of site conditions and development scenarios.

In response, TRCA initiated a project to prepare a technical document to guide the planning, design, construction, operations and maintenance of landforms for the purpose of flood protection. This document is referred to as the Flood Protection Land Forming Technical Design Considerations (the Document). AECOM Canada Limited (AECOM) was retained to prepare this Document under RFQ #100004096.

1.2 Objectives and Scope

The key purpose of the Flood Protection Land Form Technical Design Considerations is to streamline the planning and design processes where a FPL could be the preferred option to provide flood protection to an existing flood vulnerable community. In addition, this document is expected to offer TRCA and their municipal and provincial partners design considerations for landform solutions that can be applied either as a standalone measure, or as part of a comprehensive flood remediation strategy. This Document gives regard to current legislation and policies in the Province of Ontario, such as the Lakes and Rivers Improvement Act (LRIA), (2011) and the Provincial Policy Statement (PPS), (2014). In addition, this Document has been developed in consideration of the current standards stipulated by Ontario Ministry of Natural Resources and Forestry (MNRF), such as the Technical Guide, River and Stream Systems, Flooding Hazard Limit (2002) for the methods used to establish the level of protection requirements (e.g. Regional Storm).

However, the intent of this Document is not to substitute or contradict any of the MNRF documents, or to allow for standardization under the umbrella of the Canadian Standard Association (CSA). Instead, the Document has been developed primarily as an internal planning and design tool. While this Document provides general guidance on planning, design, construction and operations of landforms, it is recognized that a variation of the approaches defined in this Document may be required due to site-specific considerations. As such, this Document represents the minimum criteria based on current understanding of landforms, primarily based on the experience with the West Don Lands and international industry standards. The application of landforms though is largely based on the local site conditions, and more rigorous assessments and design considerations may be required depending on the site conditions.

While it is recognized that the landform concept is relatively new, the function of a landform is similar to those of dams and dykes. This implies that the same design considerations are applicable to both landforms and other similar flood protection measures. However, landforms are designed to prevent the modes of failure commonly associated with dams and dykes. In essence, landforms are more robust than dams and dykes to the point where the risk of failure is approaching zero.

The subject Document provides a summary of applicable design considerations in a consolidated document and is comprised of the following key components:

- Overview of the current state of practice in Ontario and other jurisdictions, including a policy context and summary of applicable standards and guidelines;
- Key differentiators between landforms and more traditional dams and dykes;
- Summary of design and operational elements; and
- List of references.

It recognized that designing and implementing flood protection measures could be a very complex process. Such a process may involve a number of disciplines, each of them requiring application of different methods. It is emphasized that a detailed description of these methods is outside the scope of the subject Document. This Document rather provides a summary of design and operational elements and then refers to more detailed documents addressing these individual elements.

1.3 Sources Used in Development of Flood Protection Land Forming Technical Design Considerations

The Document has been primarily based on the following sources:

- Comprehensive review of applicable acts, regulations, policies, standards and guidelines;
- Experience gained through planning, design, construction and operation of the West Don Lands Landform; and
- Additional input provided by various technical disciplines, reviewing agencies and other stakeholders.

A further discussion on the received input and applicable documents is included in Section 2 of this Document. The complete list of references is included in Section 5.

1.4 Document Format and Content

This Document has been organized in a format that allows for sections dedicated to individual design and operational elements to be consulted separately without referring to the whole document. For this purpose, the Document follows the following format:

- Section 1 provides a narrative dedicated to the study scope, objectives and sources;
- Section 2 provides policy context and key differentiators between landforms and traditional dams and dykes;
- Section 3 provides a summary of design and operational elements in a “fact sheet” format;
- Section 4 provides a conclusion and suggested next steps for further study by TRCA; and
- Section 5 includes list of references used in preparation of this document.

Table 2 includes a design checklist for quick reference of the key design considerations.

2. Policy Context

2.1 Flood Protection Landform Concept

A flood protection landform is generally defined as a non-structural measure made of earth that provides permanent flood protection (refer to **Figure 1** example). Landforms are similar to dykes, since they are man-made barriers placed adjacent to river corridors to provide passive protection from flooding. Unlike traditional dykes, however, landforms are built on a much larger scale with very gentle slopes (refer to **Figure 2**).

(American Society of Landscape Architects, 2016)

Figure 1: West Don Lands Flood Protection Landform Embedded within the Corktown Common Park

Furthermore, landforms are designed to generally require less maintenance and provide a significantly higher level of protection in terms of typical modes of failure. In a risk-based decision making system, therefore, a landform allows for risks associated with flooding to be substantially eliminated or reduced to an acceptable level of risk.

2.2 Difference between Landforms and Traditional Flood Protection Measures

Traditional flood protection measures such as dams, flood walls and dykes normally rely on a structural component that is clearly different from the surrounding landscape to hold water. Because of their size, on the other hand, landforms are integrated with landscape as they become part of it to the point where they are no longer considered to be structural elements separate from the surrounding landscape and natural valley.

In addition, dams, flood walls and dykes require regular maintenance, especially if mechanical and electrical components are part of the flood protection system (e.g. gates, pumping stations). Such systems are also more sensitive to seepage, animal burrowing and root systems because of the relatively small footprint. Landforms provide a significantly wider cross section and greater volume of fill than traditional dykes. Quantifiable comparisons between landforms and traditional dykes are included in **Figure 2**, which includes 1:1 scaled profiles, a range of cross section widths for various heights, and a comparison of above grade fill volume. Due to their size and absence of active controls, landforms are less sensitive to the effects of seepage, animal burrowing and root systems, and as a result require less maintenance.

While structural measures such as dams or dykes do allow for functional flood protection, they do not remove regulatory restrictions as per the MNRF policies. Landforms, on the other hand, create opportunities for more latitude in this regard, as they are engineered to never fail and essentially form part of the surrounding landscape. Landform dimensions are significant enough to the extent it no longer functions as a dyke and it becomes resistant to all characteristic modes of failure. That being said, the current MNRF policies do not recognize the distinction between dykes and landforms, and the removal of development restrictions (e.g. Special Policy Area) has only been approved in concept for the West Don Lands landform.

Although the considerations offered above are all reflective of the differences between landforms and other flood protection measures, the key differentiators are found in standard modes of failure associated with almost all flood protection measures. The three standard modes of failure are identified below with further description provided in **Table 1** and illustrations provided in **Figures 3** to **5**:

- Overtopping and external erosion;
- Seepage (e.g. internal erosion, soil piping, and loss of support); and
- Settlement (e.g. instability, excess deformations, and bearing capacity).

<u>This implies that in most instances landforms can be distinguished from other flood protection measures in quantifiable terms.</u> While in most instances site-specific criteria would have to be developed, for the purpose of this Document a landform has been defined as an earthen flood protection measure that allows for the following:

- Integration with the surrounding landscape to the point where the measure cannot be practically differentiated from the rest of the features;
- 5 – 10% wet side slopes with 10 – 15% for localized areas, and 1.5 – 3.5% dry side slopes, or as determined through geotechnical analysis;
- Minimum 3 m wide crest with 5 m preferred or greater;
- 0.5 m of freeboard protection for the greater of the 100-year storm or the Regional Storm event (including 0.2 m for climate change considerations);
- Overtopping velocities on the dry side limited to 1.2 m/s or less (MTO Design Chart 2.17, 1997); and
- Seepage/groundwater exit gradient limited to 0.5 or less (USACE, 2005).

It is noted that quantification would be more complex in terms of the seepage and settlement modes of failure, as it would greatly depend on local conditions. Regardless, the larger footprint would generally offer much better resistance in terms of slumping, transitional/rotational failure and cracks and liquefaction due to earthquakes.

2.3 Current State of Practice

Earthen dykes can be found in various locations within the TRCA jurisdiction and elsewhere in Ontario, and are typically located adjacent to river banks, within floodplain areas and can be used in combination with other engineered flood control works, including conveyance channels. While dykes hold waters similar to how a dam holds back water in a reservoir, the purpose of dykes is generally to perform this function over a much shorter period of time (e.g. during flood events).

Regardless, dykes are subject to many of the same structural issues as dams, such as seepage, loads, extreme weather events, seismic events, as well as rapid increase and drawdown of water levels. Given the similarity between dams and dykes from an engineering perspective, most of the dam design guidelines have been extrapolated to dyke design.

There are two primary design philosophies currently used in dam and dyke engineering practices: deterministic and risk-based design. Deterministic design relies on standard numerical methods such as safety factors and is the approach accepted by the MNRF and LRIA in Ontario. The specific requirements are established in standards and guidelines that by their nature are neither site-specific nor project-specific. Deterministic design involves the use of established conservative practices and standards that have been developed to provide protection. For example, the United States (US) Federal Emergency Management Agency (FEMA) deterministic approach to levee design with respect to hydraulics specifies that the flood level from a 100-year return period be used to guide design and requires and additional minimum freeboard of 3 feet (0.91 m) for added safety to address uncertainty.

Dam design guidance in Canada (as per the Canadian Dam Association, 2007), the Netherlands and the United Kingdom are more focused on risk-based principles. Risk-based analysis establishes design criteria based on a hazard classification for the specific project and the probability that adverse events will occur. This method is site-specific and project-specific and involves few firm guidelines; few regulations and numerical requirements are available due to the specific nature of risk-based analysis. For example, the Canadian Dam Association (2007) provides a classification system where dams are categorized based on the population at risk, as well as the potential for loss of life, environmental and cultural values and infrastructure.

The increased probability of extreme conditions due to climate change can be considered in the design and operations of dykes. This concern can be incorporated into both deterministic and risk-based design methods. For example, a deterministic approach may use a higher design flood, or employ higher safety factors for slope design. A risk-based approach can also incorporate climate change scenarios when establishing the hazard evaluation and criteria for probability of failure.

Although the current movement in the engineering community is towards risk-based design philosophies, the majority of published information and design guidance is centered on deterministic design. In both approaches the goal is to provide adequate protection and reduce the risks to life and property to as low as reasonably practicable.

2.4 Experience with the West Don Lands Landform

To date (2018), only one flood protection landform has been constructed in TRCA's jurisdiction, which is located within the West Don Lands in the City of Toronto. The design process included comprehensive consultations under the Conservation Ontario Class EA for Remedial Flood and Erosion Control Projects and required technical input from a number of disciplines including civil engineering, water resources, geotechnical, hydrogeology, structural and landscape architecture, which was documented in the *West Don Lands, Toronto, Flood Protection Landform Municipal Roadways and Associated Services Preliminary Design Report* (Ontario Realty Corporation, 2006). The key design criteria from this document and the approach used for the West Don Lands landform is summarized below and was considered in preparation of the design and operational consideration fact sheets in **Section 3**:

West Don Lands Landform Design Criteria

- In order to permanently protect against the three principal potential modes of landform failure (overtopping, saturation and boils), the minimum required FPL width is 120 m;
- For hydraulic conveyance considerations, the toe of the flood protection landform must be set a minimum of 40 m from the west bank edge of the Don River;
- To ensure the integrity of the earth fill, locating buried utilities (e.g. storm and sanitary sewers) on the flood protection landform should be restricted and regulated. In addition, the placement of deep-rooted

vegetation should also be avoided. Any proposed works within the footprint of the flood protection landform is subject to the approval of the Toronto and Region Conservation Authority;

- Climate change may result in changes within the hydrologic response of the watershed. In order to accommodate these potential changes, the flood protection landform should be constructed in a manner that will allow for it to be adapted to any changes in flow. Current indications related to a changing climate tend to reflect the potential for a higher Regulatory Flood. As such, the land use of the flood protection landform should be flexible in allowing for adaptation through an increase in its height, if required at some time in the future;
- Fill slopes on the wet (east) side of the flood protection landform should be designed with fill slopes 3-10%. The dry side fill slopes should be designed with gradients of 1.5-2.5% with a maximum of 5% in localized areas, [ultimately the constructed West Don Lands landform included wet side slopes of 10 - 15% and dry side slopes of 2.5 - 4% with a maximum of 5% at tie-in locations];
- Structure foundations should not encroach onto footprint;
- Active recreational uses and limited ancillary structures (no foundation) may be permitted on the flood protection landform beyond the 100-year flood line in keeping with the allowable uses as defined within the TRCA Valley and Stream Corridor Management Guidelines [a pedestrian trail system was incorporated into the ultimate design and construction];
- All new infrastructure services passing through/under the Flood Protection Landform shall be placed in native ground (i.e. under the proposed Landform structure) and shall be placed in a carrier pipe.

<u>West Don Lands Landform Geotechnical Considerations</u>

- Seepage – A seepage analysis using finite element modelling of the landform was carried out. The results show that a 2 m wide clay core under the crest of the FPL will ensure that the seepage design criterion will be met. The base of the clay core should extend to 1 m below present grades. Hydraulic gradient and internal erosion need not be considered since the landform will not be subjected to sustained steady seepage;
- Stability – The slopes of the FPL must be stable under all operating conditions. The slope on the dry side will be flatter than 5%, slope stability is not considered a problem. On the wet side, the gradient of the slopes along most of the FPL will be under 15%. Even assuming full saturation, stability of the maximum 4 m high slopes is not a concern provided that the fill materials are well compacted. At the north end of the landform, the slope gradient on the wet side will be locally steepened to 3H:1V to avoid placing fill around the piers of the existing Queen Street structure. Stability analysis indicates that the landform will be stable provided that the angle of shearing resistance of the fill materials is 33° or higher. The construction material in this area of the landform will be more selective, and will require a higher degree of compaction; and
- Foundation Support – The foundation soils must be able to support the weight of the landform without bearing capacity failure or excessive settlement. The pressure at the base of the landform will not exceed 100 kPa. The existing fill materials underlying the site are considered capable of support of the landform without bearing capacity failure; however, some settlements will occur. In most areas, the magnitude of the settlement should be less than 50 mm and should occur during construction. However, in certain areas, deep deposit of highly compressible organic silts exists under the fill. The settlement in these areas 0.3 to 1.5 m of long term settlements are expected. In these areas, the landform can be overbuilt, and regraded after most of the settlements have occurred. The landform can be surcharged to shorten the period of settlement.

(Ontario Realty Corporation, 2006)

2.5 Applicable Acts, Regulations, Standards and Guidelines

The Lakes and Rivers Improvement Act (LRIA), which is administered by the Ministry of Natural Resources and Forestry (MNRF), provides general guidance for dam design and safety in Ontario. The purpose of the LRIA is, among others, to "provide for protection of persons and of property by ensuring that dams are suitably located, constructed, operated and are of appropriate nature". Under the LRIA, a " 'dam' means a structure or work forwarding, holding back or diverting water and includes a dam, tailings dam, dike [dyke], diversion, channel alteration, artificial channel, culvert or causeway". As such, dykes and consequently landforms are interpreted to be a subset of dams under the LRIA.

The Planning Act and Provincial Policy Statement (PSS), which are administered by Ontario Ministry of Municipal Affairs and Housing (MMAH), address regulatory restrictions associated with flood hazards.

It is emphasized that MNRF have traditionally taken a position that earthen dykes are not considered as a form of permanent flood control. This position is based on the risk related to the three failure modes that are inherent in the typical design of a dyke structure (i.e. overtopping, seepage, and settlement).

In 2007, Canadian Dam Association (CDA) published a series of Technical Bulletins addressing a number of design and operational elements, including dam classification, failure modes, geotechnical and structural considerations, seismic hazards, surveillance and public safety.

In 2011, MNRF published a series of Technical Bulletins addressing similar elements, including design floods, spillways and freeboard for flood control structures.

While these documents provide invaluable input into the planning and design of dams and dykes, they do not include specific design methodologies and calculations, and are not intended to serve as design guidelines. As such, there are currently (2018) no specific Ontario guideline for the design and operation of dykes. US agencies, such as FEMA, the US Army Corps of Engineers (USACE), the US Department of Agriculture (USDA), and the US Department of the Interior Bureau of Reclamation provide significantly more specific guidance on dykes. Given that US documents exclusively use the term "levee", this term is considered to be interchangeable with the terms "dyke" and "berm" in this Document when making references to US resources.

Additional discussion of applicable standards and guidelines is offered in subsequent sections of this Document in relation to various hydrotechnical, geotechnical, structural and other design considerations.

3. Design and Operational Considerations Fact Sheets

This Document serves to consolidate the key design and operational considerations from the extensive amount of background information that has already been prepared by agencies experienced with dyke design and operation. Based on the experience with the West Don Lands landform, other projects of similar nature, and the extensive background information available, the design stage typically requires consideration for the following design and operational elements:

- Planning Process;
- Hydrology;
- Hydraulics;
- Fluvial Geomorphology;
- Site Characterization and Geotechnical Assessments;
- Geotechnical and Structural Design;
- Environmental;
- Public and Private Infrastructure;
- Landscaping;
- Engineering Submission, Tendering and Construction;
- Operations and Maintenance;
- Public Access and Social Impacts; and
- Cost Benefit Analysis.

In the following section, each of the above design and operational considerations has been summarized in a standardized format of fact sheets, which include the following information:

- Description;
- Impact on landform design;
- Design requirements and considerations;
- Design tools and information; and
- Additional information.

A checklist of the key design considerations is provided in **Table 2** (provided at the end of the Document) and illustrated in **Figures 6** and **7**.

PLANNING PROCESS

Description	▪ Provides the required framework that development of the FPL must adhere to.
Impact on Landform Design	▪ Affects the process of FPL design and consultation requirements; ▪ Affects the siting of the landform and the final approval to construct; ▪ Affects the project schedule if authorizations or permits are required; and ▪ Influences the sources of design and operation funding.
Design Requirements and Considerations	▪ FPL and associated land uses must be in compliance with local municipal official plan and guidelines; ▪ FPL is not meant to facilitate new development in regulated areas, but to allow for intensification of already developed land in urban areas. It is recognized this has only been approved in concept by the MNRF for the West Don Lands; ▪ FPL is meant to be in keeping with all other applicable policies as set out by the Ministry of Natural Resources and Forestry (MNRF), including the Technical Guide, River and Stream Systems, Flooding Hazard Limit (2002) requirements for establishing the level of protection; ▪ Municipal approval of Official Plan Amendments (OPA) and re-zoning to allow for the land to be used for flood control; ▪ FPL land ownership must remain publicly owned to ensure long term maintenance and operation; ▪ Completion of an Environmental Assessment to demonstrate the technical, environmental, social, and financial feasibility; and ▪ Hazard and risk assessment may be completed by the Municipality or TRCA to justify the use landform flood protection.
Design Tools and Information	▪ Municipal Class Environmental Assessment Process; ▪ Conservation Authority Class Environmental Assessment Process ▪ Review of official plans, secondary plans and official plan amendments, zoning by-laws; ▪ Determine approval requirements; and ▪ Complete stakeholder consultations.
Additional Information	▪ Conservation Ontario. (2013). Class Environmental Assessment. Retrieved from https://conservationontario.ca/conservation-authorities/planning-and-regulations/class-environmental-assessment/ ▪ Ministry of the Environment, Conservation and Parks. (2013). Class EA for Remedial Flood and Erosion Control Projects. Retrieved from https://www.ontario.ca/page/class-ea-remedial-flood-and-erosion-control-projects ▪ Municipal Engineers Association. (October 2000, amended 2007, 2011, & 2015). *Municipal Class Environmental Assessment*. ▪ Municipal Official Plans (depends on site location). ▪ Ontario Ministry of Affairs and Housing. (2014). Provincial Policy Statement. Retrieved from http://www.mah.gov.on.ca/ ▪ Ontario Ministry of Natural Resources (OMNR)(MNR). (2002). *Technical Guide - River and Stream Systems: Flooding Hazard Limit* (Section C – 1, 2 ,3 & 4). ▪ Ontario Ministry of Natural Resources (OMNR)(MNR). (2002). *Technical Guide - River and Stream Systems: Erosion Hazard Limit* (Section 3.0). ▪ Ontario Ministry of Natural Resources (OMNR)(MNR). (August 2011). *Classification and Inflow Design Flood Criteria - Technical Bulletin* (Section 2.0). ▪ Ontario Ministry of Natural Resources (MNR). (August 2011). *Lakes and Rivers Improvement Act Administrative Guide*. ▪ Ontario Ministry of Natural Resources and Forestry (MNRF), *Lakes and Rivers Improvement Act* (LRIA), R.S.O., c. L.3 (1990).

HYDROLOGY

Description	▪ Characterizes the surface water flow contributing to the FPL site under consideration through identification of the catchment area, contributing water courses, and land use affecting surface runoff response. A detailed understanding of the hydrologic function of the watershed may allow for consideration of alternatives or pairing with other options such as storage, flow diversion, or land use policy changes.
Impact on Landform Design	▪ The peak flow rate identified by the hydrology analysis is used for hydraulic modelling and determination of the maximum level of protection required for FPL, which affects the overall geometry and footprint of the FPL; and ▪ The frequent storm return periods (i.e. 0.5 – 2-year) can affect, through the results of the hydraulic analysis, the need for toe protection and the selection of wet side landscaping materials.
Design Requirements and Considerations	▪ Hydrology models used for landform design should remain current and reflective of existing and approved future conditions (i.e. Official Plan). Where hydrology models are older than 10 years, or where land use planning initiatives are proceeding beyond the approved Official Plan, than a hydrology model update should be completed prior to undertaking a landform design exercise; ▪ Identification of the steady state peak flow rate, which is the greater of the 100-year design storm or the Regional Storm events; ▪ Determine drainage patterns and peak flows associated with local and adjacent drainage (e.g. dry side or external drainage areas); ▪ Consider hydrologic responses in view of the existing, interim and ultimate development conditions and FPL service life; and ▪ Consider hydrologic responses in view of climate change impacts.
Design Tools and Information	▪ Event and continuous hydrologic simulations using approved modelling tools (e.g. PCSWMM); ▪ Review of existing and future development scenarios in terms of land uses and potential changes to urban and riverine systems; ▪ Model calibration and verification; ▪ Trend analyses to consider climate change: ▪ Data Requirements: ○ LiDAR/Photogrammetry bare earth Digital Elevation Model (DEM), or other topographic data; ○ Ontario Soil Reports; ○ Land use classification features; ○ Rainfall and flow monitoring (e.g. baseflow and event); ○ Orthophotography; and ○ Rainfall data including: ▪ 0.5 – 100-year design storm Intensity Duration Frequency (IDF) curves; and ▪ Regional Storm intensity.
Additional Information	▪ Canadian Dam Association (CDA). (2007). *Dam Safety Guidelines* (*Hydrotechnical Considerations for Dam Safety*; *Inundation, Consequences, and Classification for Dam Safety Technical Bulletin,* Section 2.0). ▪ Ontario Ministry of Natural Resources (MNR). (2002). *Technical Guide - River and Stream Systems: Flooding Hazard Limit* (Section C). ▪ Ontario Ministry of Natural Resources (MNR). (August 2011). *Classification and Inflow Design Flood Criteria - Technical Bulletin* (Section 3.0).

HYDROLOGY

	▪ United States Army Corps of Engineers (USACE), CIRIA, and French Ministry of Ecology. (2013). *The International Levee Handbook* (Section 7.3.3). ▪ United States Army Corps of Engineers. (1995). *EM 1110-2-1419: Hydrologic Engineering Requirements for Flood Damage Reduction Studies (Chapter 2)*. ▪ United States Department of Agriculture - Natural Resources Conservation Service - Conservation Engineering Division. (2005). *Earth Dams and Reservoirs TR-60* (Part 2). ▪ United States Department of the Interior Bureau of Reclamation. (1987). *Design of Small Dams* (Chapter 3).

HYDRAULICS

Description	▪ Quantifies the estimated water surface elevation, depth and velocity, and characterizes the extent of inundation at the site of the FPL and upstream and downstream in the channel.
Impact on Landform Design	▪ Identifies the flood vulnerable areas and establishes the maximum flood protection required for FPL design; and ▪ Determines the estimated velocity in the channel, which determines the necessity of toe protection and the selection of wet side landscaping materials.
Design Requirements and Considerations	▪ Identification of downstream structures and obstructions susceptible to ice blockages, which could increase water surface elevations (refer to **Figure 6**); ▪ Potential effects of ice build-up on the wet side slope leading to scour damage and ice above the elevated design water level; ▪ Determine water surface elevations and velocities for all design (e.g. 0.5 – 100-year) and historical events up to and including the maximum level of protection (refer to **Figure 7**); ▪ Consider changes in water surface elevations as a result of sediment deposition, wind and wave action; ▪ Determine the overtopping velocity (dry side) and the external erosive flows (wet side) (refer to **Figure 3**); and ▪ An assessment of the dry side overtopping velocity should be completed during detailed design to determine the maximum permissible overtopping depth that can maintain the recommended velocity of < 1.2 m/s.
Design Tools and Information	▪ Preparation of hydraulic models for both the baseline condition and proposed flood protection landform alternatives to provide a detailed characterization of the upstream and downstream impacts due to FPL implementation; ▪ Hydraulic simulations (1D, 1D/2D, or 2D) using approved modelling tools (e.g. MIKE); ▪ Additional modelling consideration for: o Overtopping dry side velocities; o Ice transport modelling; o Scour modelling; o Wind and wave modelling; and o Sediment transport modelling. ▪ Data Requirements: o LiDAR/Photogrammetry bare earth DEM, or other topographic data; o Watercourse bathymetry; o Water level and/or flow monitoring data; o Hydraulic structure as-builts (e.g. bridges and culverts); o Building footprints; o Land use classification features; and o Orthophotography.

Additional Information	▪ Canadian Dam Association (CDA). (2007). *Dam Safety Guidelines* (*Hydrotechnical Considerations for Dam Safety Technical Bulletin Section; Inundation, Consequences, and Classification for Dam Safety Technical Bulletin,* Section 2.0). ▪ Ontario Ministry of Natural Resources (MNR). (2002). *Technical Guide - River and Stream Systems: Flooding Hazard Limit* (Sections C-4 & G). ▪ Ontario Ministry of Natural Resources (MNR). (2002). *Technical Guide - River and Stream Systems: Erosion Hazard Limit* (Section 3.1.2). ▪ Ontario Ministry of Natural Resources (MNR). (August 2011). *Lakes and Rivers Improvement Act: Spillways and Flood Control Structures* (*Sections 4 & 5).* ▪ United States Army Corps of Engineers (USACE), CIRIA, and French Ministry of Ecology. (2013). *The International Levee Handbook* (Section 7.3.2.2). ▪ United States Army Corps of Engineers. (1993). *EM 1110-2-1416: Engineering and Design River Hydraulics*.

FLUVIAL GEOMORPHOLOGY

Description	▪ Characterizes the form and function of the channel and the interaction between the channel, FPL, and the surrounding landscape.
Impact on Landform Design	▪ Siting of the proposed landform in relation to channel planform. ▪ In conjunction with the hydraulic analysis, determines the need for hardened toe protection, and the selection of terrestrial and aquatic landscaping vegetation.
Design Requirements and Considerations	▪ Identify potential geomorphological risks associated with erosion and sedimentation due to the localized disconnection of the river from its floodplain (at, and upstream and downstream of the FPL site); ▪ Consideration for the location of the FPL site in relation to the inside or outside meander of the channel. The inside meander would likely be a depositional site with channel migration away from the FPL, while the outside meander would likely be an erosive site with channel migration towards the FPL; ▪ Determine degree of valley confinement upstream and downstream from the FPL site to determine where sediment would migrate; ▪ Determine the location of the proposed FPL in relation to the channel planform; ▪ Identify existing bed and bank substrate and degree of mobility (judged by degree of vegetation of deposits in the field, existing extent of bank protection) combined with hydraulic analysis; ▪ Propose appropriate horizontal and vertical setbacks from the watercourse; ▪ Propose appropriate channel realignment; and ▪ Propose appropriate erosion protection or sediment removal (e.g. dredging) measures.
Design Tools and Information	▪ Field Reconnaissance including Rapid Geomorphological Assessment (Aggradation, Widening, Degradation, Planimetric Adjustment) – overall score classifies the reach in terms of stability, individual score indicates the dominant active processes. Different processes will require a different approach to address them (e.g. if planimetric adjustment, channel may eat into proposed landform over time). Most urban channels likely to be degrading then widening due to knock impacts of urbanisation on the hydrograph and subsequent channel adjustment; ▪ Bed material and sheer stress analyses; ▪ Freedom Space Approach to define mobility space and support identifying flood space, using historic photography and LiDAR/Photogrammetry, as well as quantification of bank erosion rates (based on measurements from historic aerial photography at specific meander bends), and interpreting previous fluvial processes where heavily urbanised; ▪ Design of any required localised thalweg / low flow channel / channel realignment to work with natural processes as far as possible; ▪ Design of any required erosion protection – protection technique (potentially including vegetation / bioengineering), harder approaches stone sizing dependant on velocities / shear stresses (refer to **Figure 7**); ▪ Categorization of geomorphological reaches in relation to the FPL site; and ▪ Data Requirements: ○ Photography (current and historical); ○ LiDAR/Photogrammetry bare earth DEM; ○ Flow data from hydrology analysis; and ○ Water surface elevation and velocity from hydraulics analysis.
Additional Information	▪ Ontario Ministry of Natural Resources (MNR). (2002). *Technical Guide - River and Stream Systems: Erosion Hazard Limit* (Section 2.1). ▪ Ontario Ministry of Natural Resources (MNR). (August 2011). *Lakes and Rivers Improvement Act: Spillways and Flood Control Structures* (Section 4.1). ▪ United States Army Corps of Engineers (USACE), CIRIA, and French Ministry of Ecology. (2013). *The International Levee Handbook* (Section 7.5).

SITE CHARACTERIZATION AND GEOTECHNICAL ASSESSMENTS

Description	▪ Encompasses consideration for the selection of FPL construction materials, the suitability and/or removal of native materials, the seepage condition of both imported and native materials, and the seismic conditions of the area.
Impact on Landform Design	▪ Influences the wet and dry side slopes and in turn the footprint of the FPL; and ▪ Determines the material composition, the design of the clay core or liner, and the embedded depth of the FPL (refer to **Figure 7**).
Design Requirements and Considerations	▪ Cohesive foundation materials such clay and clayey soils should be selected for FPL construction which have a high shear strength, and low permeability, compressibility, erodibility, moisture content, and low to medium plasticity (refer to **Figure 7**); ▪ Avoid the use of very wet, highly organic, or loose fine grained non-cohesive foundation soils, which are susceptible to internal erosion, soil piping, loss of support or similar modes of failure; ▪ Geotechnical analysis of the in situ and imported fill material should include at minimum moisture content, Atterberg limits, grain size distribution, density, specific gravity, composition of salt, chalk and organics, and other tests as required; ▪ Determine the permeability, erodibility, compressibility, seismicity, plasticity, and drained and undrained shear strength of the soils; ▪ Any material selected should achieve at-least 98% compaction; ▪ A slope stability analysis is required to confirm that the fill materials are suitable for the promised FPL wet and dry side slopes; ▪ Soils in previously developed areas may be heterogeneous and geotechnical properties may be difficult to assess; ▪ Completion of Phase 1 and/or Phase 2 Environmental Site Assessments; ▪ FPL fill material should not be contaminated; ▪ The FPL foundation should be embedded to sufficient depth to meet the seepage criterion, to displace compressible foundation soils, and to allow for the lowering of the adjacent channel invert elevation due to watercourse movement, or future channel dredging operations; ▪ The maximum seepage exit gradient on the dry side is less than 0.5. Exit gradients in excess of 0.5 can lead to slope instability and failure (refer to **Figure 7**); ▪ Selection of the Maximum Design Earthquake for the FPL should be determined based on the site specific characteristics and in consideration of the MNRF's Design Earthquake Criteria (OMNR, August 2011), or most stringent standards if applicable to the location. The minimum design earthquake frequency required by the MNRF for dams with a Low Hazard Potential Classification is 1:500 year. A more stringent design frequency may be necessary depending on the risk posed to Life Safety, Property, Environment and Cultural/Built Heritage at the site; ▪ Evaluation of seismic performance should address the potential for loss of soil strength due to cyclic loading and significant deformations that could reduce the design level of protection. Seismic action varies significantly depending on proximity to a tectonic plate boundary and thickness of surface deposits. Seismic activity as a result of earthquakes in the Toronto area has been generally low; and ▪ Ongoing QA/QC should be completed during construction to confirm that imported materials meet the geotechnical design requirements for the FPL construction.
Design Tools and Information	▪ Review of well records, borehole logs, surficial geologic maps and associated reports; ▪ Finite Element Seepage modelling (e.g. SEEP/W) is required to determine the exit

SITE CHARACTERIZATION AND GEOTECHNICAL ASSESSMENTS

	gradient of the in situ soils and imported fill material; ▪ Submit subsurface geotechnical plan to TRCA for review and approval; ▪ Implement monitoring program to determine groundwater levels. Following completion of the monitoring program, remove monitoring wells/piezometers as per current Ministry of the Environment, Conservation and Parks requirements; ▪ Post condition assessment and analysis requirements/criteria following an earthquake event (e.g. post liquefaction condition) should be identified by geotechnical engineer during detailed design; ▪ Additional investigations may be required at the discretion of the geotechnical engineer based on the site specific conditions, design requirements, and the scope of work (e.g. Cone Penetration Testing and Dynamic Cone Penetration Testing).
Additional Information	▪ Canadian Dam Association (CDA). (2007). *Dam Safety Guidelines* (*Seismic Hazard Considerations for Dam Safety Technical Bulletin; Dam Safety Analysis and Assessment, and Geotechnical Considerations for Dam Safety Technical Bulletin*). ▪ Ontario Ministry of Natural Resources (MNR). (2002). *Technical Guide - River and Stream Systems: Erosion Hazard Limit* (Section 2 & 4). ▪ Ontario Ministry of Natural Resources (MNR). (2002). *Technical Guide - River and Stream Systems: Flooding Hazard Limit* (Section D - Part 2). ▪ Ontario Ministry of Natural Resources (MNR). (August 2011). *Classification and Inflow Design Flood Criteria - Technical Bulletin* (Section 2.3). ▪ Ontario Ministry of Natural Resources (MNR). (August 2011). *Geotechnical Design and Factors of Safety - Technical Bulletin.* ▪ Ontario Ministry of Natural Resources (MNR). (August 2011). *Seismic Hazard Criteria, Assessment and Considerations - Technical Bulletin.* ▪ Ontario Ministry of Natural Resources (MNR). (August 2011). *Structural Design and Factors of Safety – Technical Bulletin*. ▪ Ontario Realty Corporation. (2006). West Don Lands, Toronto, *Flood Protection Landform Municipal Roadways and Associated Services Preliminary Design Report* (Sections 3.4 & 3.7). ▪ United States Army Corps of Engineers (USACE), CIRIA, and French Ministry of Ecology. (2013). *The International Levee Handbook* (Section 4). ▪ United States Army Corps of Engineers (USACE). (April 30, 2000). *EM1110-2-1913: Design and Construction of Levees* (Section 5 & 6). ▪ United States Army Corps of Engineers (USACE). (2003). *EM1110-2-1902: Slope Stability* ▪ United States Army Corps of Engineers (USACE). (July 31, 1995). *ER1110-2-1806: Earthquake Design and Evaluation for Civil Works Projects (Sections 7, 8 & 10).* ▪ United States Army Corps of Engineers (USACE). (June 30, 1995). *EM1110-2-1908: Instrumentation of Embankment Dams and Levees* (Section 3). ▪ United States Army Corps of Engineers (USACE). (June 4, 2012). *INTERIM: Hurricane and Storm Damage Risk Reduction System Design Guidelines* (Section 3). ▪ United States Army Corps of Engineers (USACE). (May 1, 2005). *ETL1110-2-659: Design Guidance for Levee Underseepage.* ▪ United States Department of Agriculture - Natural Resources Conservation Service - Conservation Engineering Division. (2005). *Earth Dams and Reservoirs TR-60* (Parts 4 & 5). ▪ United States Department of the Interior Bureau of Reclamation. (1987). *Design of Small Dams* (Section D).

GEOTECHNICAL AND STRUCTURAL DESIGN

Description	▪ Further expands the geotechnical analysis for consideration of slope stability, settlement, seepage, seismic, static loading and dynamic loading from wind, waves, ice, sediment and debris.
Impact on Landform Design	▪ Determines the wet and dry side slopes and in turn the footprint of the FPL; and ▪ Determines the material composition, the design of the clay core or liner, and the embedded depth of the FPL.

Design Requirements and Considerations	▪ Determine appropriate slopes, embedded depth, top height and width and setbacks based on stability, settlement, seepage and seismic analyses (refer to **Engineering Submission, Tendering and Construction** section for acceptable design geometry ranges);
	▪ Assess primary static load of FPL material;
	▪ Confirm that appropriate safety factors have been applied to account for potential loss of material due to toe erosion, settlement, vegetation growth and animal activity (refer to **Figure 7**);
	▪ Completion of a settlement analysis by the geotechnical engineer to confirm that both the immediate and long-term settlements for the FPL are admissible so that the integrity and function of various elements of the FPL are not impacted in both the short and long term (refer to **Figure 7**);
	▪ Confirm that sufficient clay core is proposed to prevent seepage (refer to **Figure 7**);
	▪ Select the specifications of the clay core by the geotechnical engineer including materials, range of moisture content, plasticity and compaction requirements to mitigate potential cracks or fissures in the clay core as a result of deformations and/or environmental degradation in the long term.
	▪ Propose appropriate measure to mitigate settlement during and after construction (refer to **Figure 7**). Potential measures to mitigate settling could include:
	  ○ Preloading of the FPL construction area to pre-compress soils prior to construction of FPL;
	  ○ Installation of wick drains prior to FPL construction, in conjunction with preloading to facilitate faster pre-compression and removal of groundwater. Wick drains would need to be removed or sealed upon completion of the preloading phase;
	  ○ Overbuilding of the FPL height during construction to prevent future reduction in the level of protection due to settlement; and/or
	  ○ Increasing the design crest width to allow for future increases to the FPL height following construction (i.e. to compensate for settlement following construction).
	▪ In addition to the primary static load of the FPL, additional consideration should be made for potential secondary loads such as:
	  ○ Horizontal loading of the side slopes due to wind, ice accumulation and expansion, and accumulation of debris against barriers and fences;
	  ○ Unplanned loads due to emergency works such as operating heavy machinery during maintenance reports, or emergency installation of sand/metre bags to temporarily increase FPL height;
	  ○ Temporary stock piling or dumping of material by adjacent land owners; and
	  ○ Traffic loading if FPL intersects, or ties into an active roadway.
	▪ Select tie-in points with surrounding land or infrastructure features and provide sufficient measures to prevent seepage, undermining, or flanking of the FPL;
	▪ Assess the potential occurrence and impact of animal burrows and propose appropriate mitigation measures such as impenetrable barriers (e.g. buried stone);

GEOTECHNICAL AND STRUCTURAL DESIGN

	▪ Wave load may need to be considered for areas exposed to large open bodies of water with long fetch lengths (length of which wind can blow over open body of water), but is generally less applicable to riverine systems.
Design Tools and Information	▪ Complete stability (e.g. slope and base stability, 2D or 3D Finite Element analysis), settlement, seepage (e.g. SEEP/W) and seismic (e.g. pseudostatic) analyses; and ▪ Appropriate pseudostatic analysis or seismic finite element modelling should be completed to assess the seismic stability of the slope.
Additional Information	▪ Canadian Dam Association (CDA). (2007). *Dam Safety Guidelines* (*Seismic Hazard Considerations for Dam Safety Technical Bulletin; Geotechnical Considerations for Dam Safety Technical Bulletin; Structural Considerations for Dam Safety Technical Bulletin*). ▪ Ontario Ministry of Natural Resources (MNR). (2002). *Technical Guide - River and Stream Systems: Erosion Hazard Limit* (Section 2 & 4). ▪ Ontario Ministry of Natural Resources (MNR). (August 2011). *Seismic Hazard Criteria, Assessment and Considerations - Technical Bulletin.* ▪ Ontario Ministry of Natural Resources (MNR). (August 2011). *Geotechnical Design and Factors of Safety - Technical Bulletin.* ▪ Ontario Ministry of Natural Resources (MNR). (August 2011). *Structural Design and Factors of Safety – Technical Bulletin*. ▪ Ontario Realty Corporation. (2006). West Don Lands, Toronto, *Flood Protection Landform Municipal Roadways and Associated Services Preliminary Design Report* (Sections 3.4 & 3.7). ▪ United States Army Corps of Engineers (USACE), CIRIA, and French Ministry of Ecology. (2013). The International Levee Handbook *(Section 4 & 9)*. ▪ United States Army Corps of Engineers (USACE). (April 30, 2000). *EM1110-2-1913: Design and Construction of Levees* (Section 5 & 6). ▪ United States Army Corps of Engineers (USACE). (2003). *EM1110-2-1902: Slope Stability* ▪ United States Army Corps of Engineers (USACE). (July 31, 1995). *ER1110-2-1806: Earthquake Design and Evaluation for Civil Works Projects (Section 7 & 10).* ▪ United States Army Corps of Engineers (USACE). (June 30, 1995). *EM1110-2-1908: Instrumentation of Embankment Dams and Levees* (Section 3). ▪ United States Army Corps of Engineers (USACE). (June 4, 2012). *INTERIM: Hurricane and Storm Damage Risk Reduction System Design Guidelines (Section 3).* United States Army Corps of Engineers (USACE). (May 1, 2005). *ETL1110-2-659: Design Guidance for Levee Underseepage.* ▪ United States Department of Agriculture - Natural Resources Conservation Service - Conservation Engineering Division. (2005). *Earth Dams and Reservoirs TR-60* (Parts 4 & 5). ▪ United States Department of the Interior Bureau of Reclamation. (1987). *Design of Small Dams* (Section D).

ENVIRONMENTAL

Description	▪ Characterizes the environmental components of the FPL site and adjacent area to assess impacts to natural and cultural heritage features.
Impact on Landform Design	▪ Siting and design of the proposed landform in relation to natural and cultural heritage features; ▪ Affects the project schedule if authorizations or permits are required, which may include construction and maintenance timing restrictions, and mitigation measures to avoid sensitive wildlife periods (e.g. breeding bird season and in-water work timing windows); and ▪ Influences landscaping and aquatic vegetation selection, and toe protection design.
Design Requirements and Considerations	▪ Preparation of environmental assessments (EA) and/or environmental impact studies (EIS); ▪ Consideration of Oak Ridges Moraine Conservation Plan, 2002, Greenbelt Plan, 2017 and Provincially Planning Statement, 2014; ▪ Agency consultation to determine EA/EIS and permitting requirements and expectations; ▪ Obtain necessary authorizations or permits under various provincial, municipal and federal legislations prior to onset of construction: o Endangered Species Act, 2007 (ESA); o Species at Risk Act, 2002 (SARA); o Fisheries Act; o O.Reg. 166/06: TRCA – Regulation of Development, Interference with Wetlands and Alterations to Shorelines and Watercourses; o O.Reg. 387/04 Water Taking Regulation (Permit to Take Water); o Ontario Heritage Act, 1990; and o Municipal official plan policies and tree removal/protection-bylaws. ▪ Identification of design alterations to construction footprint, hydraulics and habitat leading to flow changes, scour and deposition patterns, and vegetation placement and abundance; ▪ Provide mitigation and avoidance measures, as well as monitoring during construction and maintenance to avoid or minimize effects on natural and cultural features; ▪ Preparation of environmental management plans (e.g., Erosion and Sediment Control Plans, Soil Management Plans, Spill and Response Plan, Tree Protection Plans, etc.); ▪ Identify and mitigate impacts to Species at Risk (SAR) protected under the ESA and SARA, and procure necessary permits and complete habitat compensation requirements, if required; ▪ Preparation of a Fisheries and Oceans Canada (DFO) Self-assessment under the Fisheries Act to determine whether a DFO Request for Review (RoR) is warranted, if work is in, above or in proximity to watercourses; and ▪ Preparation of a noise and vibration assessment for construction works.
Design Tools and Information	▪ Natural (aquatic and terrestrial) assessments (if applicable): o Data collection from secondary source information and agency consultation; o Ecological Land Classification (ELC) surveys and plant inventories; o Wildlife surveys and wildlife habitat assessments (e.g., breeding bird surveys, amphibian surveys, fish community surveys, fish habitat assessments, etc.); o SAR surveys; and

	○ Arborist tree surveys in accordance with municipal tree removal/protection bylaws. ▪ Cultural heritage assessment (archeology and built heritage); and ○ Stage 1: Background study and property inspection; ○ Stage 2: Property assessment; ○ Stage 3: Site-specific assessments; ○ Stage 4: Mitigation of development impacts as required; and ○ Review of municipal heritage property register. ▪ Noise and vibration assessment
Additional Information	▪ Fisheries and Oceans Canada. (2018). DFO Self Assessment. Retrieved from http://www.dfo-mpo.gc.ca/pnw-ppe/index-eng.html ▪ Municipal Official Plans and Tree Removal/Protection Bylaws (depends on site location). ▪ Ontario Ministry of Affairs and Housing. (2014). Provincial Policy Statement. Retrieved from http://www.mah.gov.on.ca/ ▪ Ontario Ministry of Municipal Affairs and Housing. (2002). Oak Ridges Moraine Conservation Plan. Retrieved from http://www.mah.gov.on.ca/ ▪ Ontario Ministry of Municipal Affairs and Housing. (2017). Greenbelt Plan. Retrieved from http://www.mah.gov.on.ca/ ▪ Ontario Ministry of Natural Resources and Forestry (MNRF). (2018). How to get an Endangered Species Act permit or authorization. Retrieved from https://www.ontario.ca/page/how-get-endangered-species-act-permit-or-authorization ▪ Ontario Ministry of Natural Resources and Forestry. (2018). Natural Heritage Reference Manual for Natural Heritage Policies of the Provincial Policy Statement, 2005. ▪ Toronto and Region Conservation Authority. (2014). TRCA Environmental Impact Statement Guidelines.

PUBLIC AND PRIVATE INFRASTRUCTURE

Description	▪ Characterizes the existing and proposed public and private infrastructure intersecting and adjacent to the FPL site.
Impact on Landform Design	▪ Existing and proposed roads and infrastructure adjacent to the site can affect the placement, geometry, and embedded depth of the FPL; and ▪ Site preparation works to displace infrastructure from the footprint of the FPL could cause longer construction periods and additional costs.
Design Requirements and Considerations	▪ At minimum, avoid roads with high traffic and frequent maintenance needs on the FPL (preferred would be to preclude all municipal roads, and bridge abutments from crossing the landform); ▪ Displacement of utility crossings from the FPL footprint is required to eliminate risk of seepage and piping (refer to **Figures 5** & **6**). Otherwise all utility crossings must be placed below the FPL subgrade materials. If there is an absolute necessity to have a utility crossing through the FPL, then a rigorous design strategy would need to be developed to mitigate the risk of piping from floodwaters, or failure of the utility (e.g. wet utility failure and internal erosion); ▪ All utility crossings (e.g. passing below the FPL subgrade) must incorporate access maintenance holes outside the FPL footprint to allow for inspections, spill control and maintenance without disturbing the embankment.
Design Tools and Information	▪ Composite utility plans showing conflicts using appropriate drawing format. Preparation of a 3D composite utility plan can be beneficial for conflict analysis in busier locations; ▪ Staging and constructability plans for third party roads and utilities; ▪ Operation and maintenance plans for third party roads and utilities; and ▪ Subsurface investigation.
Additional Information	▪ Canadian Dam Association (CDA). (2007). *Dam Safety Guidelines (Public Safety and Security Around Dams Technical Bulletin; Geotechnical Considerations for Dam Safety,* Section 3). ▪ Ontario Ministry of Natural Resources (MNR). (August 2011). *Geotechnical Design and Factors of Safety - Technical Bulletin* (Section 3). ▪ Ontario Realty Corporation. (2006). West Don Lands, Toronto, *Flood Protection Landform Municipal Roadways and Associated Services Preliminary Design Report* (Section 5.1.4). ▪ United States Army Corps of Engineers (USACE). (June 4, 2012). *INTERIM: Hurricane and Storm Damage Risk Reduction System Design Guidelines* (Section 3).

LANDSCAPING

Description	▪ Includes the terrestrial and aquatic vegetation and materials that comprise the surface of the FPL.
Impact on Landform Design	▪ Surface vegetation protects the landform from erosive forces acting on the wet and dry sides of the FPL; and ▪ Affects the aesthetic and integration of the FPL with the surrounding landscape and provide for select recreational uses (refer to **Public Access and Social Impacts** section).
Design Requirements and Considerations	▪ Promote plant species that minimize erosion, settlement, animal activity and vandalism; ▪ Select plant species and/or toe protection that can handle the typical range of velocities and shear stresses anticipated for frequent storm events (e.g. 0.5 – 2 years); ▪ Avoid plant species with deep or large root systems (e.g. trees), or species with extensive maintenance requirements, including irrigation; ▪ Trees can only be planted on the dry side slope provided that a minimum of 1.5 m of top soil is provided on top of the FPL, and shallow species are selected that do not have deep or wide root systems, do not grow to large sizes, or require irrigation. Tree and shrubs that could be considered include Red-Osier Dogwood (*Cornus stolonifera*), Narrow-leaved Meadow-sweet (*Spiraea alba*), and Common Elderberry (*Sambucus canadensis*) if some height is desired (2-3 m height); ▪ The additional top soil placed on the dry side is not required to adhere to the minimum dry side slope requirements provided that the internal FPL structure maintains a 1.5 – 3.5% dry side slope (e.g. the soil could be tapered or retained at the toe of the structure); ▪ Confirm that landscaping plans are prepared in accordance with municipal and TRCA standards; and ▪ The wet side slope of the FPL should be mowed to allow inspection of the slope.
Design Tools and Information	▪ Identification of planting strategy needed to maximize the FPL service life and facilitate maintenance; and ▪ Identification of planting strategy to minimize erosion, settlement, animal activity or unauthorized access.
Additional Information	▪ Ontario Ministry of Natural Resources (MNR). (2002). *Technical Guide - River and Stream Systems: Erosion Hazard Limit (*Appendix 4: Biotechnical & Soil Bioengineering Methods). ▪ Ontario Ministry of Transportation. (1997). *Drainage Management Manual (Design Chart 2.17).* ▪ United States Army Corps of Engineers (USACE). (April 30, 2014). *TL1110-2-583: Guidelines for Landscape Planting and Vegetation Management at Levees, Floodwalls, Embankment Dams, and Appurtenant Structures.*

ENGINEERING SUBMISSION, TENDERING AND CONSTRUCTION	
Description	▪ Defines the engineering, tendering and construction of the FPL, including the overall shape, footprint, and the connection with the surrounding landscape and existing grades for the FPL.
Impact on Landform Design	▪ Determines the crest width and height, the wet and dry side slopes, the overall shape and footprint of the FPL (refer to **Figures 6** and **7**); ▪ Determines the connection with the surrounding landscape and existing grades, and influences the integration with transportation, transit, and other uses and infrastructure; and ▪ The height of the FPL affects the geotechnical material requirements, and the need of material preloading and wick drains to mitigate the effects of long-term settlement.
Design Requirements and Considerations	▪ Clearly document the design process, including site-specific criteria; ▪ Clearly document the construction methodology; ▪ FPL slope requirements, or as determined through geotechnical analyses (refer to **Figure 7**): ○ Wet side slope of 5 – 10% with 10 – 15% allowable for localized areas ○ Dry side slope of 1.5 – 3.5% ▪ Minimum design freeboard of 0.5 m from the maximum level of protection to the crest of the FPL. This includes 0.3 m of normal design freeboard and an additional 0.2 m for climate change considerations (refer to **Figure 7**); ▪ Minimum crest width of 3 m, and a typical range of 3 – 5 m (preferred 5 m or greater) for inspection and maintenance, or as needed to accommodate multiple uses (refer to **Figure 7**). TRCA Planning and Development may require further setbacks for policy and planning purposes. ▪ Minimum offset of 6 m and 4 m from the toe of the wet and dry side slopes, respectively, to allow for vehicular maintenance access and staging (refer to **Figures 6** and **7**); ▪ Illustrate top elevations along the axis parallel to the watercourse, inclusive of freeboard requirements (0.5 m freeboard) (refer to **Figure 6** and **7**); ▪ Illustrate embedded elevation for engineered fill to show removal of native soils or unsuitable existing fill; ▪ Determine low permeability core dimensions. The core dimensions are to be determined based on the site conditions to meet the seepage, moisture content, Atterberg limits, permeability, and grain size distribution requirements determined by the geotechnical engineer; ▪ Identify infrastructure crossings, including conflict identification and seepage collars (refer to **Figure 6**); ▪ Identify horizontal and vertical setbacks from the watercourse (refer to **Figures 6** and **7**); ▪ Identify and design local drainage requirements for the FPL including suitable collection and discharge points (e.g. swale at the toe of slope connected to a ditch inlet catchbasin/local sewer system that travels away from and does not cross the FPL); ▪ Connectivity with the surrounding terrain to minimize application of retaining walls and prevent external drainage from reaching the dry side; and ▪ Identify potential activities and setbacks requiring TRCA approval (e.g. deep excavations, vibrations from construction, transit and roadways, changes in groundwater levels, and settlement from adjacent construction/structures).
Design Tools and	▪ Plans, profiles and additional design specifications (e.g. OPSD) prepared using approved drawing format;

ENGINEERING SUBMISSION, TENDERING AND CONSTRUCTION	

Information	▪ CAD based grading tools to facilitate rapid design iteration and presentation; and
	▪ Data Requirements:
	  ○ Topographic survey; and
	  ○ Water surface elevation and velocity from hydraulics analysis.

Additional Information	▪ Ontario Realty Corporation. (2006). *West Don Lands, Toronto, Flood Protection Landform Municipal Roadways and Associated Services Preliminary Design Report.* ▪ Toronto and Region Conservation Authority (TRCA). (May 2015). West Don Lands to the DMNP, Flood Protection in a Brownfields Environment, Issues and Lessons Learned.

OPERATIONS AND MAINTENANCE

Description	▪ Defines the operation, maintenance and emergency preparedness considerations following construction of the FPL.
Impact on Landform Design	▪ Influences the geometry and toe setbacks to provide ease of access for maintenance vehicles; and ▪ Affects the selection of landscape materials and vegetation.
Design Requirements and Considerations	▪ Develop an Operations, Maintenance and Surveillance (OMS) manual for the FPL (refer to **Figure 7**); ▪ Define legal responsibilities for operations and maintenance, including reporting and cost sharing agreements; ▪ Define prohibited land uses and activities; ▪ Monthly monitoring and maintenance should occur during the summer months to maintain plantings, and remove invasive vegetation and debris (refer to **Figure 7**); ▪ Animal burrows left unchecked and/or unmitigated can pose a potential risk to the FPL through the exacerbation of seepage conduits and shortening of the flow travel distance between the wet and dry sides (refer to **Figure 7**), although substantially less than the risk posed to dykes, and through proper mitigation measures such as impenetrable barriers (e.g. buried stone) the risk can be nearly eliminated. The presence of animal burrows should still be monitored and documented during the routine monitoring and maintenance period during the summer months. Recognizing that the location and size of each FPL would be different, the criteria for animal burrow monitoring and removal should be determined during detailed design; ▪ Ongoing survivability of plantings and vegetation should be monitored to ensure continued erosion control. Dead or toppled vegetation should be replaced, and holes left by root balls should be filled; ▪ Ongoing monitoring of external erosion, settlement, seepage, debris and sediment accumulation, groundwater levels and vandalism (refer to **Figure 7**); ▪ Re-establishment of the design crest elevation is recommended to occur following 50 mm of settlement, (this is generally the minimum accuracy provided by Unmanned Aerial Vehicle (UAV) survey drones), but may be redefined during detailed design based on site specific requirements. The maintenance threshold criteria for external erosion, seepage, and groundwater levels are site specific and would need to be determined during detailed design; and ▪ Maintenance inspections following construction of the FPL should monitor for the appearance of cracks and fissuring, slumping, and surface scour due to concentrated runoff and high-water events.
Design Tools and Information	▪ Data requirements for inclusion in OMS: ○ As-built drawings including clearly delineated areas where no maintenance excavation can occur; ○ Best maintenance practices and practices to avoid; ○ Contact information and responsibilities of stakeholders; ○ Emergency response procedures; ○ Environmental considerations affecting OMS (i.e. bird nests, bat habitat, fish habitat and associated timing windows); ○ Inspection checklist and documented maintenance log; ○ Legal requirements for maintenance; ○ Maintenance frequency schedule, and procedure to respond to problems with the FPL; ○ Manufacturers specifications for equipment/structures and list of authorized

OPERATIONS AND MAINTENANCE

	products for use on the FPL (i.e. seed mixtures and concrete, rip-rap type); ○ References to FPL design standards; ○ Monthly to quarterly topographic surveys using settlement markers, or UAV survey drones following construction and increased to annual frequency once post construction settlement as stabilized is recommended, but may be subject to change during detailed design based on the site specific requirements; ○ Risk register of associated risks in relation to the FPL (i.e. contaminated material in the area, risks to environment due to failure; and ○ Training and equipment requirements.
Additional Information	▪ Canadian Dam Association (CDA). (2007). *Dam Safety Guidelines (Public Safety and Security Around Dams; Surveillance of Dam Facilities).* ▪ Ontario Ministry of Natural Resources (MNR). (August 2011). *Dam Safety Reviews - Technical Bulletin.* ▪ Ontario Ministry of Natural Resources (MNR). (2002). *Technical Guide – River and Stream Systems: Erosion Hazard Limit* (Section 2.3, Appendix 3) ▪ Ontario Ministry of Natural Resources (MNR). (2016). *Alterations, Improvements and Repairs to Existing Dams - Technical Bulletin* (Sections 2, 3, & 4.4). ▪ United States Army Corps of Engineers (USACE), CIRIA, and French Ministry of Ecology. (2013). *The International Levee Handbook* (Section 4). ▪ United States Army Corps of Engineers (USACE). (April 30, 2014). *TL1110-2-583: Guidelines for Landscape Planting and Vegetation Management at Levees, Floodwalls, Embankment Dams, and Appurtenant Structures* (Section 5). ▪ United States Army Corps of Engineers (USACE). (June 30, 1995). *EM1110-2-1908: Instrumentation of Embankment Dams and Levees* (Section 8). ▪ United States Army Corps of Engineers (USACE). (June 4, 2012). *INTERIM: Hurricane and Storm Damage Risk Reduction System Design Guidelines* (*Section 3.7.2.*).

PUBLIC ACCESS AND SOCIAL IMPACTS

Description	▪ Defines the social impacts and the acceptable recreational uses for the FPL.
Impact on Landform Design	▪ Influences the selection of landscape materials and the inclusion of elements for ongoing public use; and ▪ Identifies uses in addition to the primary flood protection purpose.
Design Requirements and Considerations	▪ Access along the wet side is provided for operation and maintenance purposes only; ▪ Define appropriate recreational uses that minimize deterioration to the FPL. Recreational uses such as pedestrians and mountain bikes can cause erosion and rutting leading to accelerated deterioration and lowering of the crest, and should be limited to well defined pathways on the dry side; ▪ Recreational uses requiring auxiliary structures (e.g. pavilions) may be considered on the dry side provided that the FPL is overbuilt with additional fill and the risk of failure is not increased, and the design is deemed acceptable by the geotechnical engineer; ▪ Public access can exacerbate the spread of invasive species and overcrowd the original design landscape species, potentially reducing effectiveness of erosion protection measures; ▪ Loss of surface vegetation could lead to desertification and creation of excessive dust in adjacent communities. This can be mitigated by an effective landscaping maintenance and irrigation program; ▪ Beautification of the FPL through landscaping, frequent maintenance, removal of litter, debris and invasive species can provide beneficial greenspace to the community; ▪ Provide appropriate signage to identify appropriate uses for the FPL and to prohibit non-appropriate uses and dumping; ▪ Provide appropriate signage to identify the risks of high water events and emergency contact numbers; and ▪ Provide emergency floatation and retrieval equipment at the site of the FPL (e.g. ring buoy, shepherds crook, and buoyant throw rope).
Design Tools and Information	▪ Public outreach program, including information signage and radio/digital information campaigns.
Additional Information	▪ Canadian Dam Association (CDA). (2007). *Dam Safety Guidelines (Public Safety and Security Around Dams).* ▪ Ontario Ministry of Natural Resources (MNR). (2002). *Technical Guide - River and Stream Systems: Flooding Hazard Limit* (Section 3.4. ▪ Ontario Ministry of Natural Resources (MNR). (August 2011). *Public Safety Around Dams - Best Management Practices - Technical Bulletin.* ▪ United States Department of the Interior Bureau of Reclamation. (1987). *Design of Small Dams* (Chapter 2 – F).

COST BENEFIT ANALYSIS

Description	▪ Provides the justification for implementation of the FPL over other flood protection alternatives.
Impact on Landform Design	▪ Contributes to determination of the overall feasibility of the FPL versus other flood protection alternatives.
Design Requirements and Considerations	▪ Complete cost-benefit analyses for various scenarios (e.g. level of flood protection, property cost, environmental and social impacts); and ▪ Present a business case for the FPL implementation.
Design Tools and Information	▪ Assess capital and maintenance costs over the FPL service life ▪ Assess direct and indirect flood damages without the FPL in place ▪ Assess indirect costs, such as delays in allowing for development
Additional Information	

4. Conclusion & Next Steps

The Flood Protection Land Forming Technical Design Considerations is intended as a resource to support the planning and design process for landforms within TRCA's jurisdiction through consolidation of the relevant technical design considerations as identified by comprehensive review of applicable acts, regulations, policies, standards and guidelines; experience gained through the planning design, construction and operation of the West Don Lands Landform; and additional input provided by various technical disciplines, reviewing agencies and other stakeholders.

Since land forming is a relatively new concept and to date (2018) only one landform has been constructed within TRCA's jurisdiction, there are no design requirements specifically intended for landforms, and as a result most of the design considerations in this Document originate from well established design guidelines and requirements for dykes and dams. The design and operational characteristics of landforms are generally similar to dykes and dams, with the primary difference that landforms are not intended to regularly retain water and are intended to only be operating during extreme rainfall such as the 100-year or Regional Storm events. Furthermore, due to landforms shallow wet and dry side slopes, and significantly larger size and width, landforms are designed to be resilient to the common modes of failure of dams and dykes. Recognizing that each landform would have site specific design considerations, the design of each FPL should further assess the following:

- Potential failure mode analyses for failure modes including overtopping velocity, breaches, seepage/soil piping, settlement and seismic;
- Conduct a risk analysis including the development of risk assessment criteria and quantification of risks;
- Development of Hazard Potential Classification;
- Criteria and targets for deterministic design including factors of safety, Maximum Design Earthquake, and Probable Maximum Flood; and
- Exploration of the "never" fail requirement.

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Tables

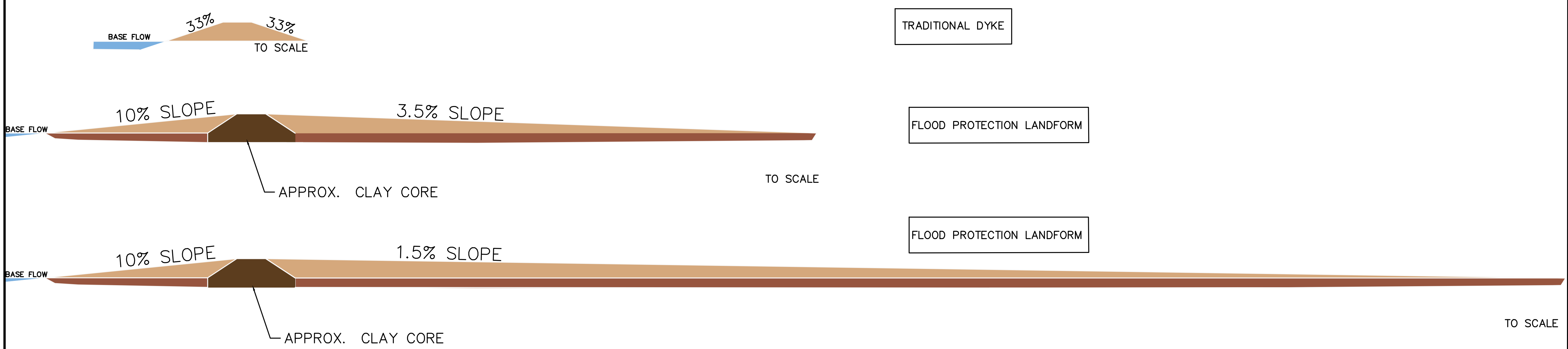
TABLE 1: FLOOD PROTECTION MODES OF FAILURE

MODE OF FAILURE	DESCRIPTION	ISSUES ASSOCIATED WITH TRADITIONAL DYKES	MITIGATING ISSUES WHEN USING FLOOD PROTECTION LANDFORM
Failure Due to Overtopping and External Erosion (Figure 3)	The overtopping failure is a situation where inadequate freeboard leads to unexpected and/or uncontrolled overtopping of a structure, which can cause major scour and ultimately compromise the integrity of the structure. This mode of failure is generally caused by (a) exceedance or underestimation of design storm levels; and (b) reduction in the level of protection due to settlement or material loss. The external erosion failure is generally reflected in scour and loss of material because of (a) improper local drainage; (b) erosion on the wet side caused by moving water, waves, wind, ice accumulation; (c) erosion on the wet side due to storm outlets; and (d) road traffic and navigational impacts.	Traditional dykes typically have moderately steep slopes (33% to 50%). Overtopping of a typical dyke can lead to concentrated flow on the dry side, with velocities exceeding permissible values, which results in major scour and ultimately in a breach of the structure. It is difficult to maintain maximum velocities to less than 1.2 m/s due to relatively steep slopes. Such moderately steep slopes also offer limited opportunities to implement spillway and energy dissipation structures on the dry side and toe protection on the wet side.	Flood Protection Landforms (FPL) have gentler slopes both on the wet (5-10%, up to 15% localized) and dry (1.5-3.5%) side. In case of overtopping this allows for a shallow sheet flow on the dry side, thus minimizing velocities. The maximum velocities can be limited to less than 1.2 m/s. The gentle slope on the wet side creates better opportunities for implementation of erosion control measures. The wider geometry of the FPL cross section provides more resiliency to failure during overtopping as there is considerably more material to be eroded as the breach occurs in comparison to traditional dykes. The flatter wet and dry slope also minimize the potential impacts of local drainage.
Failure Due to Seepage (Figure 4)	Seepage is generally caused by hydraulic gradient on the wet side, forcing water to move either through or under the structure, and can lead to failure through internal erosion, soil piping, boils, and loss of support. The extent of seepage is normally a function of the material composition, hydraulic gradient, structure dimensions, as well as presence of utilities, vegetation growth, animal activity or cracks due to settlement. Boils are caused by water reaching the dry side, which is typically characterized by soil uplift. Seepage can be exacerbated through pathways created by utility conduits, animal burrows, roots or cracks due to settlement.	Traditional dykes typically have a narrow cross section due to their steeper slopes and symmetrical wet and dry sides. Due to the narrow cross section, the flow path is relatively short, which increases the risk of boils and seepage. The narrow cross section also provides limited space for the implementation of impermeable barriers (e.g. clay core) and other protection measures.	The wider cross section of the FPL provides a much longer travel distance time for water moving through or under the structures. Exit gradient can be designed as 0.5 or less. The wider cross section of the FPL also provides better opportunities for the implementation of impermeable barriers (e.g. clay core).
Failure Due to Settlement (Figure 5)	The settlement mode of failure includes slumping, sliding or rotational failure as a result of insufficient loading capacity, cracks due to settlement, or seismic failure caused by an earthquake, which may lead to cracks or material liquefaction.	Traditional dykes typically have a narrow cross section. The smaller cross section is more vulnerable to impacts of settlement failure or earthquake, as even a relatively small affected area can result in a breach.	FPLs have a much larger volume/mass, thus creating more resilience to earthquakes. For example, for 5 m of maximum flood protection, landforms with 10% wet side slopes, and 3.5% or 1.5% dry side slopes, respectively, would have 5 and 9.8 times more mass/volume than a traditional dyke with 33% side slopes. This larger mass creates more resilience to impacts due to earthquakes, settlement failures. Smaller areas affected by settlement or liquefaction will not necessarily result in a breach of the structure.

TABLE 2: FLOOD PROTECTION LAND FORMING DESIGN CHECKLIST

1. PLANNING PROCESS	2. HYDROLOGY	3. HYDRAULICS
✓ FPL and associated land uses must be in compliance with applicable municipal planning documents; ✓ FPL is not meant to facilitate new development in regulated areas, but to allow for intensification of already developed land in urban areas; ✓ FPL is meant to be in keeping with all applicable policies as set out by Ministry of Natural Resources and Forestry (MNRF); and ✓ FPL land ownership must remain publicly owned to ensure long term maintenance and operation.	✓ Identification of the steady state peak flow rate, which is the greater of the 100-year design storm or the Regional storm event; ✓ Where hydrology models are older than 10 years, or where land use planning initiatives are proceeding beyond the approved Official Plan, than a hydrology model update should be completed prior to undertaking a landform design exercise; ✓ Determine drainage patterns and peak flows associated with local drainage (e.g. dry side or external drainage areas); and ✓ Consider hydrologic responses in view of the existing, interim and ultimate development conditions and FPL service life.	✓ Determine water surface elevations and velocities for all design and historical events up to and including the maximum level of protection; ✓ Consider changes in water surface elevations as a result of ice transport, scour, sediment deposition, wind and wave action; and ✓ Overtopping velocity (dry side) and external erosive flows (wet side).
4. FLUVIAL GEOMORPHOLOGY	**5. SITE CHARACTERIZATION AND GEOTECHNICAL ASSESSMENTS**	**6. GEOTECHNICAL AND STRUCTURAL DESIGN**
✓ Identify potential geomorphological risks associated with erosion and sedimentation due to the localized disconnection of the river from its floodplain (at, upstream and downstream of the FPL site); ✓ Propose appropriate horizontal and vertical setbacks from the watercourse; ✓ Propose appropriate channel realignment; and ✓ Propose appropriate erosion protection or sediment removal (e.g. dredging) measures.	✓ Confirm that only cohesive foundation materials are selected for FPL construction; ✓ Confirm that native and imported materials have sufficient shear strength, as well as low permeability, low compressibility, low erodibility and low liquefaction potential; ✓ Confirm that the FPL foundation is sufficiently embedded to allow for anticipated watercourse movement and address compressible or low bearing soils; and ✓ Confirm that sufficient clay core is proposed to prevent seepage.	✓ Propose appropriate slopes, embedded depth, top height and width and setbacks based on stability, settlement, seepage and seismic analyses; ✓ Confirm that appropriate materials are selected to support the primary static load of the FPL and any potential secondary loads (e.g. wind, ice accumulation, roadway tie-ins and maintenance equipment); ✓ Confirm that appropriate safety factors have been applied to account for potential loss of material due to toe erosion, settlement, vegetation growth and animal activity; and ✓ Propose appropriate measure to mitigate settlement (e.g. preloading, installation of wick drains, overbuilding of the FPL).
7. ENVIRONMENTAL	**8. PUBLIC AND PRIVATE INFRASTRUCTURE**	**9. LANDSCAPING**
✓ Obtain all necessary authorizations or permits under various provincial, municipal, and federal legislations prior to the onset of construction; ✓ Identify areas requiring protection and/or mitigation measures and propose appropriate habitat compensation; ✓ Define construction and maintenance timing windows in relation to breeding and spawning seasons and other considerations; ✓ Prepare a noise and vibration assessment for construction works; and ✓ Complete a cultural and built heritage assessment.	✓ Displacement of utility crossings from the FPL footprint is required to eliminate risk of seepage and piping (refer to **Figures 5** & **6**). Otherwise all utility crossings must be placed below the FPL subgrade materials. ✓ At minimum, avoid roads with high traffic and frequent maintenance needs on the FPL (preferred would be to preclude all municipal roads, and bridge abutments from crossing the landform); and ✓ All utility crossings (e.g. passing below the FPL subgrade) must incorporate access maintenance holes outside the FPL footprint to allow for inspections, spill control and maintenance without disturbing the embankment.	✓ Promote plant species that minimize erosion, settlement, animal activity and vandalism; ✓ Avoid plant species with deep root systems, or species with extensive maintenance requirements, including irrigation; ✓ Select plant species and/or toe protection that can handle the typical range of velocities and shear stresses anticipated for frequent storm events (e.g. 0.5 – 2 years); and ✓ Confirm that landscaping plans are prepared in accordance with municipal and TRCA standards.
10. ENGINEERING SUBMISSION, TENDERING AND CONSTRUCTION	**11. OPERATIONS AND MAINTENANCE**	**12. PUBLIC ACCESS AND SOCIAL IMPACTS**
✓ Wet slope ranging from 5-10% with 10-15% allowable for localized areas, or as determined through geotechnical analysis; ✓ Dry slope ranging from 1.5-3.5%, or as determined through geotechnical analysis; ✓ Minimum crest freeboard of 0.5 m from the maximum level of protection; ✓ Minimum crest width of 3 m (preferred 5 m or greater) for inspection and maintenance; ✓ Minimum setback of 6 m and 4 m on the wet and dry sides, respectively, to allow for inspection and maintenance; and ✓ Infrastructure crossings (must cross below FPL subgrade), including conflict identification and seepage collars.	✓ Develop and implement Operations, Maintenance and Surveillance manual ✓ Define legal responsibilities for operations and maintenance, including reporting and cost sharing agreements; ✓ Determine frequency for monitoring, vegetation management and animal control; ✓ Confirm feasibility of mitigation practices associated with slope stability (e.g. increasing height) or seepage control; and ✓ Define prohibited land uses and activities.	✓ Access along the wet side is provided for operation and maintenance purposes only; ✓ Define appropriate recreational uses that minimize deterioration of the FPL (e.g. well defined pedestrian walkways to limit off trail erosion); ✓ Provide appropriate signage to identify appropriate uses for the FPL and to prohibit non-appropriate uses and dumping; ✓ Provide signage to identify high water risks, and emergency floatation and retrieval equipment at the site of the FPL; and ✓ Implement public outreach program to educate the public on allowable and prohibited activities on the FPL.
13. COST BENEFIT ANALYSIS		
✓ Complete cost-benefit analyses for various scenarios (e.g. level of flood protection, property cost, environmental and social impacts); and ✓ Present a business case for the FPL implementation.		

Figures



COMPARISON OF TRADITIONAL DYKE VS. LANDFORM CROSS SECTION WIDTHS FOR VARIOUS HEIGHTS

HEIGHT (m)	DYKE		LANDFORM			DYKE	LANDFORM	
	WET SIDE SLOPE	DRY SIDE SLOPE	WET SIDE SLOPE	DRY SIDE SLOPE	DRY SIDE SLOPE	WET AND DRY SIDE SLOPES	DRY SIDE SLOPE	
	33%	33%	10%	3.50%	1.50%	33%	1.50%	3.50%
	WIDTH (m)					TOTAL CROSS SECTION WIDTH (m)		
1	3.0	3.0	10.0	28.6	66.7	11.1	43.6	81.7
1.5	4.5	4.5	15.0	42.9	100.0	14.1	62.9	120.0
2	6.1	6.1	20.0	57.1	133.3	17.1	82.1	158.3
2.5	7.6	7.6	25.0	71.4	166.7	20.2	101.4	196.7
3	9.1	9.1	30.0	85.7	200.0	23.2	120.7	235.0
3.5	10.6	10.6	35.0	100.0	233.3	26.2	140.0	273.3
4	12.1	12.1	40.0	114.3	266.7	29.2	159.3	311.7
4.5	13.6	13.6	45.0	128.6	300.0	32.3	178.6	350.0
5	15.2	15.2	50.0	142.9	333.3	35.3	197.9	388.3

NOTE 1: 5 m CREST WIDTH USED FOR BOTH TRADITIONAL DYKE AND LANDFORM.

COMPARISON OF LANDFORM AND DYKE VOLUME

	LENGTH (m)	HEIGHT (m)	CREST WIDTH (m)	WET SIDE SLOPE	DRY SIDE SLOPE	VOLUME (ABOVE GRADE) (m^3)	LANDFORM VS. DYKE VOLUME COMPARISON (LANDFORM VOL./DYKE VOL.)
DYKE	100	5	5	33%	33%	10,075	
LANDFORM	100	5	5	10%	3.5%	50,714	5x
	100	5	5	10%	1.5%	98,333	9.8x

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FLOOD PROTECTION LANDFORMING TECHNICAL DESIGN CONSIDERATIONS

FLOOD PROTECTION DYKE AND LANDFORM COMPARISON

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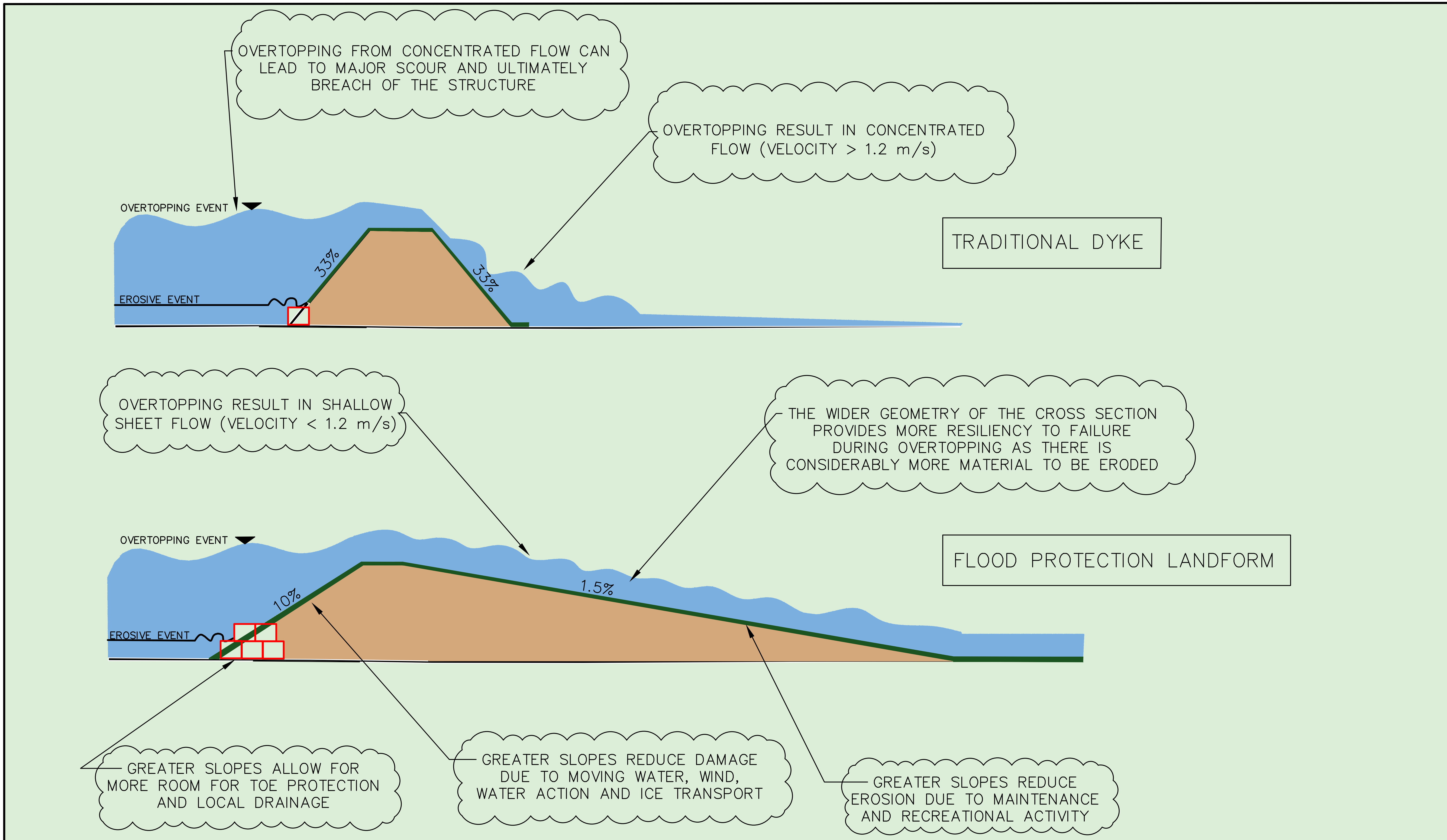
DATE DECEMBER 2018

FIGURE 2



Toronto and Region Conservation for The Living City.	AECOM	FLOOD PROTECTION LANDFORMING TECHNICAL DESIGN CONSIDERATIONS	FAILURES DUE TO OVERTOPPING AND EXTERNAL EROSION	SCALE NTS DRAWN BY S.S/S.N DATE DECEMBER 2018	FIGURE 3

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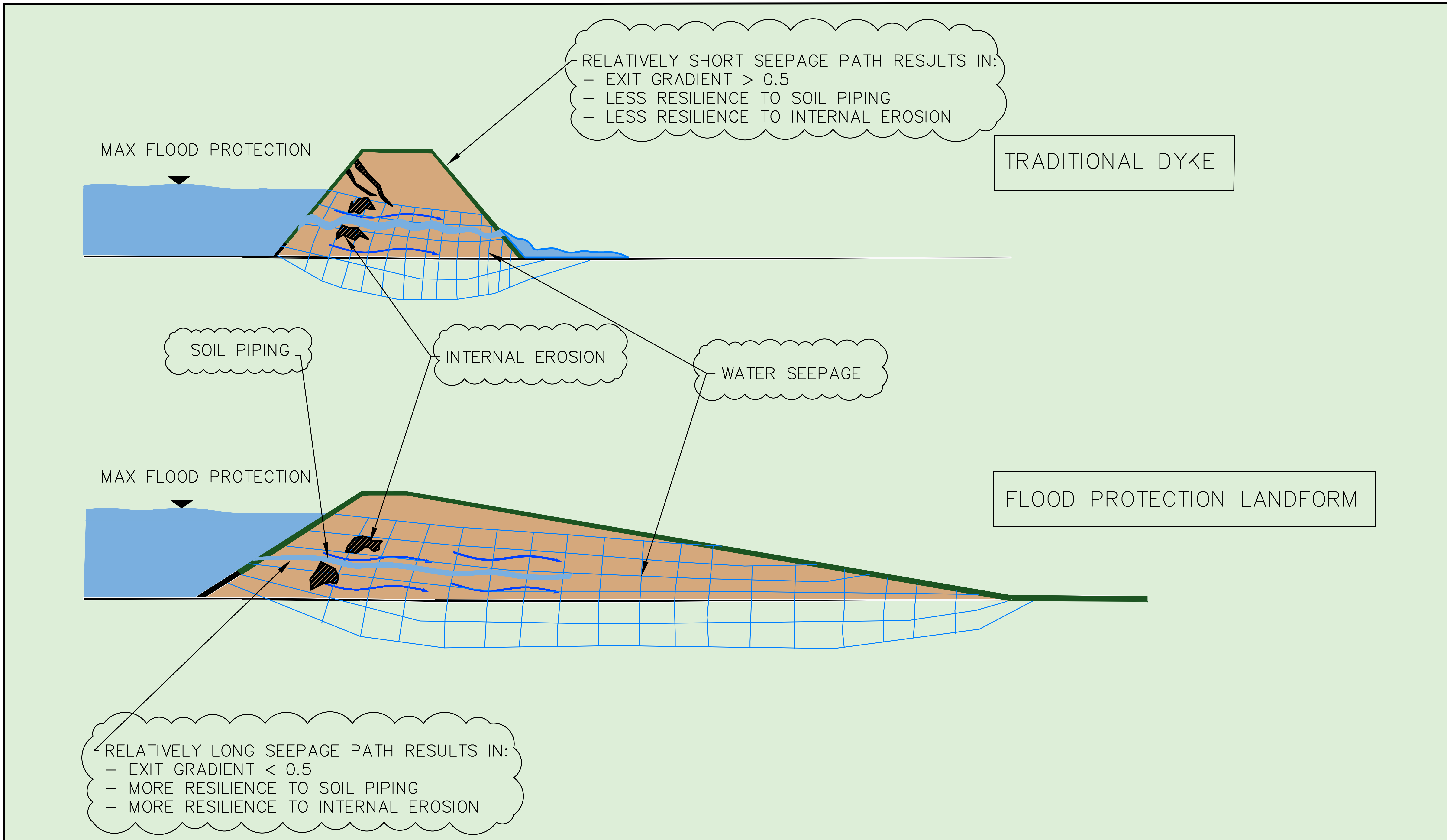

Toronto and Region Conservation for The Living City.	AECOM	FLOOD PROTECTION LANDFORMING TECHNICAL DESIGN CONSIDERATIONS	FAILURES DUE TO SEEPAGE	SCALE NTS DRAWN BY S.S/S.N DATE DECEMBER 2018	FIGURE 4

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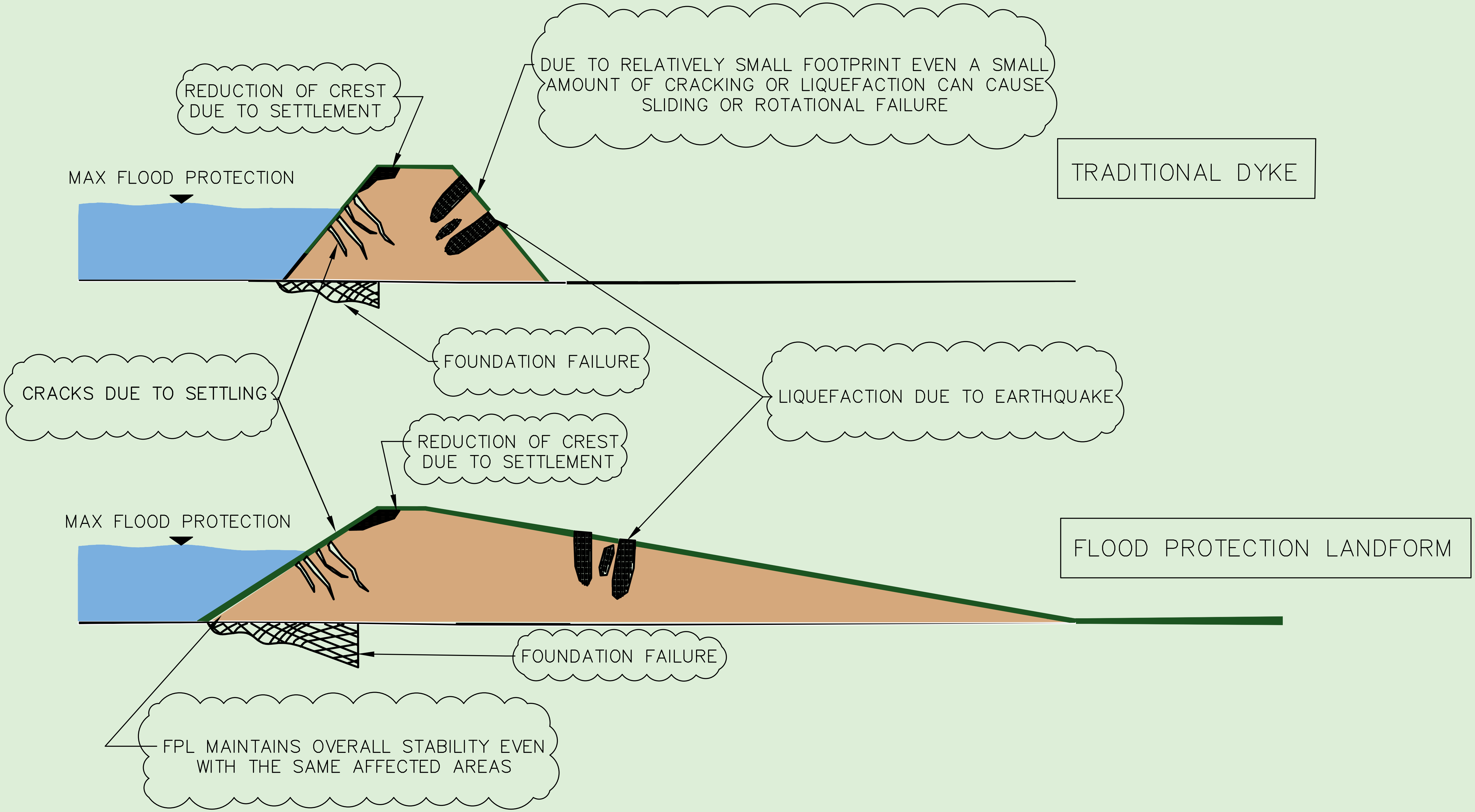

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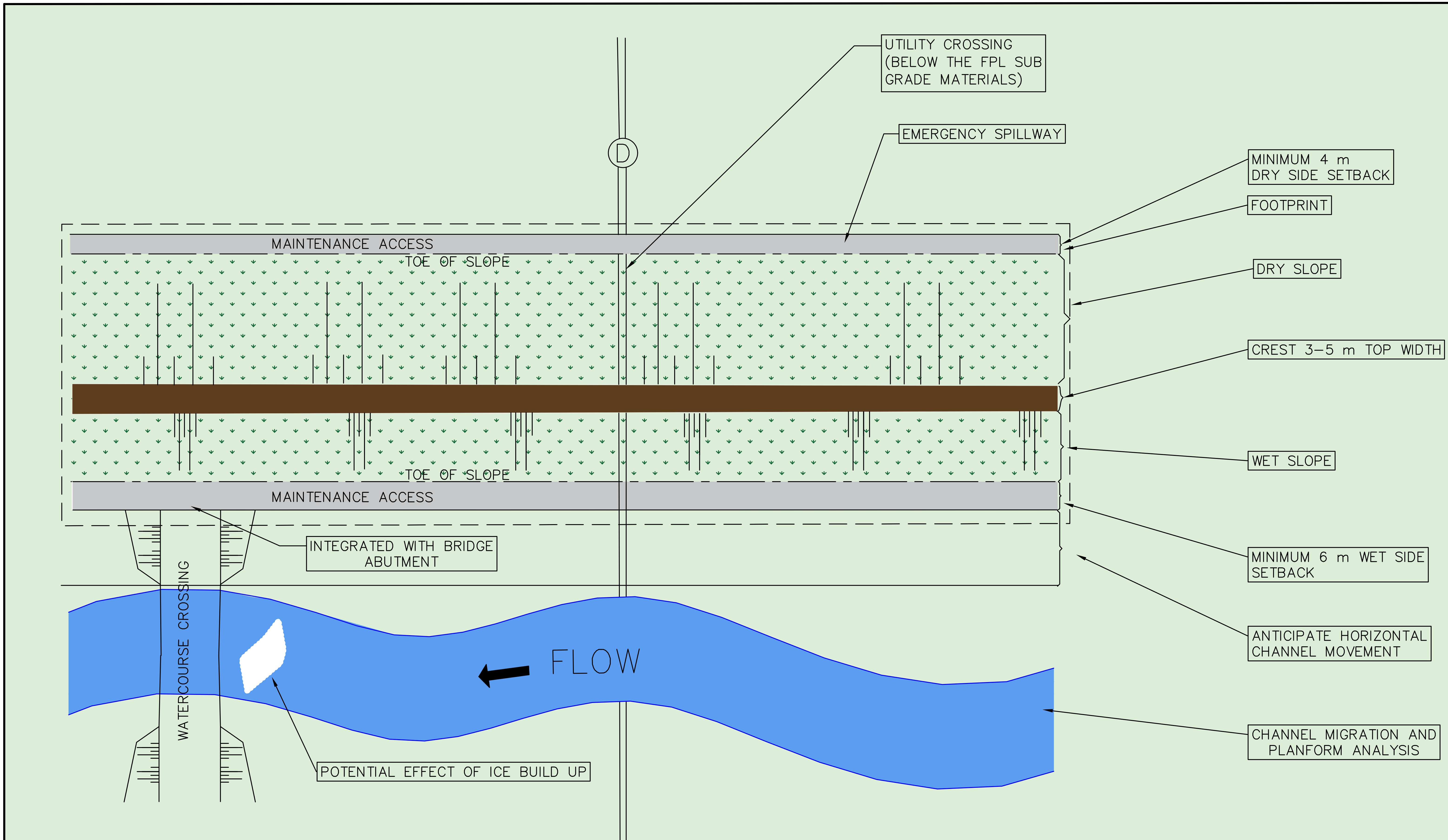
FLOOD PROTECTION LANDFORMING TECHNICAL DESIGN CONSIDERATIONS	FAILURE DUE TO SETTLEMENT	SCALE NTS	DRAWN BY S.S/S.N	DATE DECEMBER 2018	FIGURE 5



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FLOOD PROTECTION LANDFORMING
TECHNICAL DESIGN CONSIDERATIONS

TYPICAL DESIGN AND OPERATIONAL ELEMENTS OF FLOOD PROTECTION LANDFORM (PLAN)

SCALE	NTS
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DATE	DECEMBER 2018

FIGURE 6

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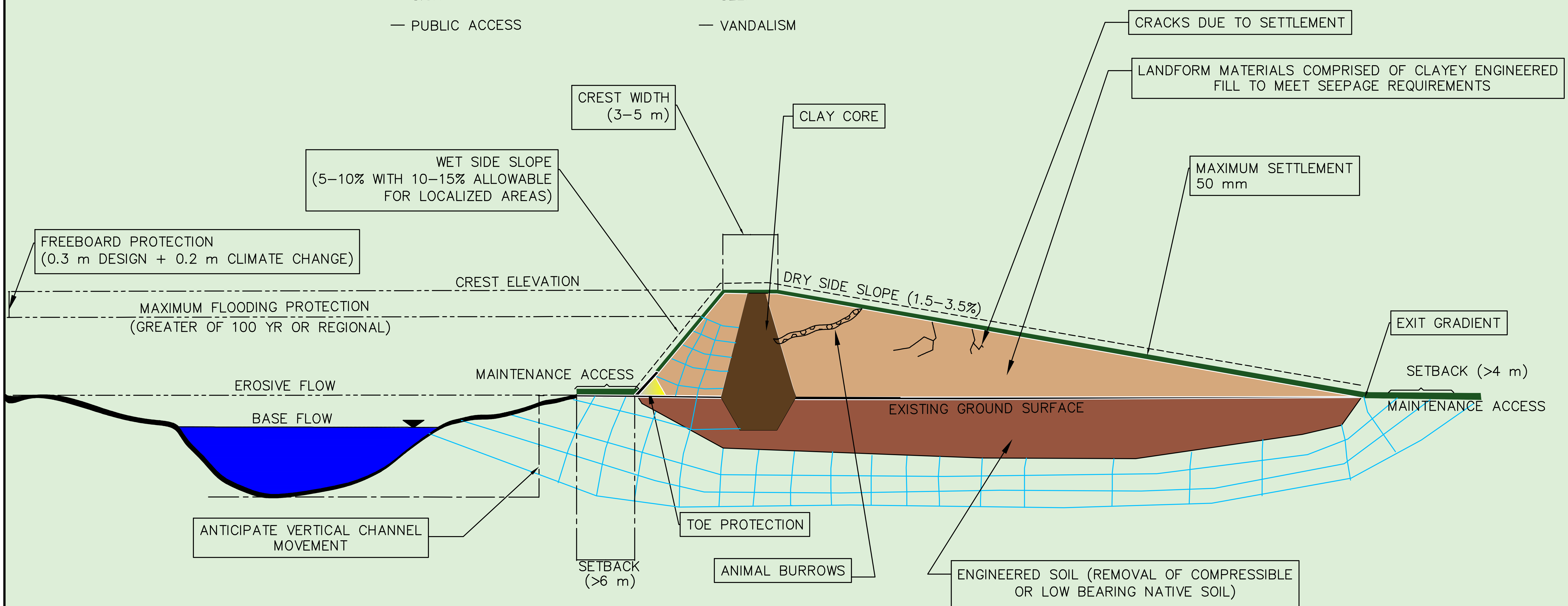
OPERATIONS

- ANIMAL CONTROL
- VEGETATION MANAGEMENT
- SLOPE STABILIZATION
- PUBLIC OUTREACH
- SIGNAGE
- PUBLIC ACCESS

MONITORING

- SETTLEMENT
- ANIMAL ACTIVITY
- VEGETATION
- GROUNDWATER LEVEL MONITORING
- SEEPAGE
- VANDALISM



Toronto and Region Conservation for The Living City	AECOM	FLOOD PROTECTION LANDFORMING TECHNICAL DESIGN CONSIDERATIONS	TYPICAL DESIGN AND OPERATIONAL ELEMENTS OF FLOOD PROTECTION LANDFORM (PROFILE)	SCALE NTS DRAWN BY S.S/S.N DATE DECEMBER 2018	FIGURE 7