Upper Thames River
Conservation
Authority

DAM SAFETY ASSESSMENT REPORT FOR
Harrington Dam
Final
July, 2007

prepared by
ACRES
International

UPPER THAMES RIVER
CONSERVATION AUTHORITY

DAM SAFETY ASSESSMENT REPORT FOR

Harrington Dam

Final
July, 2007

prepared by
ACRES
International

UPPER THAMES RIVER
CONSERVATION AUTHORITY

DAM SAFETY ASSESSMENT REPORT FOR

Harrington Dam

Final
July, 2007

prepared by

ACRES
International

Disclaimer

This report, including the estimate contained herein, has been prepared by Acres International Limited (“Acres”) for the sole and exclusive use of Upper Thames River Conservation Authority (the “Client”) for the purpose of assisting the management of the Client in making decisions with respect to the dam safety assessment of the Harrington Dam; and shall not be (a) used for any other purpose, or (b) provided to, relied upon or used by any third party.

This report contains opinions, conclusions and recommendations made by Acres, using its professional judgment and reasonable care. The estimate has been prepared by Acres, using its professional judgment and exercising due care consistent with the agreed level of accuracy. Any use of or reliance upon this report and estimate by Client is subject to the following conditions:

(a) the report and estimate being read in the context of and subject to the terms of the Agreement between Acres and the Client dated October 29, 2002 (the “Agreement”), including any methodologies, procedures, techniques, assumptions and other relevant terms or conditions that were specified or agreed therein;
(b) the report, including the estimate contained herein, being read as a whole, with sections or parts hereof read or relied upon in context;
(c) the conditions of Harrington Dam may change over time (or may have already changed) due to natural forces or human intervention, and Acres takes no responsibility for the impact that such changes may have on the accuracy or validity or the observations, conclusions and recommendations set out in this report;
(d) the estimate is based on several factors over which Acres has no control, including without limitation site conditions, cost and availability of inputs, etc; and Acres takes no responsibility for the impact that changes to these factors may have on the accuracy or validity of this estimate; and
(e) the report and estimate are based on information made available to Acres by the Client or by certain third parties; and unless stated otherwise in the Agreement, Acres has not verified the accuracy, completeness or validity of such information, makes no representation regarding its accuracy and hereby disclaims any liability in connection therewith.

Table of Contents

List of Tables

List of Tables - 2

List of Figures

List of Figures - 2

List of Drawings

Executive Summary

Executive Summary

The Harrington Dam is located in the town of Harrington on Harrington Creek, a tributary of Trout Creek which flows into the reservoir for the Wildwood Ducks Unlimited Dam. The dam comprises a 65-m long embankment dam on the left* side and a 20-m long embankment dam on the right side; these are separated by a concrete spillway structure. The head across the dam on November 12, 2002 was approximately 3.3 m and freeboard at the embankment dams was of the order of 1 m.

The dam controls a drainage area of 12 km^2 comprising mostly agricultural land. The Harrington Pond surface area is small and is impounded by a dam structure located at the northern end of the reservoir. The reservoir surface area is about 0.03 km^2 and is approximately 300 m in length. Flow releases from the dam enter a creek that passes under Road 96 through a twin box culvert, approximately 100 m downstream from the spillway structure. The creek bends around a farm lot and flows in an easterly direction for approximately 300 m before joining Trout Creek

The area is one of low relief, less than 15 m. Both banks of the reservoir are low and comprise overburden. Downstream of the dam, both sides of the channel are also of overburden. No bedrock was observed.

The dam has a surface area of 0.03 km^2. Outflow through the dam is controlled by a gravity-concrete outlet structure comprised of three stop log bays with a sloping face to the downstream channel. The dam is approximately 4.0 m high and impounds a total estimated storage volume of 0.02 x 10^6 m^3. This classifies the structure as a SMALL dam on the basis of height and a SMALL dam on the basis of storage impounded.

On the basis of the results of the year 2002/2003 dam safety assessment,

- the dam is founded on overburden over its entire length

---

* The orientations of all structures are given in terms of left and right as looking downstream. All geological orientations are given in terms of dip direction/dip degree with respect to True North.

- the dam can be classified as a SMALL dam on the basis of reservoir size and height

- the dam is classified as a VERY LOW incremental hazard potential (IHP) structure for a dam failure during a flood event

- the inflow design flood (IDF) for this dam is the flood resulting from the 50-yr, 3-day summer storm event

- the dam, with two stop logs in place, is overtopped during passage of the IDF and has inadequate freeboard. The dam is deemed to have inadequate spillway capacity to pass the IDF.

- the embankment crests near the spillway as well as the pedestrian bridge must be raised to provide adequate freeboard

- both upstream and downstream left embankment slopes meet slope stability acceptance criteria but the right downstream slope does not

- the spillway structure does not meet stability criteria.

The costs associated with the maintenance repairs recommended to ensure the ongoing safe operation of this dam are in the order of $320,600.

Figure ES-1

Harrington Dam

Description: **Earth Embankment + Concrete Gravity Spillway**

Original Construction: 1846
Last Upgrade: 1952
Last Repairs: 2000
Height: approx. 4.0 m
Length: approx. 95 m
Reservoir Area: 0.03 km^2

Hydrotechnical Issues

Overall IHP Classification: VERY LOW
- Flood VERY LOW (economic loss or loss of life)
- Earthquake VERY LOW (economic loss or loss of life)

IDF: 50-yr, 3-day summer storm event
Spillway Capacity: Inadequate

Issues

General Condition: Concrete generally in fair condition. Seepage occurring on downstream slope.
Stability: Spillway structure does not meet acceptance criteria. Both upstream and downstream slopes meet criteria.

Safety and Operating Issues

Operations: Not operated
Signage: Inadequate
Debris Boom: Not applicable
Fall Arrest Systems: Not applicable

Recommendations

- Repair riprap on upstream slope.
- Install additional signs to satisfy Ministry of Natural Resources' draft standards.
- Increase discharge capacity of spillway.
- Test the emergency preparedness plan.
- Raise crest of dam near spillway and raise deck of pedestrian bridge.
- Decrease opening size at guardrails.

Costs $138,750

1 Introduction

1.1 Background

The province of Ontario has not yet implemented dam safety regulations. However, as part of their mandate under the Lakes and Rivers Improvement Act, the Ontario Ministry of Natural Resources (MNR) has introduced dam safety and flood emergency contingency planning requirements that are based, in part, on the Canadian Dam Association Guidelines. These have been formalized in the form of a draft document entitled “Ontario Dam Safety Guidelines” (ODSG).

There are approximately 2200 dams in Ontario. Nearly half of these are privately owned, with the remainder owned by Ontario Power Generation (OPG) and conservation authorities (CAs). The Upper Thames River Conservation Authority (UTRCA), one of 36 CAs in the province of Ontario, operates as do most CAs, under the direction of a Board of Directors comprised of local municipal representatives. Various committees give direction to the CA’s programs and projects involving numerous partnerships. UTRCA owns, operates and maintains dams and other control structures on the Upper Thames River and its various tributaries.

In October 2002, Acres International (Acres) was retained by UTRCA and Ausable Bayfield Conservation Authority (ABCA) to undertake an independent dam safety review of 15 dams and control structures located in the Upper Thames and Ausable/Parkhill basins. Thirteen structures were examined for UTRCA under this review.

This report presents the results of civil, geotechnical, hydrologic and hydraulic assessments for the Harrington Dam located on Harrington Creek, a tributary to Trout Creek which flows into the reservoir for the Wildwood Ducks Unlimited Dam (Figure 1.1).

1.2 Dam Safety Review Objectives

According to the draft ODSG, a dam safety review

> *". . . involves a phased process beginning with the collection and review of existing information, proceeding to detailed inspections and analyses, and culminating with formal documentation."*

With this as a basis, the objectives of a dam safety review include

- assessment of the conditions of the dam and its components
- performance of detailed site inspections
- identification of any necessary repairs and/or continuing maintenance needs
- establishment of an emergency action plan to help minimize adverse impacts
- documentation of the results of the safety assessment so that the information is available in times of need and can be readily updated
- assessment of operational methods and equipment.

Specifically, the safety assessment of a dam comprises a procedural evaluation of the ability of a water-retaining structure to safely withstand all forces that could be expected to act on such a structure during its lifetime. Figure 1.2 displays the general dam safety assessment process, which is a graphical representation of the Ontario dam safety process. A number of criteria have been developed to allow a systematic evaluation and classification of structures with respect to the potential failure risk it imposes. These criteria incorporate a classification system that addresses the following aspects:

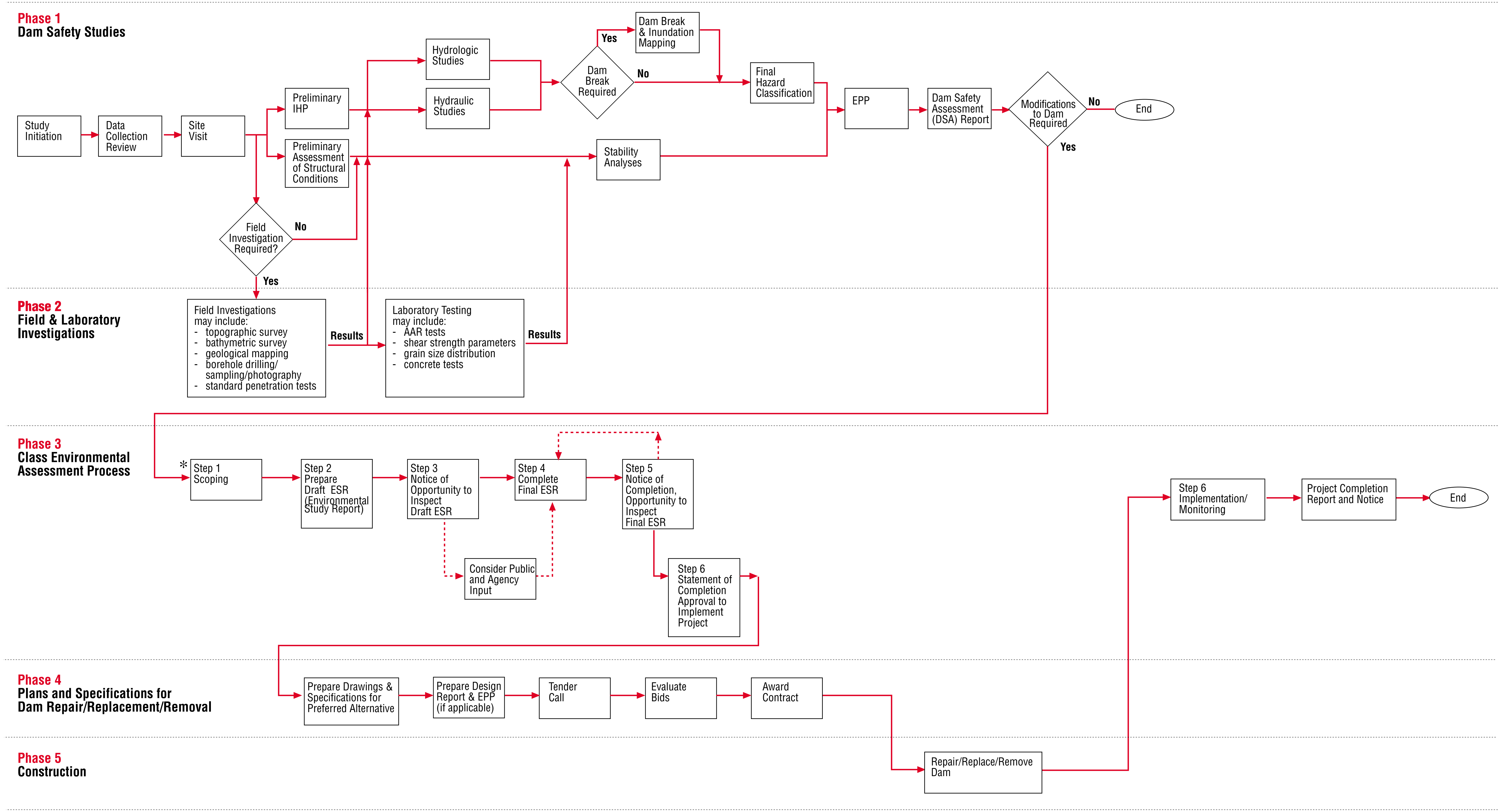
- hazard classification
- flood handling capability evaluation
- geological/geotechnical assessments
- dam break flood evaluation [to evaluate incremental hazard potential (IHP) classification]
- structural integrity and stability assessment.

The first step in the process involves a comprehensive site inspection and an evaluation of the incremental hazards that failure of the dam could pose. This evaluation includes an assessment of the potential incremental economic

Figure 1.1
Upper Thames River Conservation Authority
Dam Safety Assessment Report
Aerial Photograph of Dam and Surrounding Area

ACRES International

BACK OF FIGURE 1.1



Optional Step

Optional Flow

* Assumes a Category C Project under MNR Resource Stewardship and Facility Development Projects Class EA (MNR, 2003)

Figure 1.2
Upper Thames River Conservation Authority
Dam Safety Assessment Report
Dam Safety Assessment Evaluation Activities

ACRES International

P14504.03_rm

FIGURE 1.2 – BACK OF PAGE

damages, environmental losses and the potential for incremental loss of life in the event of a dam failure.

Based on this assessment, an IHP is determined on the basis of guidelines provided in the draft ODSG as detailed in Table 1.1. Once the IHP is determined, an appropriate inflow design flood (IDF) is selected, using the criteria detailed in Table 1.2, and the maximum design earthquake (MDE) is selected using the criteria detailed in Table 1.3. The discharge facilities are then rated on the basis of their capacity to pass the IDF as well as the capability of the structure to be operated reliably during emergency conditions. Water levels are then established for normal and flood (IDF) conditions and an assessment of available freeboard is made for fill structures.

Once loading conditions have been established on the basis of the hydrotechnical analyses and the IHP rating for the dam, the structural integrity of the dam to resist the loads imposed on it during normal conditions, during passage of the IDF and during an earthquake is determined. The results of these assessments, together with an assessment of the overall condition of the structure and issues such as public and workplace safety, are then reviewed and detailed recommendations/costs for measures to upgrade the structure to satisfy current dam safety requirements are established.

The deliverables for the dam safety evaluation include a comprehensive dam safety assessment (DSA) report and a review of the emergency preparedness plan (EPP).

1.3 The Harrington Dam Safety Assessment

The Harrington Dam is located on Harrington Creek, a tributary of Trout Creek which flows into the reservoir for the Wildwood Ducks Unlimited Dam, as shown in Figure 1.3.

Characteristics of this dam are shown in Table 1.4.

Table 1.1

Hazard Potential Classification for Dams
SELECTION CRITERIA

(Source: MNR, Draft ODSG)

Hazard Potential	Loss of Life	Economic and Social Losses	Environmental Losses
Very Low	Potential for LOL: None.	Damage to dam only. Little damage to other property. Estimated losses do not exceed $100,000.	Environmental Consequences: Short-term: Minimal Long-term: None
Low	Potential for LOL: None. The inundation area (the area that could be flooded if the dam fails) is typically undeveloped.	Minimal damage to agriculture, other dams or structures not for human habitation. No damage to residential, commercial, industrial or land to be developed within 20 years. Estimated losses do not exceed $1 million.	No significant loss or deterioration of fish and/or wildlife habitat. Loss of marginal habitat only. Feasibility and/or practicality of restoration or compensating in kind is high, and/or good capability of channel to maintain or restore itself.
Significant	Potential for LOL: None expected. Development within inundation area is predominantly rural or agricultural, or is managed so that the land usage is for transient activities such as with day-use facilities. There must be a reliable element of warning if larger development exists.	Appreciable damage to agricultural operations, other dams or residential, commercial, industrial development, or land to be developed within 20 years. Estimated losses do not exceed $10 million.	Loss or significant deterioration of important fish and/or wildlife habitat. Feasibility and/or practicality of restoration and/or compensating in kind is high, and/or good capability of channel to maintain or restore itself.
High	Potential for LOL: One or more. Development within inundation area typically includes communities, extensive commercial and industrial areas, main highways, public utilities and other infrastructure.	Extensive damage to communities, agricultural operations, other dams and infrastructure. Typically includes destruction of or extensive damage to large residential areas, concentrated commercial and industrial land uses, highways, railways, power lines, pipelines and other utilities. Estimated losses exceed $10 million.	Loss or significant deterioration of critical fish and/or wildlife habitat. Feasibility and/or practicality of restoration and/or compensating in kind is low, and/or poor capability of channel to maintain or restore itself.

* Supporting References: MNR Guidelines for Approval Under the Lakes and River Improvement Act, 1977
MNR Fisheries Section, 1999
US Army Corps of Engineers, Dam Safety Assurance Program, 1995
Dam Structure Assessment Program, Ontario Hydro, 1990

Notes:

1. Consideration should be given to the cascade effect of dam failures in situations where several dams are situated along the same watercourse. If failure of an upstream dam could contribute to failure of a downstream dam(s), the minimum hazard potential classification of the upstream dam should be the same as or greater than the highest downstream hazard potential classification of the downstream dam(s).

2. Economic losses refer to all direct and indirect losses to third parties; they do not include losses to owner, such as loss of the dam, associated facilities and appurtenances, loss of revenue, etc.

3. Estimated losses refer to incremental losses resulting from failure of the dam or misoperation of the dam and appurtenant facilities.

4. For Hazard Potential Classification and Safety Criteria for tailings dams, refer to “Guidelines for Proponents, Rehabilitation of Mines”, issued by Ontario Ministry of Northern Development and Mines, 1995.

Table 1.2

Minimum Inflow Design Floods for Dams

(Source: MNR, Draft ODSG)

<table>
<tr><th rowspan="3">Hazard Potential</th><th colspan="6">Size of Dam and Inflow Design Floods</th></tr>
<tr><th colspan="2">Small</th><th colspan="2">Medium</th><th colspan="2">Large</th></tr>
<tr><th>Height
< 7.5 m</th><th>Storage
< 100 x 10^3 m^3</th><th>Height
7.5 to 15 m</th><th>Storage
100 x 10^3 to 1000 x 10^3 m^3</th><th>Height
> 15 m</th><th>Storage
> 1000 x 10^3 m^3</th></tr>
<tr><td>Very Low</td><td colspan="2">25-year flood
to
50-year flood</td><td colspan="2">50-year flood
to
100-year flood</td><td colspan="2">100-year flood
to
RF</td></tr>
<tr><td>Low</td><td colspan="2">25-year flood
to
100-year flood</td><td colspan="2">100-year flood
to
RF</td><td colspan="2">RF
to
PMF</td></tr>
<tr><td rowspan="2">Significant</td><td colspan="2" rowspan="2">100-year flood
to
RF</td><td colspan="2" rowspan="2">RF
to
PMF</td><td colspan="2">PMF</td></tr>
<tr><td colspan="2">Policy for existing dams is under consideration</td></tr>
<tr><td rowspan="2">High</td><td colspan="2">RF
to
PMF</td><td colspan="2">PMF</td><td colspan="2">PMF</td></tr>
<tr><td colspan="6">Policy for existing dams is under consideration</td></tr>
</table>

Legend: RF – regulatory flood
PMF – probable maximum flood

Notes:

1. For Minimum Inflow Design Floods for Mine Tailings dams, refer to “Guidelines for Proponents, Rehabilitation of Mines”, issued by Ontario Ministry of Northern Development and Mines, 1995.

2. Existing dams refer to those structures built prior to 1978.

Table 1.3

Criteria for Design Earthquakes

Hazard Potential Classification [(a)]	**MDE**	
	Deterministically Derived	**Probabilistically Derived (Annual Exceedance Probability)**
High	50% to 100% MCE [(b)] [(c)] [(d)]	1:1000 to 1:10 000 [(d)]
Significant	– [(e)]	1:100 to 1:1000 [(e)]

Notes:

(a) Hazard potential classification established separately for each dam.

(b) For a recognized fault or geographically defined tectonic province, the maximum credible earthquake (MCE) is the largest reasonably conceivable earthquake that appears possible. For a damsite, MCE ground motions are the most severe ground motions capable of being produced at the site under the presently known or interpreted tectonic framework. Use upper values in the range, where loss of life and property damage due to failure would be unacceptably high.

(c) An appropriate level of conservatism shall be applied to the factor of safety calculated from these loads, to reduce the risks of dam failure to tolerable values. Thus, the probability of dam failure could be much lower than the probability of extreme event loading.

(d) In the high hazard potential category, the MDE is based on the consequences of failure. Design earthquake approaching MCE would be required where loss of life and property damage due to failure would be unacceptably high.

(e) If a structure in the significant hazard potential category cannot withstand the minimum criteria, the level of upgrading may be determined by economic risk analysis, with consideration of environmental and social impacts.

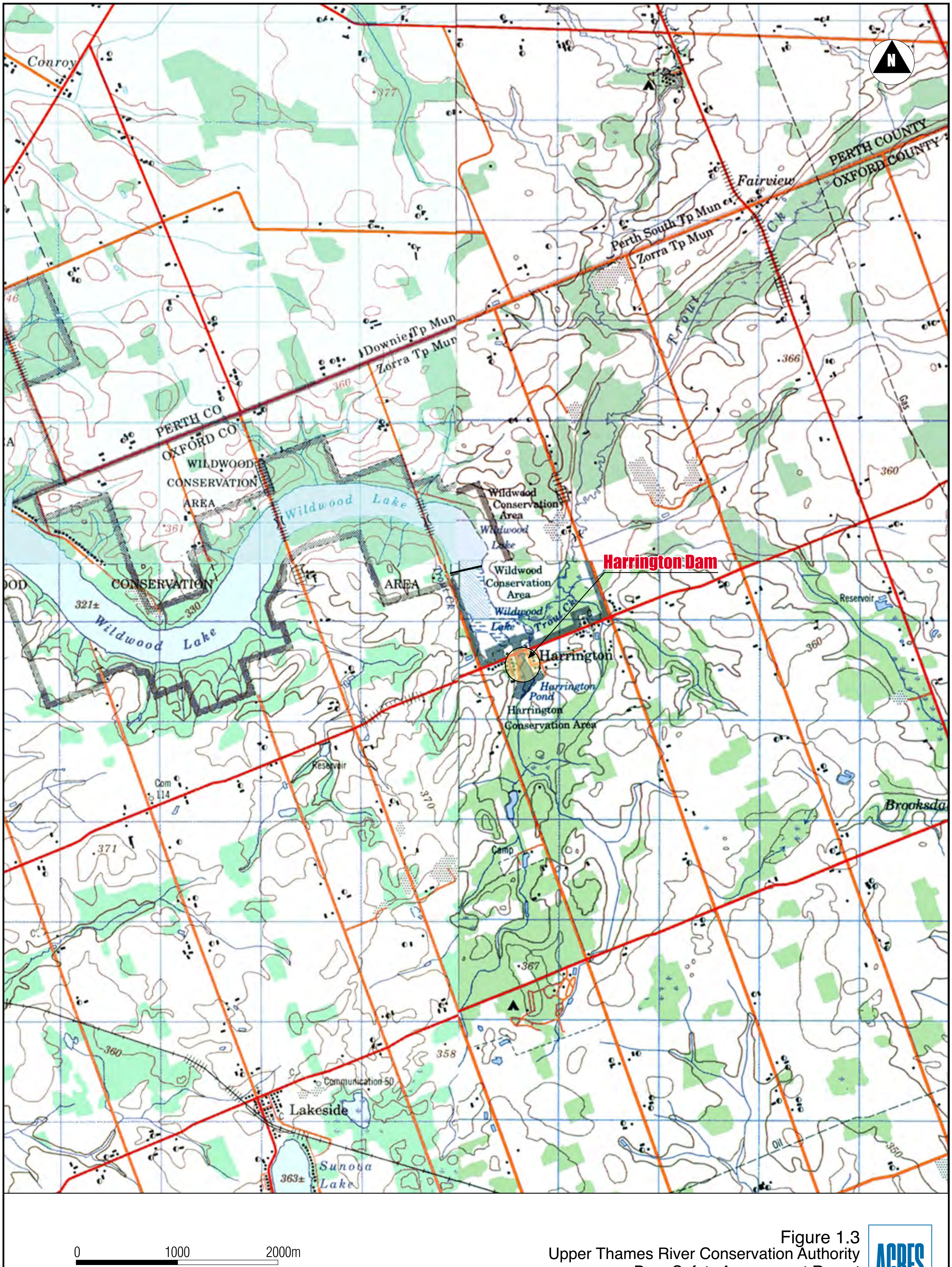


Figure 1.3

Upper Thames River Conservation Authority

Dam Safety Assessment Report

Location of Harrington Dam

ACRES International

FIGURE 1.3 BACK OF PAGE

Table 1.4

Description of the Dam

Name of Dam	Access	Description				
		Drainage Area (km^2)	Reservoir Area (km^2)	Height (m)	Length (m)	No. of Sluices
Harrington Dam	Off County Road 96	12	0.03	4.0	≈95	Overflow weir with stop logs and one low-level gated outlet

Photographs of the damsite and the dam itself are contained in Appendix A of this report. Details of the analyses and assessments performed for this dam are described in the following main sections:

- Executive Summary
- Section 1 – introduction and explanation of approach
- Section 2 – history of the Harrington Dam
- Section 3 – details of the initial data review including the types of documents reviewed
- Section 4 – details of the comprehensive site inspections including civil, structural, geotechnical and hydrotechnical observations
- Section 5 – details of the results of any site investigations performed to fill data gaps identified during the initial site inspections
- Section 6 – details of the hydrological/hydraulic assessments. The section includes the following main topics:
  - descriptions of river basin characteristics
  - development of flood and storm events
  - development of rainfall/runoff and flood routing models
  - flood flow estimates

  - preliminary IHP and IDF classifications
  - determination of the IDF.

- Section 7 – details of the civil/structural stability assessments are provided. These include a description of the load cases evaluated, the rationale for the selection of shear strength parameters and details of any measures that might be needed to upgrade the dam to satisfy current dam safety requirements.

- Section 8 – details the geotechnical assessments performed including the stability of any earth embankments, seepage, erosion and liquefaction problems and instrumentation found or needed at the dam

- Section 9 – details the results of the evaluation of workplace and public safety at the dam. It includes issues such as the need for fall restraint, signage, operational methods used, the requirement for log booms and other related issues.

- Section 10 – provides a summary of details of the EPP

- Section 11 – provides a summary of the recommended remedial measures needed at the dam and estimated costs.

2

The Harrington Dam

2 The Harrington Dam

2.1 History[*]

From the time Milton Betteridge first suggested, in 1948, that the Harrington damsite be acquired as a conservation area, until 1952, when the first piece of property was bought, lengthy negotiations were involved and several obstacles overcome.

Representatives of the Authority inspected the property and Gordon Ross reported that a large section of the 35-ft spillway had been undermined and washed away. It was estimated that to repair the dam and enlarge the pond, from 4 to 8 acres, would cost approximately $10,000. This was beyond the Authority's means. Furthermore, the Conservation Branch of the Department of Planning and Development ruled that it would not consider a grant for this dam, or similar projects elsewhere, without complete engineering and cost estimates. Plans for the dam and spillway were prepared by R. K. Kilborn & Associates and the Conservation Branch supplied a plan for the pond.

Negotiations for property purchase were opened with Robert Duncan, who owned the dam and pond, and with adjoining property owners William Simpson, Mrs. Levi Nimock and George Robinson. In all, about 12 acres were obtained. Work started on July 1952 and the project was virtually completed by the end of one year. Service buildings were added later.

After almost 2 years of negotiations, the Authority came into possession of the mill at the site in 1966, when it was purchased from Mr. Duncan. It was one of the few remaining water-powered grist mills in western Ontario. The original mill was built in 1846 by a man named Demerest and was purchased by Mr. Duncan in 1920. That mill was destroyed by fire in 1923 and replaced the same year.

The dam was overtopped twice in the summer of 2000 with subsequent repair work performed on the downstream embankment slopes adjacent to the spillway.

---

[*] Reproduced, with permission, from "Twenty Five Years of Conservation on the Upper Thames Watershed", 1947 to 1973. Published by the Upper Thames River Conservation Authority.

3 Initial Data Collection/ Review

3 Initial Data Collection/Review

As a first step in the assessment process, a detailed review of the information contained in the UTRCA files was made on November 8, 2002 and on February 5 to 7, 2003. As part of this process, the following documents were examined:

- watershed maps showing damsites and drainage areas
- correspondence files
- previous internal inspection reports
- Ontario Geological Survey maps and documents
- historical records
- meteorological data from selected stations
- records of water levels
- data from selected streamflow gauging stations from Water Survey of Canada (WSC)
- selected topographic maps (1:50 000-scale)
- rating curve calculations.

Provided in Table 3.1 is a list of all documents obtained from UTRCA records. The results of this review provided a general understanding of the characteristics of the site and the operational issues and the types of structural problems that might be expected on the basis of the prevailing topographic, climatic and geological conditions. Generally, the dams located in this region are small- to medium-sized concrete or embankment dams constructed on competent bedrock or till foundations with either glacial till or bedrock abutments. The following are some problems which may be expected to occur at dams of this type:

- leakage at overburden contacts, at defects in the concrete, at the concrete/ foundation contact or through open discontinuities
- typical concrete deterioration problems
- sliding stability problems associated with winter ice loadings
- inadequate spill capacity
- public and operational safety issues (signage, fall arrest systems, handrail condition, etc).

During the site inspection, the potential for these types of problems were specifically addressed in addition to other issues that became apparent during the course of the site visit.

UPPER THAMES RIVER CONSERVATION AUTHORITY
Reference Information

Dam	Year	Type of Document	Author	Title	UTRCA Document No.	Filed Under (Dam/Multi)	Acres has Original Document	Acres has Copy of Document	Acres has Summary Notes of Document	Date Received	Date Returned	Comments
Harrington	2003	Web Page	Harrington Grist Mill Restoration project	History	-	Dam	No	Yes	-	31-Mar-04	-	
Harrington	2002	Geotechnical Investigation Report	Atkinson, Davies Inc.	Geotechnical Investigation for Proposed Grist Mill Rehabilitation, Harrington, Ontario	-	Dam	No	Yes	No	31-Mar-04	-	From the web
Harrington	2001	Drawing	R.P. of UTRCA	Dam Hazard Identification, Harrington Dam (WECS Program)	-	Dam	No	Yes	-	08-Nov-02	-	
Harrington	2000	Inspection Report	Chris Tasker and Al Merry (UTRCA)	-		Dam	No	Yes	No	08-Nov-02	-	2 page report
Harrington	2000	Newsletter	Harrington Community Club	Update - July 2000	-	Dam	No	Yes	-	31-Mar-04	-	Found on the web
Harrington	1985	Inspection Report	B. Bevan and J.C. Campbell (UTRCA)	Harrington Dam Inspection Report		Multi	No	No	Yes	-	-	
Harrington	1985	Response Summary	B. Bevan (UTRCA)	Summary of UTRCA Responses RE: 1985 MNR Inspections	WM.2.1	Multi	No	Yes	No	08-Nov-02	-	
Harrington	1982	Inspection Report	J. Jilek and P. Bane (UTRCA)	-		Multi	No	No	Yes	-	-	no comments
Harrington	1952	Drawings	3 - Kilborn; 1 - Unknown	-	sml/stru/968/968; sml/stru/2015/5007; sml/stru/966/966; sml/stru/2016/5010	Dam	No	Yes	-	19-Feb-03	-	From drawing CD received from UTRCA

4 Comprehensive Site Inspections and Condition Assessments

4 Comprehensive Site Inspections and Condition Assessments

4.1 Introduction

A site evaluation of the Harrington Dam was made on November 12, 2002, by Acres civil and geotechnical engineers, and on November 19, 2002, by hydrotechnical personnel as part of the Dam Safety Program: Review of Dams Owned/Operated by UTRCA and ABCA. The results of these inspections are presented in the following sections, on digital photographs and on Forms B1 and B2 (see Appendix B), all in accordance with MNR, Ontario Dam Safety Guidelines (Draft), August 1999 and the requirements of the request for proposal (RFP), July 2002.

4.2 Antecedent Weather Conditions

Seepage observations noted during site inspections at water-retaining structures may be influenced by weather conditions which occurred at the time of the inspection and during the preceding period. Table 4.1 is a summary of recorded daily precipitation for the month of November 2002 at several locations close to the Harrington damsite. Trout Creek is geographically closest to the site. From the table, it can be seen that no rain fell on November 12, the day of the inspection, with precipitation occurring on November 6, 7, 10 and 11 (total of 41.8 mm during the week prior to the inspection).

4.3 Record of Observations

4.3.1 General Description

The Harrington Dam comprises a 60-m long (approximate) embankment dam, on the left* side (Photo 1) and a short embankment dam on the right side (Photo 2); these are separated by a concrete spillway structure (Photo 3). The head across the dam on November 12, 2002 was 3.3 m and freeboard at the embankment dams was of the order of 1 m. An abandoned millrace is

---

* The orientations of all structures are given in terms of left and right as looking downstream. All geological orientations are given in terms of dip direction/dip degree with respect to True North.

Table 4.1

Summary of Daily Precipitation Records from UTRCA's HEC-DSS Database

Year	Day, Month	Trout Creek (mm)	St. Marys (mm)
2002	1-Nov	0.40	0.00
	2-Nov	7.00	0.00
	3-Nov	3.40	0.00
	4-Nov	0.00	0.00
	5-Nov	1.00	0.00
	6-Nov	7.60	0.00
	7-Nov	0.20	0.00
	8-Nov	0.00	0.00
	9-Nov	0.00	0.00
	10-Nov	32.20	13.50
	11-Nov	1.80	0.50
	12-Nov	0.00	0.00
	13-Nov	0.00	0.00
	14-Nov	2.40	0.50
	15-Nov	1.20	0.00
	16-Nov	0.00	0.00
	17-Nov	0.00	0.00
	18-Nov	2.40	0.00
	19-Nov	1.60	0.00
	20-Nov	0.00	0.00
	21-Nov	0.00	0.00
	22-Nov	0.80	0.00
	23-Nov	0.00	0.00
	24-Nov	0.00	0.00
	25-Nov	4.00	0.00
	26-Nov	0.00	0.00
	27-Nov	0.00	0.00
	28-Nov	0.00	0.00
	29-Nov	0.60	0.00
	30-Nov	2.80	0.00

Note: No recordings for Waubuno Creek station during the month of November 2002.

situated on the right embankment (Photo 4) and provides additional discharge capacity at the site.

The dam is located on Harrington Creek, a tributary to Trout Creek. The dam and reservoir are currently used for recreational purposes and are adjacent to County Road 96. A local road from Road 96 transverses the area on the left side of the reservoir and crosses it at its upstream extremity and leads into a cultivated farm. The entrance to the dam, reservoir and park area is from Road 96. There is an old unused mill located on the right or east bank immediately downstream from the damsite (Photo 5).

4.3.2 Hydrotechnical Aspects

The dam controls a drainage area of 12 km^2 comprising mostly agricultural land. The Harrington Pond surface area (Photo 6) is small and is impounded by a main dam structure, located at the northern end of the reservoir. The reservoir surface area is about 0.03 km^2 and is approximately 300 m in length. Flow releases from the dam enter a creek channel (Photo 5) that passes under Road 96 through a twin box culvert (Photo 7), approximately 100 m downstream from the spillway structure. The creek bends around a farm lot and flows in an easterly direction for approximately 300 m before joining Trout Creek. From this point, the creek flows directly into the reservoir for the Wildwood Ducks Unlimited Dam at the upstream end of Wildwood Lake.

The Harrington Pond has a limited fetch and, therefore, has negligible wind-generated waves. The upstream shorelines are well-vegetated with grasses and bushes with trees along some sections (Photo 6).

The dam comprises left and right sections of embankment dams separated by a 3-bay reinforced concrete spillway. The overflow spillway has a trapezoidal concrete section with stop logs on the crest between two sets of steel stanchions (Photo 3). There is also a gated pipe (0.9-m diameter) outlet through the left abutment and embankment of the spillway (Photo 3). This was closed at the time of inspection. During the site visit, stop logs were in place with a small spill over the top. There is no permanent lifting equipment for the removal of stop logs at the site or on the spillway deck. One row of logs was removed in 2000. The main spillway has concrete wingwalls extending downstream to the apron of the stilling basin with some riprap pitching at the apron edge in the creek (Photo 3). There is an abandoned millrace located on the right or east embankment that appears to be in the same position as the old concrete trough that previously conveyed flows to the old mill house (Photo 4). The longitudinal profile across the emergency spillway seems to rise above the concrete spillway deck level, thus preventing any discharge through the channel. The present land levels may inhibit the functioning of this facility to convey significant emergency spill flows.

Flow from the 3-bay spillway discharges onto a very short concrete apron at the toe of the spillway slope which extends the full width of the bays (Photo 2). The channel area immediately downstream from the apron is relatively shallow with exposed rocks and boulders in the channel bed (Photos 3 and 5). The downstream channel slopes gradually away from the concrete apron, and the creek banks are overgrown with grasses, bushes and trees (Photo 5). The dam was previously overtopped twice in the summer of 2000, and the high outflows eroded the channel reach in the area of the spillway. Gabion baskets were subsequently placed in the affected areas (Photos 2 and 8). At the time of the inspection, the water level in the reservoir was about 0.5 m below the crest of the dam.

The downstream floodplain area of the river channel up to Road 96 is a park area which is grassed with several trees (Photo 9). There are permanent dwellings located on both sides of the creek banks. The houses located on the right bank, including the old mill, are set at higher elevations compared to those of the left bank floodplain. There is one house on the left side of the channel (Photo 10) plus one house downstream of the culvert that is located at or near the same elevation as the floodplain. This house may be partly inundated during the passage of large floods (e.g., the regulatory flood); hence, its footing levels should be established relative to the dam crest.

4.3.3 Geotechnical Aspects

The area is one of low relief, less than 15 m. Both banks of the reservoir are low and comprise overburden. Downstream of the dam, both sides of the channel are also of overburden. No bedrock was observed.

A raised access road embankment extends from the end of the crest of the left embankment down to the parking lot. The terrain downstream of the left embankment dam is very flat (Photo 9).

About 50 m downstream from the downstream toe of the dam is a well fed by artesian water (Photo 5). The well stands 1.3 m above ground and has an overflow pipe; this pipe takes the artesian flow and discharges it to a roadside ditch nearby. This well apparently provided drinking water in the past. The depth of penetration of the well is unknown; the bottom of the well could be in overburden or in bedrock. It seems more probable that it is in bedrock. It is possible that the source of this water is the dam reservoir, that is, water may be percolating down through the overburden underlying the reservoir down into the bedrock and traveling through the bedrock to the well.

4.3.3.1 Left Embankment

The upstream slope of the left-side embankment (Photo 11) shows no sign of sloughing, cracking, settlement, sinkholes or displacement. Sparse slope protection exists in the form of random cobbles and boulders. Benching due to erosion by wave action has occurred up to 0.5 m; this has resulted in an irregular and oversteepened slope.

No cracking, displacement, settlement or sinkholes were observed on the crest of the left embankment (Photo 11). No camber was evident. The surface is grassed.

The downstream slope of the left embankment (Photo 1) is grassed and shows no sign of cracking, sloughing or sinkholes; however, there is a suggestion of bulging type of deformation which may be caused by a high groundwater table in the dam, as discussed below. This bulging is located about halfway down the downstream slope and on the right side of the access road. It covers an area of about 5 x 5 m. It is possible but improbable that it may simply be an irregularity in the slope.

There is evidence of leakage in several areas. On the downstream slope itself, there is an area of active seepage just below the bulge area described above (Photos 9 and 12). Sandbags have been placed in the seepage area; they seem to be settling into the fill. Downstream of the downstream slope, there are wet, mushy zones on either side of the access road and also several more on the flat ground, including ponded water (Photo 9). Muddy sediment was observed in one of the ponded areas. This indicates either internal erosion along the seepage path or surface runoff from the downstream slope.

The area of the contact between the embankment fill and the concrete spillway structure showed signs of washing out. Sandbags had been placed with sand in washed out areas but not along wingwalls or behind gabions. No leakage was evident at the contact. It appears that this contact area is a low point on the dam and that the washout was caused by overtopping of the dam during the 2000 floods.

Nothing unusual, i.e., movement, cracking or leakage, was observed in the left abutment.

4.3.3.2 Right Embankment

The condition of the upstream slope of the right embankment (Photo 13) is similar to that on the left embankment.

The crest is grassed and shows no cracking, displacement, sinkholes or settlement (Photo 14).

The downstream slope of the right embankment (Photo 2) shows no sign of cracking, sloughing, settlement, displacement or sinkholes. The slope, however, is fairly steep. Efforts were being made to grow more grass with the assistance of geotextile netting. No evidence of leakage was seen on the slope.

The area of the contact between the embankment fill and the concrete spillway was in good condition and no leakage was evident.

No evidence of unusual conditions was seen in the right abutment.

4.3.3.3 Instrumentation

No instrumentation for dam performance existed.

4.3.4 Civil/Structural Aspects

The right abutment and downstream wingwall have a significant amount of cracks and spalls over the entire surface (Photo 2). The crack patterns are a potential sign of alkali-aggregate reaction. A large diagonal crack has developed on the downstream right wingwall near the base of the ogee (Photo 15). Upstream of the left abutment gains, large spalls and delamination has occurred due to map cracking. This has resulted in the exposure of reinforcing bar near the left intake (Photo 16). Hydraulic erosion has taken place near the waterline at this section of the left abutment. Downstream of the left abutment gains, slight delamination has occurred along with map cracks across the face of the wall. Significant erosion of the concrete near the water level at the downstream face of the left abutment wall has developed (Photo 17).

Piers 2 and 3 consisted of steel stanchions, which also supported the deck assembly (Photo 18). Existing stop log gains are modified versions of the originals in order to accommodate more recently fabricated stop logs. The steel plate assemblies that are welded into the existing gains appear to be in good condition. A slight twisting of the new plates towards downstream was observed in the abutment slots. Stop logs are constructed of 38-mm x 191-mm (2-in. x 8-in.) boards fastened together and placed vertically in the gains. No stop logs were observed on shore. Due to the high water levels, inspection of the stop logs in place was not performed. Two rows of stop logs were in place with the third row removed in 2000. No lifting equipment was located on-site.

Inspection of the spillway ogee was not conducted due to the volume of water flowing over it. The downstream edge of the ogee appeared to be in good condition.

The deck consists of 4-mm to 51-mm deep galvanized serrated steel grating planks bolted horizontally together and spanning the entire length of the deck. The deck is supported by the abutment walls and the two center stanchions. Spot welds on the outside edges fasten the grating to the deck, allowing the potential removal of the two middle grating sections, thus providing access to the stop logs. The deck appeared to be in good condition with some minor rust. Significant deflection of the deck was obtained at the middle of the outer bays suggesting serviceability requirements are exceeded. Over the stanchions, inverted channels support the deck. The condition of the channel sections looked good, but required painting.

Guardrails along the upstream and downstream of the deck are fabricated from HSS 51-mm x 51-mm sections. The lower rails included some 25-mm square sections to reduce opening sizes. The height of the guardrail satisfies the Ontario Building Code (OBC) requirements (≥1070 mm). The condition of the railing is good, but requires painting.

An intake structure is located to the left side of the dam structure (Photo 16). The trashrack consists of 102-mm (4-in.) x 9.5-mm (3/8-in.) thick steel plate at 102-mm (4-in.) centers. No debris was observed near the intake. The concrete around the intake has significant map cracking leading to spalling and areas of exposed reinforcing bar (Photo 16). The wooden cover for the intake controls is secured down with locks and placed within a chain link fence cage to prevent vandalism. The concrete appears to be in poor condition. The outlet conduit consists of a 914-mm (36-in.) corrugated steel pipe (Photo 17). Slight leakage is occurring through the conduit. Significant erosion has taken place below and to the right of the outlet pipe. A diagonal stress crack is located on the left wall extending from the outlet pipe to the top of the left wingwall. Random crack patterns were observed on the left wingwall.

A concrete-lined trough exists in the overflow for the dam and was originally used to supply water to the old mill (Photos 3 and 19). The concrete in the channel is in poor condition and cluttered with debris or buried with overburden. A detailed inspection was not performed.

No signs were posted around the dam warning about potential hazards. The area is open to pedestrians, and full access is granted to the dam. No log boom exists upstream of the dam. This site is used as a recreational park, and use of upstream reservoir for boating or other activities is not discouraged.

5 Site

Investigations

5 Site Investigations

Harrington Dam was investigated with three boreholes which were drilled on November 21 to 24, 2003. Boreholes BH-1 and BH-2 are located in the embankment on the centerline at different positions left of the spillway pier. Borehole BH-3 was located on the downstream slope. A CME 75 hollow-stem auger was used for drilling. Close-spaced sampling was done. The locations of the boreholes are shown on Drawing 14504-HD-005.

Boreholes BH-1, BH-2 and BH-3 penetrated the embankment fill and foundation material to total depths of 8.23 m, 7.46 m and 3.65 m, respectively. The foundation level was found to be 4.67 m below the crest in BH-1 and 3.47 m below the crest in BH-2. A standpipe piezometer was installed in all boreholes.

The borehole logs attached present the detailed findings during the drilling and sampling. A summary is given below.

Laboratory testing was done on some of the samples. This included triaxial shear strength testing and testing for moisture content, Atterberg limits and grain-size distribution. Results are shown in Table 5.1. Grain-size plots, plasticity chart and triaxial test results are attached.

Table 5.1

Laboratory Test Results for Harrington Dam

Bore-hole	Sample[*]	Depth (m)	% Moist	LL (%)	PL (%)	PI (%)	Gravel (%)	Sand (%)	Fines (%)
BH-1	AQ4	3.04-3.65	22.6	29	17	13			
BH-1	AQ5	3.81-4.42	24.7						
BH-1	AQ7	5.33-5.94	18.5				2	14	84
BH-1	AS8	6.09-6.85	13.5				10	60	30
BH-2	AQ2-AQ3	1.51-2.89		21	16	6			
BH-2	AQ2	1.52-2.13	23.3						
BH-2	AQ3	2.28-2.89	21.7						
BH-3	AQ3	1.52-2.13	12.6						

---

[*] In BH-1, AQ4 and AQ5 were in embankment fill; AQ7 and AS8 were in the foundation. In BH-2, samples AQ2 and AQ3 were in embankment fill. In BH-3, AQ3 was in the fill.

Numerous split-spoon samples were taken in the embankment fill and in the foundation, along with standard penetration tests (SPTs). Some CME continuous samples were also taken.

Sampling indicates that the embankment fill comprises brown and gray clay, silt and sand. The material is classified as CL. SPT ‘N’ values in the fill range from 1 to 4, i.e., very soft to soft consistency. Liquid limits, plasticity limits and plasticity index of the fines in the embankment are 24%, 17% and 13%, respectively, indicating low plasticity. In the remolded condition, the corresponding values are 21%, 16% and 6%. Moisture content of the embankment fill ranges from 21% to 24% approximately.

Sampling in the foundation indicates three layers – a silt, clay and sand uppermost layer, overlying a sand/silt intermediate layer, overlying a silty glacial till. The upper layer is of low plasticity and stiff consistency (N = 8 - 17), and is classified as ML. The upper part of this layer comprises black organic silt and clay (N = 1 - 5) which is original ground and topsoil. In BH-3, this material forms the entire silt, clay and sand layer. The sand/silt is a medium dense, fine to coarse sand classified as SW-SP. The glacial till is a very dense silt with sand and is classified ML.

Piezometers set in the sand/silt layer register water levels about 2.8 m below the crest.

Shear strength parameters have been interpreted from the above information and from the triaxial testing for the purpose of stability analysis for the spillway and the embankment. This is discussed in Section 8.

ACRES International

List of Abbreviations and Terms

(Sheet 1)

General

Elevations

Refer to datum indicated on drilling report.

Depth

All depths are given in metres measured from the ground surface unless otherwise noted.

Sample Type

The first letter describes the sampling method and the second, the shipping container.

Sampling Method

A - Split Tube
B - Thin Wall Tube
C - Piston Sampler
D - Core Barrel
E - Auger
F - Wash
G - Shovel Grab Sample
K - Slotted Sampler

Shipping Container

N - Insert
O - Tube
P - Water Content Tin
Q - Jar
R - Cloth Bag
S - Plastic Bag
U - Wooden Box
Y - Core Box
Z - Discharged

Sample No.

Samples are numbered consecutively in the order in which they were obtained in the borehole.

Sample Size

Dimension in millimetres and refers to the nominal diameter of the sampler.

Sample Recovery

Indicates the length in millimetres of sample retained in the sampler.

Sample Retained

Indicates length of sample retained for storage or testing purposes.

Abbreviations

N/A - No applicable
N/E - Not encountered
N/O - Not observed

Permeability

Degree of Permeability	*k(cm/s)*
Very high	$>10^{-1}$
High	10^{-1} to 10^{-3}
Medium	10^{-3} to 10^{-5}
Low	10^{-5} to 10^{-7}
Practically impermeable	$<10^{-7}$

Soil

Standard Penetration Test (SPT)

The test is carried out in accordance with ASTM D-1586 and the ‘N’ value corresponds to the sum of the number of blows required by a 63.5-kg hammer, dropped 760 mm, to drive a 50-mm diameter split tube sampler the second and third 150 mm of penetration.

Grain Size

Clay	<0.002 mm
Silt	0.002 - 0.075 mm
Sand	0.075 - 4.75 mm
Gravel	4.75 - 75 mm
Cobbles	75 - 300 mm
Boulder	>300 mm

Soil Classification and Description

Precise soil classification and description follows USCS, ASTM D 2487. Soil identification that is unsupported by laboratory testing is based on visual examination and manual tests defined in ASTM D 2488.

Relative Density (Granular Soils)

	N(SPT)
Very loose	0 - 4
Loose	4 - 10
Compact	10 - 30
Dense	30 - 50
Very dense	>50

Consistency (Cohesive Soils)

		Undrained Shear Strength	
	N(SPT)	*kPa*	*psf*
Very soft	<2	0 - 12	0 - 250
Soft	2 - 4	12 - 25	250 - 500
Firm	4 - 8	25 - 50	500 - 1000
Stiff	8 - 15	50 - 100	1000 - 2000
Very stiff	15 - 30	100 - 200	2000 - 4000
Hard	>30	>200	>4000

Plasticity/Compressibility

		Liquid Limit (%)
Low plasticity clays	Low compressibility silts	<30
Med. plasticity clays	Med. compressibility silts	30 - 50
High plasticity clays	High compressibility silts	>50

Dilatancy

None - No visible change

Slow - Water appears slowly on surface of specimen during shaking and does not disappear or disappears slowly upon squeezing.

Rapid - Water appears quickly on the surface of specimen during shaking and disappears quickly upon squeezing.

Sensitivity

Insensitive	<2
Low	2 - 4
Medium	4 - 8
High	8 - 16
Quick	>16

ACRES
International

List of Abbreviations and Terms
(Sheet 2)

Rock

Core Recovery
Sums of lengths of rock core recovered from a core run, divided by the length of the core and expressed as a percentage.

RQD (Rock Quality Designation)
Sum of lengths of hard, sound pieces of rock core equal to or greater than 100 mm from a core run, divided by the length of the core run and expressed as a percentage. Measured along centerline of core. Core fractured by drilling is considered intact. RQD normally quoted for N-size core.

RQD (%) Rock Quality

90 - 100	Excellent
75 - 90	Good
50 - 75	Fair
25 - 50	Poor
0 - 25	Very Poor

Grain Size

Term	*Grain Size*
Very coarse-grained	>60 mm
Coarse-grained	2 mm - 60 mm
Medium-grained	60 µm - 2 mm
Fine-grained	2 µm - 60 µm
Very fine-grained	<2 µm

Bedding

Term	*Bed Thickness*	
Very thickly bedded	>2 m	>6.50 ft
Thickly bedded	600 mm - 2 m	2.00 - 6.50 ft
Medium bedded	200 mm - 600 mm	0.65 - 2.00 ft
Thinly bedded	60 mm - 200 mm	0.20 - 0.65 ft
Very thinly bedded	20 mm - 60 mm	0.06 - 0.20 ft
Laminated	6 mm - 20 mm	0.02 - 0.06 ft
Thinly laminated	<6 mm	<0.02 ft

Discontinuity Frequency
Expressed as the number of discontinuities per metre or discontinuities per foot. Excludes drill-induced fractures and fragmented zone.

Discontinuity Spacing

Term	*Average Spacing*	
Extremely widely spaced	>6 m	>20.00 ft
Very widely spaced	2 mm - 6 m	6.50 - 20.00 ft
Widely spaced	600 mm - 2 mm	2.00 - 6.50 ft
Moderately spaced	200 mm - 600 mm	0.65 - 2.00 ft
Closely spaced	60 mm - 200 mm	0.20 - 0.65 ft
Very closely spaced	6 mm - 60 mm	0.06 - 0.20 ft
Extremely closely spaced	<20 mm	<0.06 ft

Note: Excludes drill-induced fractures and fragmented rock.

Broken Zone
Zone of full diameter core of very low RQD which may include some drill-induced fractures.

Fragmented Zone
Zone where core is less than full diameter and RQD = 0.

Strength

Term	*Description*	*Unconfined Compressive Strength*	
		(MPa)	*(psi)*
Extremely weak rock	Indented by thumbnail.	0.25-1.0	36-145
Very weak rock	Crumbles under firm blows with point of geological hammer, can be peeled by a pocket knife.	1.0-5.0	145-725
Weak rock	Can be peeled by a pocket knife with difficulty, shallow indentations made by firm blow with point of geological hammer.	5.0-25	725-3625
Medium strong rock	Cannot be scraped or peeled with a pocket knife, specimen can be fractured with single firm blow of geological hammer to fracture it.	25-50	3625-7250
Strong rock	Specimen requires more than one blow of geological hammer to fracture it.	50-100	7250-14500
Very strong rock	Specimen requires blows of geological hammer to fracture it.	100-250	14500-36250
Extremely strong rock	Specimen can only be chipped with geological hammer	>250	>36250

Weathering

Term	*Description*
Fresh	No visible sign of rock material weathering.
Faintly weathered	Discoloration on major discontinuity surfaces.
Slightly weathered	Discoloration indicates weathering of rock material and discontinuity surfaces. All the rock material may be discolored by weathering and may be somewhat weaker than in its fresh condition.
Moderately weathered	Less than half of the rock material is decomposed and/or disintegration to a soil. Fresh of discolored rock is present either as a continuous framework or as corestones.
Highly weathered	More than half of the rock material is decomposed and/or disintegrated to a soil. Fresh or discolored rock is present either as a discontinuous framework or as corestones.
Completely	All rock material is decomposed and/or disinteweathered to a soil. The original mass structure is still largely intact.
Residual soil	All rock material is converted to soil. The mass structure and material fabric are destroyed. There is a large change in volume, but the soil has not been significantly transported.

BOREHOLE REPORT

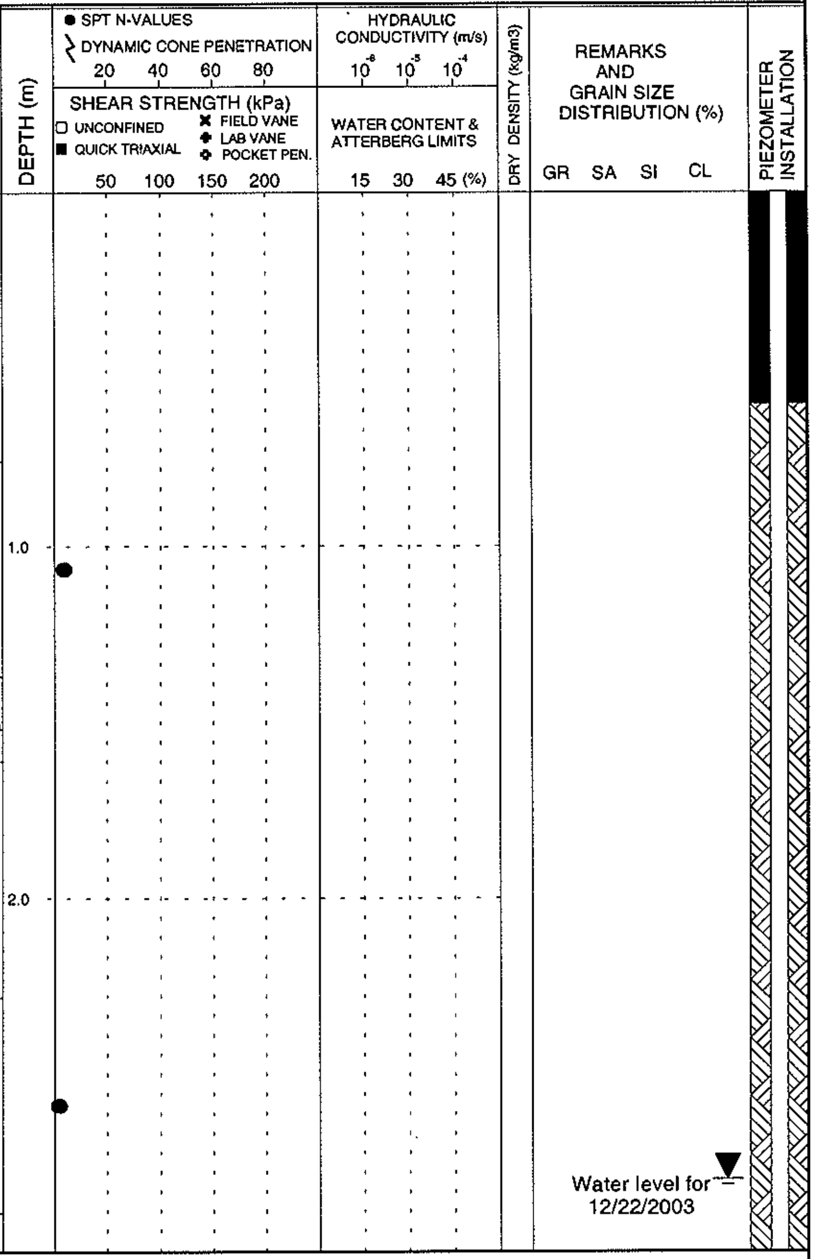
CLIENT: Upper Thames River Conservation Authority
PROJECT: Dam Safety Assessment
HOLE: HT BH1
PAGE: 1 **OF:** 4

SITE: Harrington Dam

COORDINATES:	4.90m from left pier on dam centerline	**CONTRACTOR:**	Atcost Soil Drilling Inc.	**STARTED:**	21 Nov 2003
		DRILL TYPE:	CME 75	**FINISHED:**	21 Nov 2003
DIP DIRECTION:	0	**METHOD SOIL:**	Hollow stem auger	**INSPECTOR:**	D. Besaw
DIP:	90	**ROCK:**		**LOGGED BY:**	D. Besaw
ELEVATIONS		**CASING:**	Auger 200mm OD	**REVIEWED:**	B Sinclair
DATUM:	Geodetic			**DATE:**	31/3/04
PLATFORM:		**CORE:**			
GROUND:	331.04				
END OF HOLE:	322.81				

See end of log for detailed groundwater measurements

ELEV. 331.04 DEPTH (m)	DESCRIPTION	SAMPLE DEPTH	TYPE/ NUMBER	REC'Y (mm)	RET'D (mm)	BLOW COUNTS
0.0	Embankment fill - brown and grey clay, silt and sand (CL), trace organics, medium plasticity, very soft to soft, moist, fine roots to 2.9; significant wood, root fibre and fine root mat between 1.52 and 2.28, 100-150mm thick wood at 1.52.					
		0.76 1.37	AQ 1	560	560	2 2 2
		1.52 1.61	AQ 2	100	100	>50
		2.28 2.89	AQ 3	50	50	0 0 2



Water level for 12/22/2003

SAMPLING METHOD

- A - Split Tube
- B - Thin Wall Tube
- C - Piston Sample
- D - Core Barrel
- E - Auger
- F - Wash
- G - Shovel Grab
- K - Slotted

SHIPPING CONTAINER

- N - Insert
- O - Tube
- P - Water Content Tin
- Q - Jar
- R - Cloth Bag
- S - Plastic Bag
- U - Wooden Box
- Y - Core Box
- Z - Discarded

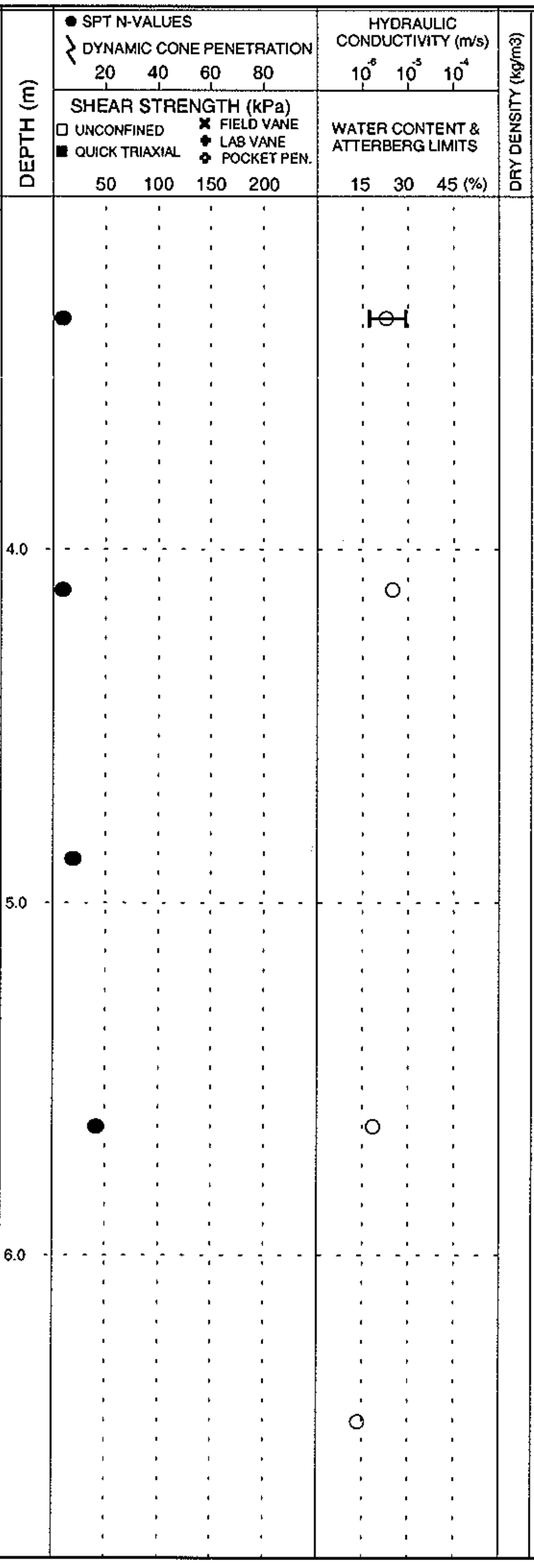
PLASTIC LIMIT W_P — NATURAL MOISTURE CONTENT W_N — LIQUID LIMIT W_L

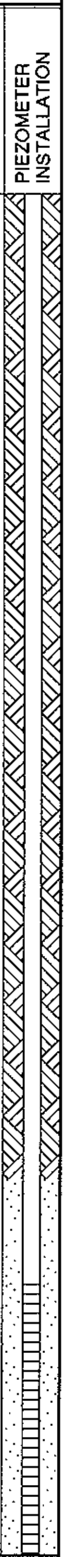
☐ Constant Head Test
▨ Falling Head Test
▩ Lab. Permeability

BOREHOLE REPORT

CLIENT: Upper Thames River Conservation Authority
PROJECT: Dam Safety Assessment
HOLE: HT BH1
PAGE: 2 **OF:** 4

ELEV. DEPTH (m)	SYMBOL	DESCRIPTION	SAMPLE DEPTH	TYPE/ NUMBER	REC'Y (mm)	RET'D (mm)	BLOW COUNTS	REMARKS AND GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
			3.04 3.65	AQ 4	610	610	0 2 2	
			3.81 4.42	AQ 5	585	585	1 1 3	
326.37 4.67		Foundation - tan colored silt, clay and sand (ML), low plasticity, stiff, moist, no dilatancy, contains roots and wood fibre, capped with 100 mm of organic sand and gravel with max size of 40 mm.	4.57 5.18	AQ 6	215	215	6 5 3	
		Original ground is defined by about 300mm of moist black organics and wood at base of embankment.	5.33 5.94	AQ 7	510	510	5 6 11	CME continuous sample also taken from 5.33-6.09 See gradation for AQ7.
324.95 6.09		Sand (SW)- fine to coarse silty sand with 10% gravel, max size gravel 75mm, fine roots, wet. At times dirty, large gravel piece in AQ 8 sample is encased in 1 cm of silt/clay.	6.09 6.85	AS 8	200	200		See gradation for AS8. AS 8 is CME continuous sampler





SAMPLING METHOD

- A - Split Tube
- B - Thin Wall Tube
- C - Piston Sample
- D - Core Barrel
- E - Auger
- F - Wash
- G - Shovel Grab
- K - Slotted

SHIPPING CONTAINER

- N - Insert
- O - Tube
- P - Water Content Tin
- Q - Jar
- R - Cloth Bag
- S - Plastic Bag
- U - Wooden Box
- Y - Core Box
- Z - Discarded

PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT

W_P W_N W_L

- ☐ Constant Head Test
- ▨ Falling Head Test
- ▩ Lab. Permeability

BOREHOLE REPORT

CLIENT: Upper Thames River Conservation Authority

PROJECT: Dam Safety Assessment

HOLE: HT BH1

PAGE: 3 **OF:** 4

ELEV. DEPTH (m)	SYMBOL	DESCRIPTION	SAMPLE DEPTH	SAMPLE TYPE/ NUMBER	SAMPLE REC'Y (mm)	SAMPLE RET'D (mm)	SAMPLE BLOW COUNTS	DEPTH (m)	● SPT N-VALUES DYNAMIC CONE PENETRATION 20 40 60 80 SHEAR STRENGTH (kPa) ☐ UNCONFINED ■ QUICK TRIAXIAL ✖ FIELD VANE ✚ LAB VANE ✜ POCKET PEN. 50 100 150 200	HYDRAULIC CONDUCTIVITY (m/s) 10^{-6} 10^{-5} 10^{-4} WATER CONTENT & ATTERBERG LIMITS 15 30 45 (%)	DRY DENSITY (kg/m3)	REMARKS AND GRAIN SIZE DISTRIBUTION (%) GR SA SI CL	PIEZOMETER INSTALLATION
								7.0					
323.42 7.62		Glacial till - silt (ML) with sand and fine subrounded gravel, very dense, low plasticity, moist.	7.62 8.23	AQ 9	480	480	5 20 30	8.0	●				
322.81 8.23		END OF BOREHOLE											

SAMPLING METHOD

- A - Split Tube
- B - Thin Wall Tube
- C - Piston Sample
- D - Core Barrel
- E - Auger
- F - Wash
- G - Shovel Grab
- K - Slotted

SHIPPING CONTAINER

- N - Insert
- O - Tube
- P - Water Content Tin
- Q - Jar
- R - Cloth Bag
- S - Plastic Bag
- U - Wooden Box
- Y - Core Box
- Z - Discarded

PLASTIC LIMIT W_P — NATURAL MOISTURE CONTENT W_N — LIQUID LIMIT W_L

- ☐ Constant Head Test
- ⛶ Falling Head Test
- ▩ Lab. Permeability

ACRES

BOREHOLE REPORT

CLIENT: Upper Thames River Conservation Authority
PROJECT: Dam Safety Assessment
HOLE: HT BH1
PAGE: 4 **OF:** 4

WATERLEVEL READINGS

11/21/2003 2:30:00 PM	2.88
12/22/2003 2:35:00 PM	2.81

NOTES/COMMENTS

1 Water level Measurements

Water level measurements are recorded from ground level.

The reservoir level was 0.93 m below borehole crest elevation for the 2.81 reading. Reservoir elevation was 330.00 m.

2 Piezometer Installation

Surface - Flush mount cap embedded in Sakcrete

0.0-0.6 Bentonite chips
0.6-5.79 Bentonite slurry
5.79-6.09 Coarse sand pack
6.09-7.6 Slottted screen in coarse sand pack
7.6-8.23 Coarse sand pack

Note: - riser and slotted screen consist of 50mm ID rigid, flush-coupled PVC

BOREHOLE REPORT

CLIENT: Upper Thames River Conservation Authority
PROJECT: Dam Safety Assessment

HOLE: HT BH2
PAGE: 1 **OF:** 4

SITE: Harrington Dam

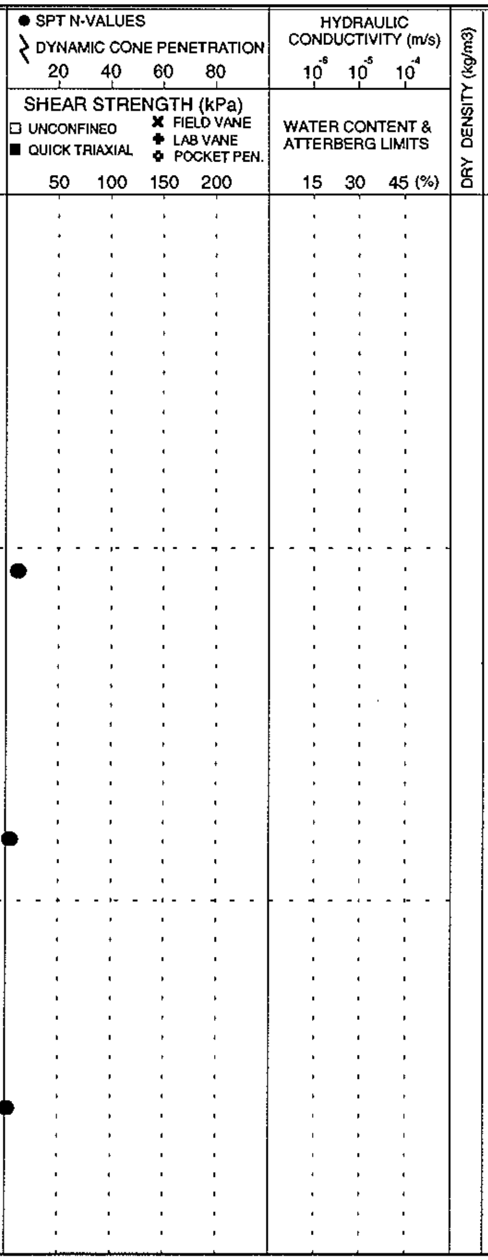
COORDINATES: 25.7 m from left pier on dam centerline
DIP DIRECTION: 0
DIP: 90
ELEVATIONS
DATUM: Geodetic
PLATFORM:
GROUND: 331.02
END OF HOLE: 323.56

CONTRACTOR: Atcost Soil Drilling Inc.
DRILL TYPE: CME 75
METHOD SOIL: Hollow stem auger
ROCK:
CASING: Auger 200mm OD
CORE:

STARTED: 21 Nov 2003
FINISHED: 21 Nov 2003
INSPECTOR: D. Besaw
LOGGED BY: D. Besaw
REVIEWED: B Sinclair
DATE: 31/3/04

See end of log for detailed groundwater measurements

ELEV. 331.02 DEPTH (m)	SYMBOL	DESCRIPTION	SAMPLE DEPTH	SAMPLE TYPE/NUMBER	SAMPLE REC'Y (mm)	SAMPLE RET'D (mm)	BLOW COUNTS	DEPTH (m)
0.0	▨	Embankment fill - dark brown and dark gray clay, silt and sand (CL), very soft, low plasticity, lenses of sand with gravel at 1 m and 2 m, trace organics, moist, fine roots to 1.3 m.						
			0.76 1.37	AQ 1	560	560	0 2 3	1.0
			1.52 2.13	AQ 2	610	610	1 1 1	2.0
			2.28 2.89	AO 3	510	510	0 0 1	



REMARKS AND GRAIN SIZE DISTRIBUTION (%)

GR SA SI CL

PIEZOMETER INSTALLATION

SAMPLING METHOD

- A - Split Tube
- B - Thin Wall Tube
- C - Piston Sample
- D - Core Barrel
- E - Auger
- F - Wash
- G - Shovel Grab
- K - Slotted

SHIPPING CONTAINER

- N - Insert
- O - Tube
- P - Water Content Tin
- Q - Jar
- R - Cloth Bag
- S - Plastic Bag
- U - Wooden Box
- Y - Core Box
- Z - Discarded

PLASTIC LIMIT — NATURAL MOISTURE CONTENT — LIQUID LIMIT
W_P — W_N — W_L

- ☐ Constant Head Test
- ⬚ Falling Head Test
- ▩ Lab. Permeability

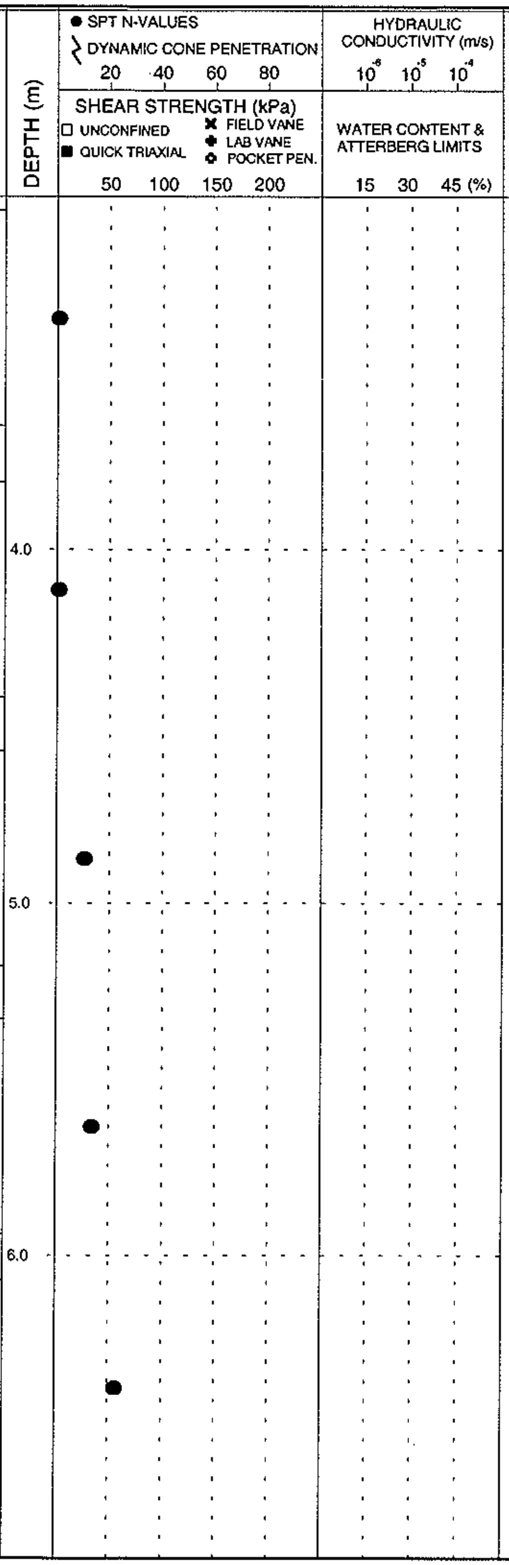
BOREHOLE REPORT

CLIENT: Upper Thames River Conservation Authority **HOLE:** HT BH2

PROJECT: Dam Safety Assessment **PAGE:** 2 **OF:** 4

ELEV. / DEPTH (m)	DESCRIPTION
327.55 3.47	Foundation -tan colored silt and sand, black clay and organics silt (120 mm), layers of organics and wood fibre (100 mm), orginal ground.
327.02 4	Silt and clay (ML) - tan colored, stiff, no dilatancy, moist.
325.02 6	Sand (SP) - coarse sand with gravel, medium density, subrounded gravel sizes, maximum size 30 mm.

SAMPLE DEPTH	TYPE/ NUMBER	REC'Y (mm)	RET'D (mm)	BLOW COUNTS
3.04 3.65	AQ 4	610	610	0 0 1
3.81 4.42	AQ 5	535	535	0 0 1
4.57 5.18	AQ 6	480	480	5 6 5
5.33 5.94	AQ 7	510	510	4 6 8
6.07 6.68	AQ 8	305	305	6 8 15



DRY DENSITY (kg/m3)

REMARKS AND GRAIN SIZE DISTRIBUTION (%): GR SA SI CL

PIEZOMETER INSTALLATION

SAMPLING METHOD

A - Split Tube
B - Thin Wall Tube
C - Piston Sample
D - Core Barrel
E - Auger
F - Wash
G - Shovel Grab
K - Slotted

SHIPPING CONTAINER

N - Insert
O - Tube
P - Water Content Tin
Q - Jar
R - Cloth Bag
S - Plastic Bag
U - Wooden Box
Y - Core Box
Z - Discarded

PLASTIC LIMIT W_P — NATURAL MOISTURE CONTENT W_N — LIQUID LIMIT W_L

☐ Constant Head Test
☐ Falling Head Test
▩ Lab. Permeability

BOREHOLE REPORT

CLIENT: Upper Thames River Conservation Authority
PROJECT: Dam Safety Assessment
HOLE: HT BH2
PAGE: 3 **OF:** 4

ELEV. DEPTH (m)	SYMBOL	DESCRIPTION	SAMPLE DEPTH	SAMPLE TYPE/NUMBER	SAMPLE REC'Y (mm)	SAMPLE RET'D (mm)	BLOW COUNTS	DEPTH (m)	● SPT N-VALUES / DYNAMIC CONE PENETRATION 20 40 60 80; SHEAR STRENGTH (kPa) ☐ UNCONFINED ■ QUICK TRIAXIAL ✖ FIELD VANE ✚ LAB VANE ✜ POCKET PEN. 50 100 150 200	HYDRAULIC CONDUCTIVITY (m/s) 10^{-6} 10^{-5} 10^{-4}; WATER CONTENT & ATTERBERG LIMITS 15 30 45 (%)	DRY DENSITY (kg/m3)	REMARKS AND GRAIN SIZE DISTRIBUTION (%) GR SA SI CL	PIEZOMETER INSTALLATION
324.07 6.95		Glacial till - silt with sand (ML) and fine subrounded gravel, very dense, moist.	6.95 7.46	AQ 9	480	480	10 18 36	7.0	●				
323.56 7.46		END OF BOREHOLE.											

SAMPLING METHOD

A - Split Tube
B - Thin Wall Tube
C - Piston Sample
D - Core Barrel
E - Auger
F - Wash
G - Shovel Grab
K - Slotted

SHIPPING CONTAINER

N - Insert
O - Tube
P - Water Content Tin
Q - Jar
R - Cloth Bag
S - Plastic Bag
U - Wooden Box
Y - Core Box
Z - Discarded

PLASTIC LIMIT W_P — NATURAL MOISTURE CONTENT W_N — LIQUID LIMIT W_L

☐ Constant Head Test
⬚ Falling Head Test
▨ Lab. Permeability

BOREHOLE REPORT

CLIENT: Upper Thames River Conservation Authority
PROJECT: Dam Safety Assessment
HOLE: HT BH2
PAGE: 4 **OF:** 4

WATERLEVEL READINGS

11/21/2003 5:27:00 AM	2.79
12/22/2003 2:35:00 PM	2.81

NOTES/COMMENTS

1 Water Level Measurements

All water level measurements are referenced to ground level.

The reservoir level was 1.02 m below borehole crest elevation for the 2.81 reading. Reservoir elevation is 330.00 m.

2 Piezometer Installation

Surface - Flush mount protection cap

0-0.3 Flush mount embedded in Sakcrete
0.3-0.76 Bentonite chips capped with sand
0.76-5.12 Bentonite slurry
5.12-5.94 Flowing material
5.94-6.25 Coarse sand pack
6.25-6.85 Slotted screen in coarse sand pack

Note: - riser pipe and slotted screen consist of 50 mm ID flush coupled PVC.

BOREHOLE REPORT

CLIENT: Upper Thames River Conservation Authority
HOLE: HT BH3
PROJECT: Dam Safety Assessment
PAGE: 1 **OF:** 3

SITE: Harrington Dam

COORDINATES: on toe of slope 14 m d/s of HT BH2
DIP DIRECTION: 0
DIP: 90
ELEVATIONS
DATUM: Geodetic
PLATFORM:
GROUND: 328.33
END OF HOLE: 324.68

CONTRACTOR: Atcost Soil Drilling Inc.
DRILL TYPE: CME 55
METHOD SOIL: Hollow stem auger
ROCK:
CASING: Auger 200mm OD
CORE:

STARTED: 24 Nov 2003
FINISHED: 24 Nov 2003
INSPECTOR: D. Besaw
LOGGED BY: D. Besaw
REVIEWED: B Sinclair
DATE: 31/3/04

See end of log for detailed groundwater measurements

ELEV. / DEPTH (m) 328.33	SYMBOL	DESCRIPTION	SAMPLE DEPTH	SAMPLE TYPE/NUMBER	SAMPLE RECY (mm)	SAMPLE RET'D (mm)	BLOW COUNTS	DEPTH (m)	● SPT N-VALUES / DYNAMIC CONE PENETRATION 20 40 60 80 / SHEAR STRENGTH (kPa) ☐ UNCONFINED ■ QUICK TRIAXIAL ✖ FIELD VANE ✚ LAB VANE ✿ POCKET PEN. 50 100 150 200	HYDRAULIC CONDUCTIVITY (m/s) 10^{-6} 10^{-5} 10^{-4} / WATER CONTENT & ATTERBERG LIMITS 15 30 45 (%)	DRY DENSITY (kg/m3)	REMARKS AND GRAIN SIZE DISTRIBUTION (%) GR SA SI CL	PIEZOMETER INSTALLATION
0.0		Embankment fill - brown clay, silt and sand (CL), organic, soft, moist.	0 – 0.61	AQ1	520	520	1 1 2						
327.83 0.5		Foundation- black, firm, organic silt and organics, moist, topsoil, original ground.	0.76 – 1.37	AQ2	360	360	1 2 3	1.0					
326.91 1.42		Sand (SW) - sand with gravel, compact, fine to coarse, clean, subrounded gravel fraction, dense, wet, max size 25 mm.	1.52 – 2.13	AQ3	390	390	4 15 12	2.0					
			2.28 – 2.89	AQ4	520	520	13 18 15						

SAMPLING METHOD

A - Split Tube
B - Thin Wall Tube
C - Piston Sample
D - Core Barrel
E - Auger
F - Wash
G - Shovel Grab
K - Slotted

SHIPPING CONTAINER

N - Insert
O - Tube
P - Water Content Tin
Q - Jar
R - Cloth Bag
S - Plastic Bag
U - Wooden Box
Y - Core Box
Z - Discarded

PLASTIC LIMIT W_P — NATURAL MOISTURE CONTENT W_N — LIQUID LIMIT W_L

☐ Constant Head Test
▨ Falling Head Test
▩ Lab. Permeability

ACRES

BOREHOLE REPORT

CLIENT: Upper Thames River Conservation Authority
PROJECT: Dam Safety Assessment
HOLE: HT BH3
PAGE: 2 **OF:** 3

ELEV. DEPTH (m)	SYMBOL	DESCRIPTION	SAMPLE DEPTH	TYPE/ NUMBER	RECY (mm)	RET'D (mm)	BLOW COUNTS	DEPTH (m)	● SPT N-VALUES ⦚ DYNAMIC CONE PENETRATION 20 40 60 80 SHEAR STRENGTH (kPa) ☐ UNCONFINED ■ QUICK TRIAXIAL ✖ FIELD VANE ✚ LAB VANE ✿ POCKET PEN. 50 100 150 200	HYDRAULIC CONDUCTIVITY (m/s) 10^{-6} 10^{-5} 10^{-4} WATER CONTENT & ATTERBERG LIMITS 15 30 45 (%)	DRY DENSITY (kg/m3)	REMARKS AND GRAIN SIZE DISTRIBUTION (%) GR SA SI CL	PIEZOMETER INSTALLATION
325.26 3.07		Glacial till - silt (ML) with fine subrounded gravel (5-10%), very stiff, maximum size gravel is 50 mm; 100 mm wide fine to coarse sand lense in till.	3.04 3.65	AQ5	560	560	8 14 22						
324.68 3.65													

END OF BOREHOLE.

SAMPLING METHOD

A - Split Tube
B - Thin Wall Tube
C - Piston Sample
D - Core Barrel
E - Auger
F - Wash
G - Shovel Grab
K - Slotted

SHIPPING CONTAINER

N - Insert
O - Tube
P - Water Content Tin
Q - Jar
R - Cloth Bag
S - Plastic Bag
U - Wooden Box
Y - Core Box
Z - Discarded

PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT
W_P W_N W_L

☐ Constant Head Test
░ Falling Head Test
▩ Lab. Permeability

BOREHOLE REPORT

CLIENT: Upper Thames River Conservation Authority
PROJECT: Dam Safety Assessment
HOLE: HT BH3
PAGE: 3 **OF:** 3

WATERLEVEL READINGS

11/24/2003 1:00:00 PM	0.0
12/22/2003 2:40:00 PM	-.02

NOTES/COMMENTS

1 **Water Level Measurements**

All water level measurements are referenced to ground level.

Reservoir elevation was 330.00 m.

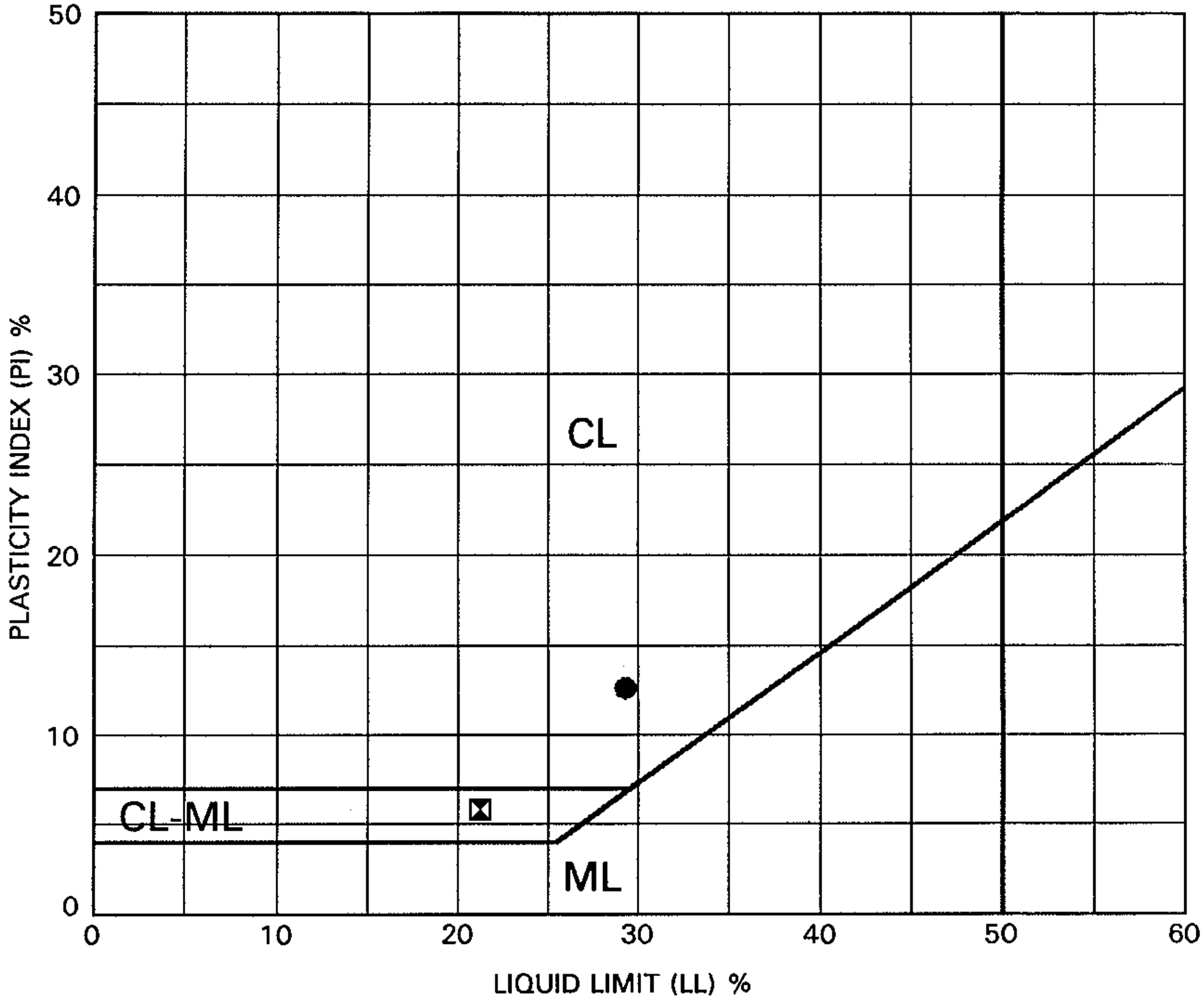
.

2 **Piezometer Installation**

Surface - Flush mount protection cap

0-0.3 Flush mount embedded in Sakcrete
0.3-1.82 Bentonite chips capped with sand
1.82-2.13 Coarse sand pack
2.13-3.07 Slotted screen in coarse sand pack
3.07-3.65 Coarse sand backfill

Note: - riser pipe and slotted screen consist of 50 mm ID flush coupled PVC.



LEGEND	BH	DEPTH (m)	LL%	PL%	PI%
●	HTBH1	3.05	29	17	13
☒	HTBH2	0.00	21	16	6

Note: Sample from HTBH2 is a remolded composite sample taken from AQ2 and AQ3 and used for triaxial testing.

NP = Non-Plastic

Geotechnical Investigations
Upper Thames Conservation Authority

PLASTICITY CHART
Harrington Dam

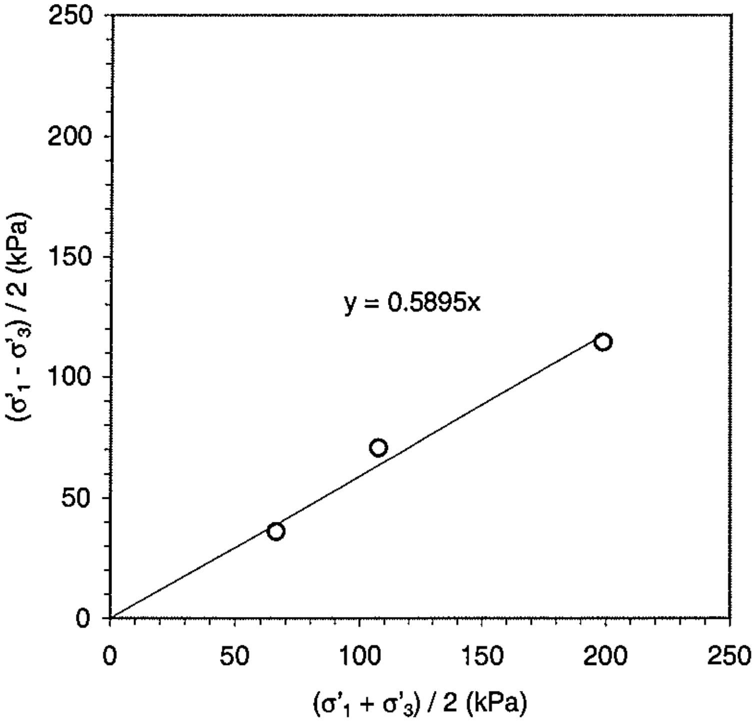
PROJECT NO. P1450404

ACRES

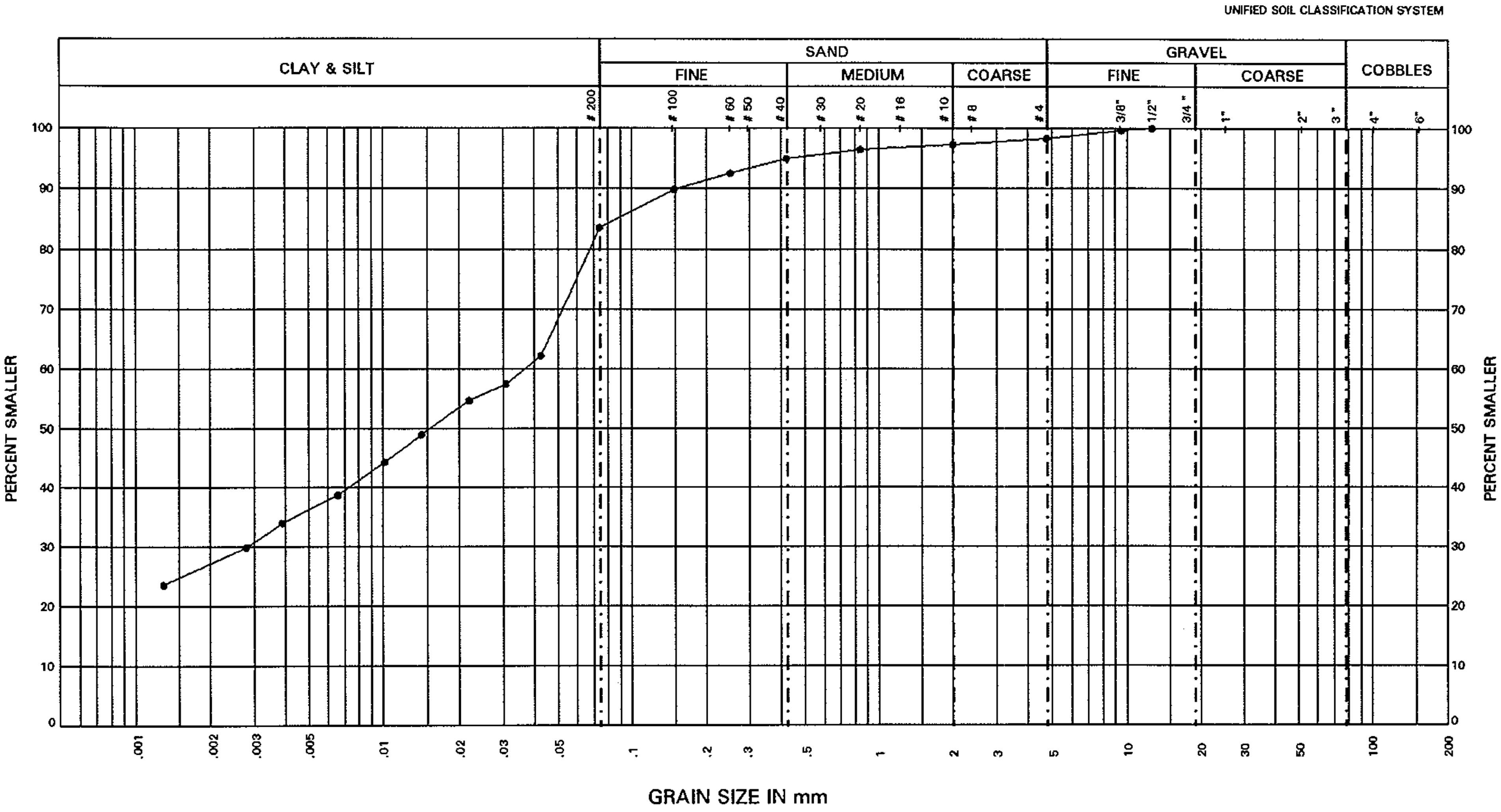
Acres International Ltd.
Project: P14504.04
Harrington Dam - UTRCA
Summary of Consolidated Undrained Triaxial Compression Tests
Date: March-04

Test	$(\sigma'_1 - \sigma'_3) / 2$ (kPa)	$(\sigma'_1 + \sigma'_3) / 2$ (kPa)
1	36.1	66.3
2	70.6	107.7
3	114.3	198.9

Harrington Dam
Consolidated Undrained Triaxial Compression Tests



Effective friction angle, $\phi' = 36^{\circ}$
Cohesion, c = 0



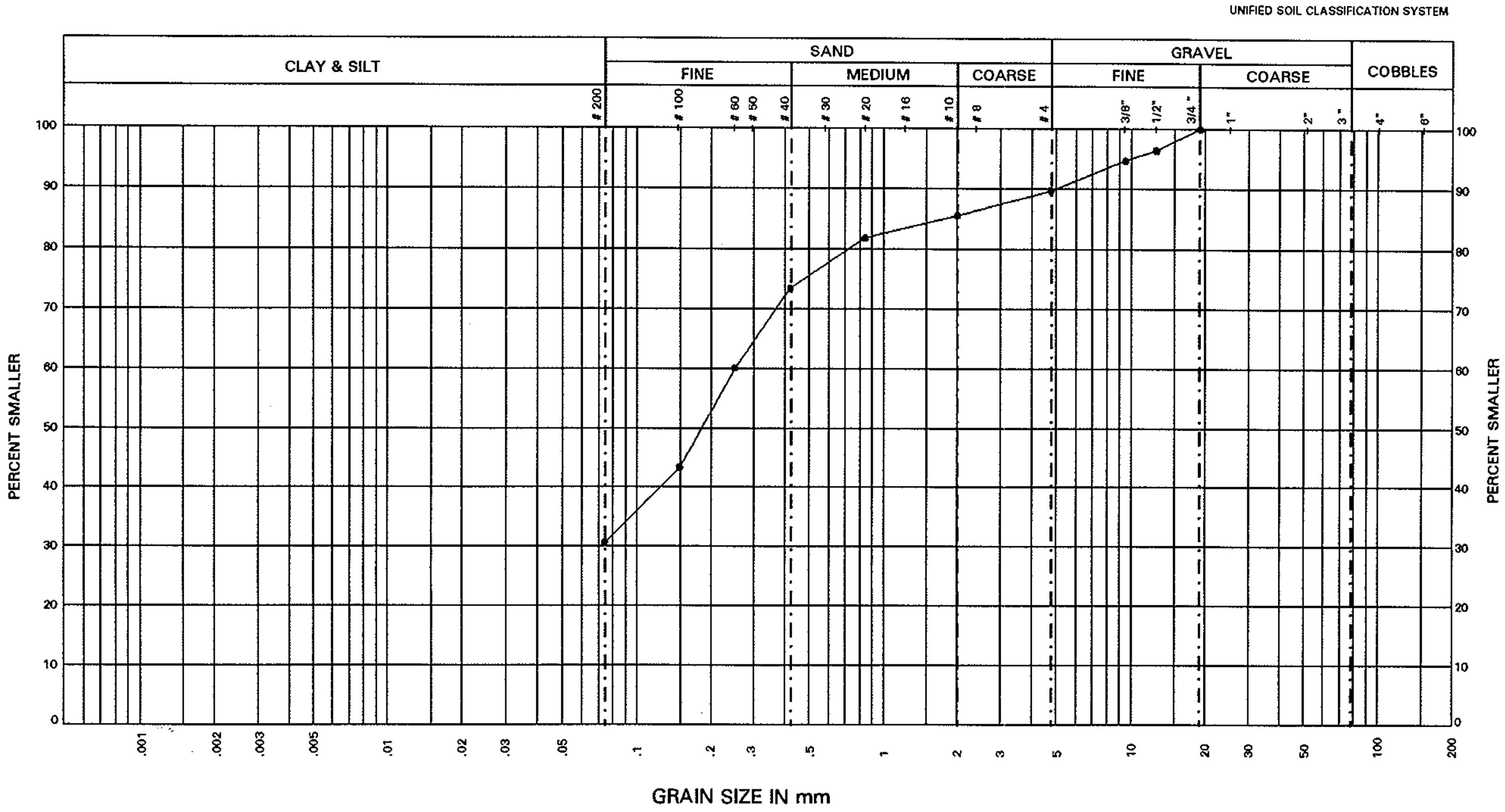
LAB SAMPLE NO.
LAB TEST NO.
DATE December 2003
TESTED BY RS
CHECKED BY AT
APPROVED BY

REMARKS: Harrington Dam
UTRCA

GRAIN SIZE DISTRIBUTION

DEPTH	SAMPLE NO.	HOLE NO.	JOB NO.
5.33m	AQ7	BH1	P14504.04

ACRES



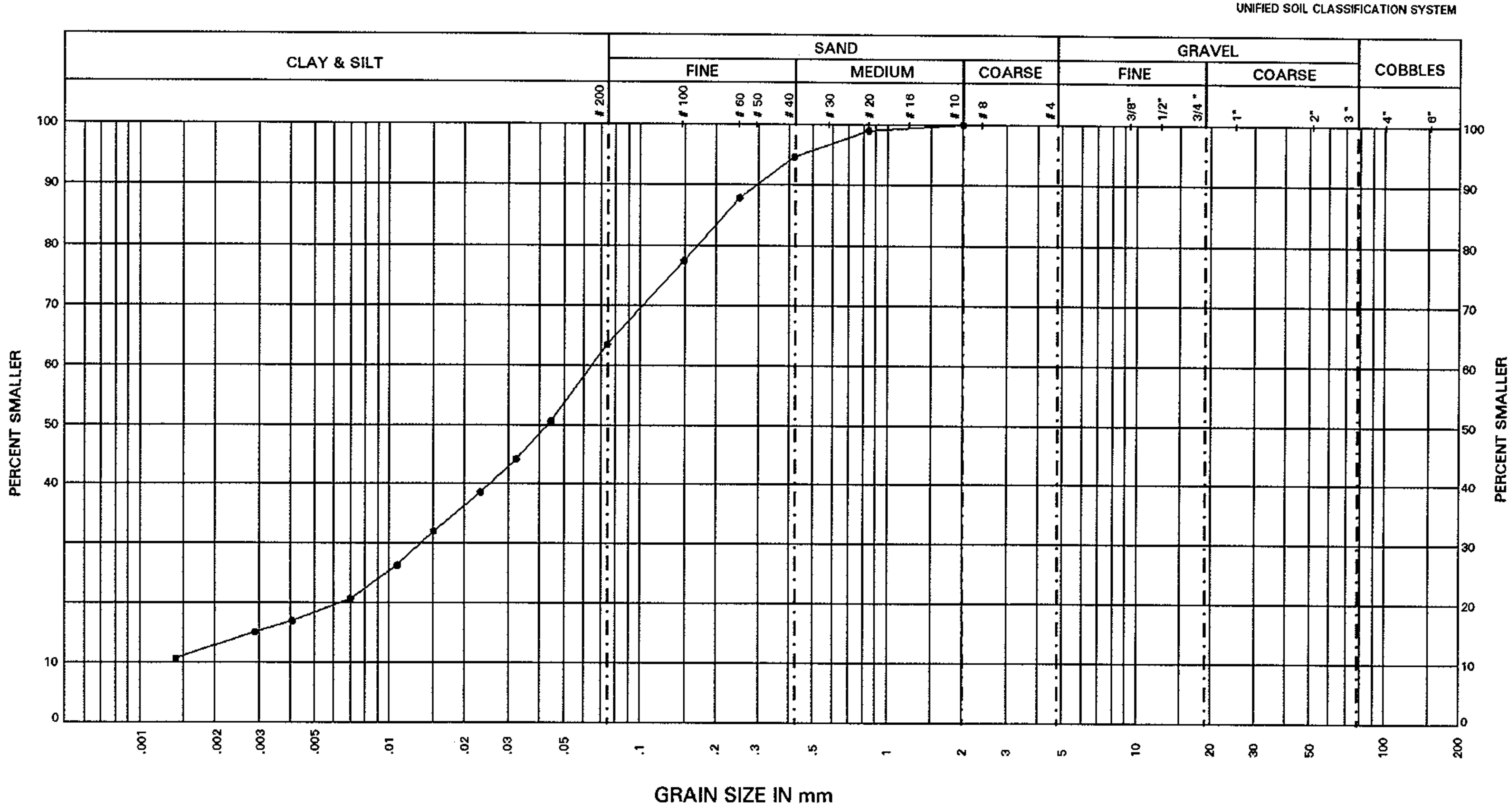
LAB SAMPLE NO.
LAB TEST NO.
DATE December 2003
TESTED BY RS
CHECKED BY AT
APPROVED BY

REMARKS: Harrington Dam
UTRCA

GRAIN SIZE DISTRIBUTION

DEPTH	SAMPLE NO.	HOLE NO.	JOB NO.
6.09m	AS8	BH1	P14504.04

ACRES



REMARKS: Harrington Dam (Triaxial Test Sample)
UTRCA

LAB SAMPLE NO.
LAB TEST NO.
DATE March 2004
TESTED BY RS
CHECKED BY AT
APPROVED BY

GRAIN SIZE DISTRIBUTION

DEPTH	SAMPLE NO.	HOLE NO.	JOB NO.
1.52m to 2.89m	AQ2 to AQ3	BH2	P14504.04

ACRES

6 Hydrotechnical Assessment

6 Hydrotechnical Assessment

6.1 Approach and Methodology

6.1.1 Hydrologic Analysis

The purpose of the hydrologic analyses was to estimate peak flood flows and hydrographs for the 2-yr, 5-yr, 10-yr, 25-yr, 50-yr, 100-yr and 250-yr return period floods (regulatory flood), and regional storm (Hurricane Hazel) for the study area shown in Figure 1.3. The design hydrographs were used in the flood routing studies and subsequent dam safety assessment analysis that are described in Sections 6.2 and 6.3.

Two methods were used for estimating peak flows:

- deterministic modeling of watershed runoff on an event basis
- statistical frequency analysis using local historical streamflow data (where streamflow data were available and prorated to the damsite) or regional flood frequency analysis.

The Harrington Dam in this study is not located at or near appropriate WSC streamflow gauging stations. Application of transposed or regional runoff flood characteristics for dam safety use requires verification, which can be only accomplished by deterministic modeling. The regulatory flood adopted by UTRCA for the study basin is frequency-based and has been selected as the 1:250-yr flood. This is approximately equivalent to the historical 1937 flood in the basin.

The deterministic peak flow estimates of the watershed hydrographs were derived using the HEC-HMS rainfall-runoff model (US Army, 2002) for the damsite. The statistical approach made use of the index flood method (MNR, 1986).

6.1.2 Rainfall-Runoff Modeling

6.1.2.1 HEC Hydrologic Modeling System (HEC-HMS)

(a) Rainfall-Runoff Model Selection

The Hydrologic Modeling System (HEC-HMS) is a computer model for precipitation-runoff analysis, developed by the Hydrologic Engineering Center of the US Army Corps of Engineers (US Army, 2002). HEC-HMS supersedes the HEC-1 Flood Hydrograph Package and was selected for application to the individual basins of the study Conservation Area because of its ability to develop discharge hydrographs for hypothetical rainfall events at one or more locations in a basin and its general versatility as an event model. The HEC-HMS model is capable of representing a single runoff event occurring over a period of time, utilizing an appropriate calculation time-step, to accurately compute runoff from the chosen event storm rainfall. The model has a wide variety of options for specifying precipitation, losses, base flow, runoff transformation and the method of routing.

(b) General Description of the Model

The HEC-HMS model is designed to simulate the surface runoff response of a river basin to precipitation by representing the basin as an interconnected system of hydrologic and hydraulic components. Each component models an aspect of the precipitation-runoff process over the entire watershed, or within a portion of the basin, commonly referred to as a subbasin. A component may represent a surface runoff entity, a stream channel, or a reservoir. Representation of a component requires a set of parameters that specify the particular characteristics of the component and mathematical relations, which describe the physical process. One model may include different versions of a component such as basin models that may be combined with different meteorological data or precipitation events. The result of the modeling process is the computation of streamflow hydrographs at desired locations in the river basin.

(c) Setup of the HEC-HMS Model

The first step in the setup of this model, for application to the individual dam basin, consisted of configuring or schematizing the basin into watersheds/subbasins, channel and reservoir/lake elements (i.e., the hydrologic and hydraulic components). Figure 6.1 shows the discretized drainage area of the Harrington site plus the 13 other area study subbasins. The additional basin (Waubuno Creek) used for model calibration is also denoted in this figure. Setup of the HEC-HMS model for application to the dam is described in Section 6.2.

(d) Input Data

Physical parameters for the river basin, including drainage area, stream-course length and average slope, were developed by measurements taken from 1:50 000-scale topographic maps (Department of Energy, Mines and Resources Canada) and 1:10 000-scale Ontario Base Maps (OBMs) from the MNR. The lag time for the river basin is a function of the basin and main stream-course characteristics and was initially estimated by the US Soil Conservation Service (SCS) method (SCS, 1985). More accurate calculations were derived based on a comparison of observed and calculated values for the calibration basin using a formula after Watt/Chow.

The curve number (CN) of the watershed was estimated based on the land-use conditions and soil mapping units prepared by UTRCA for Perth, Oxford and Middlesex counties, together with their physical soil characteristics (texture and infiltration rates). Sensitivity in the selections of the basin CN and the computed time-to-peak values were evaluated in the calibration runs of the HEC-HMS model. Weighted basin CN values for the antecedent moisture conditions (AMC) I, II and III were then computed for the calibration basin. These computed values and the similarity of the physiographic characteristics between the two basins were used to establish CN values for the study basin.

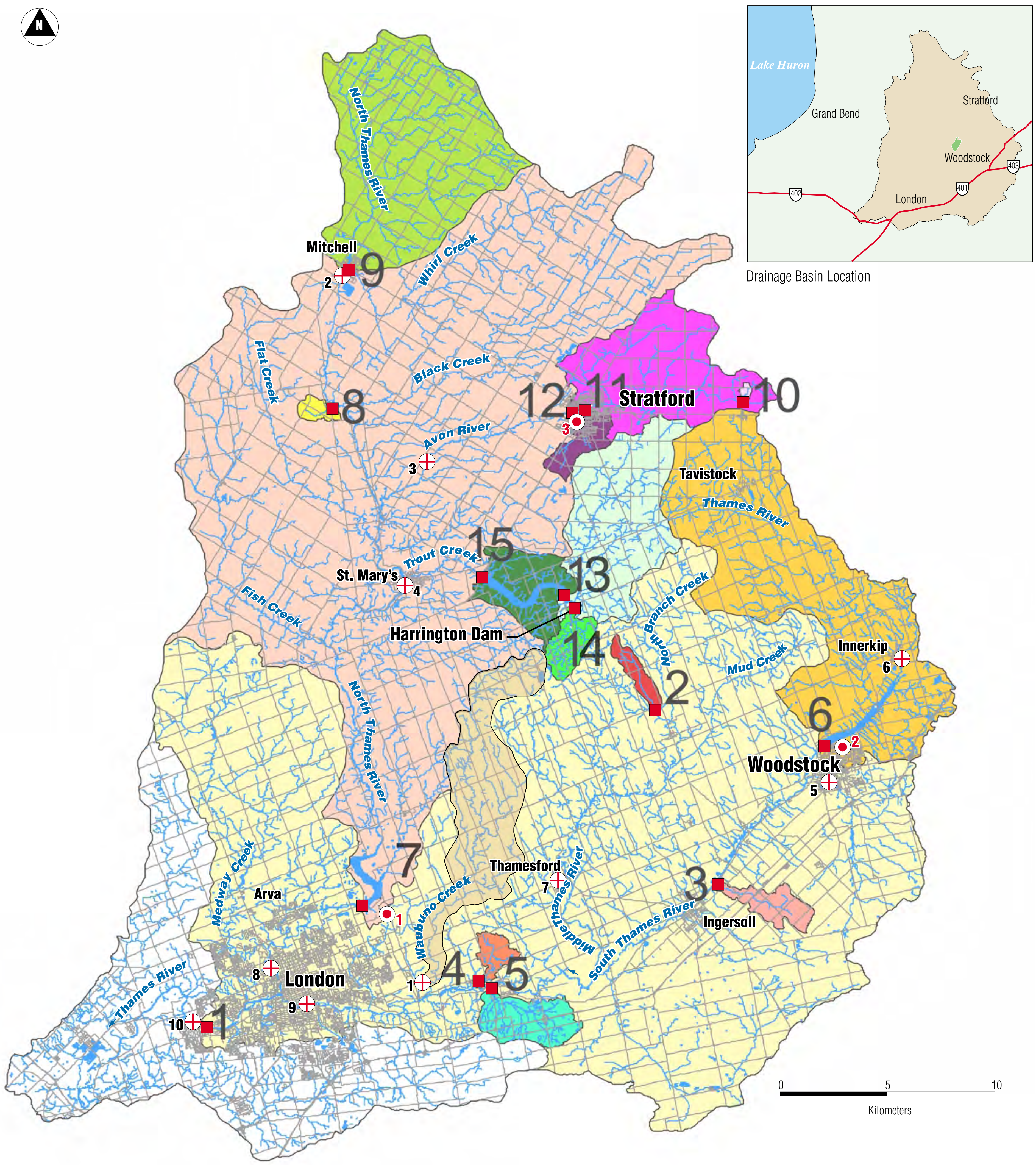
- **Precipitation:** Where more than one precipitation station data were used, the average precipitation over the basin was determined externally by applying Thiessen weighting coefficients and then input to the program. After the storm depth and duration have been established, a representative hyetograph must be selected for input to the model. The temporal distribution of the weighted rainfall in the selected storms represented southern Ontario conditions and was applied to calculate the input storm rainfall distribution or hyetograph.

- **Losses:** The runoff volume for the subbasin was computed by the US SCS CN method with an optional initial loss. This method took into account the hydrologic soil characteristics and AMC. AMC I reflects drier than average soil conditions which can develop if no significant rainfall has fallen for an extended period of time prior to a storm event. AMC II represents the case where soil saturation conditions are average prior to the rainfall event. AMC III represents the situation where significant rainfall occurring prior to the rainstorm has saturated the soil or the ground is partially or completely frozen.

- **Stream Channel Routing:** Routing of hydrographs through channels, where necessary in the HEC-HMS model, was accomplished by the Muskingum-Cunge method. Some of the watersheds in the study have limited reaches where channel routing has marginal attenuation effects, or are dominated by lakes or reservoirs, located immediately upstream of the dams. In these cases, the weighted CN value already accounts for minor channel storage effects of small river reaches and no channel routing was required.

- **Reservoir Routing:** A reservoir storage routing technique was used by the model to route flows through lakes or reservoirs upstream of damsites. Applicable reservoir elevation/outflow relationships were derived from available site information. For those sites with no information, the lake area was determined from topographical map information and a storage volume/elevation relationship developed. Discharge rating curves for the lakes or reservoirs were developed by taking into account the type and physical characteristics of the outlet structure and any bank overflow areas. The discharge rating curves are the input to HEC-HMS, used to compute the reservoir outflows.

- **Base Flow:** Base flow was specified on an individual basis by the following input variables: (a) an initial discharge at the beginning



Legend

🟥 Dam

Watercourse

Roads

Meteorological Stations in Basin
1 - London Airport
2 - Woodstock
3 - Stratford

Gauging Stations
1 - Waubuno Creek near Dorchester (02GD020)
2 - North Thames near Mitchell (02GD014)
3 - Avon River below Stratford (02GD018)
4 - North Thames at St. Mary's (02GD005)
5 - Cedar Creek at Woodstock (02GD011)
6 - Thames River at Innerkip (02GD021)
7 - Middle Thames at Thamesford (02GD004)
8 - Medway River at London (02GD008)
9 - Thames River near Earling (02GD001)
10 - Thames River at Byron (02GE002)

Basins

Springbank (3110 km²)
1 - Springbank
2 - Embro (7 km²)
3 - Centreville (13 km²)
4 - Dorchester CA (7 km²)
5 - Dorchester Mill Pond (23 km²)
6 - Pittock (250 km²)

Fanshawe (1435 km²)
7 - Fanshawe
8 - Fullarton (4 km²)
9 - Mitchell (176 km²)

Avon River Above John St. Weir (107 km²)
10 - Shakespeare (1 km²)
11 - RT Orr (93 km²)
12 - John Street Weir

Wildwood (137 km²)
13 - Ducks Unlimited (92 km²)
14 - Harrington (12 km²)
15 - Wildwood

Waubuno Creek Basin - Calibration Basin

Source: UTRCA GIS Database
Produced by Acres International Limited under licence with the UTRCA, 2003.

Figure 6.1
Upper Thames River Conservation Authority
Dam Safety Assessment Report
UTRCA Dams Watershed Areas-
Location of Dam Drainage Basins

ACRES International

FIGURE 6.1- BACK

of the simulation, (b) an exponential recession rate term and (c) a recession threshold discharge for the recession limb of the hydrograph. The base flow component of the storm hydrographs is usually not a significant parameter in relation to the magnitude of the ensuing storm runoff. However, recession discharge is part of the total storm runoff, and characteristics described in Items (b) and (c) above were calibrated in the HEC-HMS analysis.

- **Rainfall Excess To Runoff Transformation:** Precipitation excess was transformed to direct runoff using the unit hydrograph technique. The unit hydrograph adopted was expressed in terms of the SCS unit hydrograph parameters.

(e) Input Rainfall Data

Precipitation data, which is required for input to the event model, is described in Section 6.1.3.

6.1.3 Assessment of Precipitation

Precipitation data are required as the driving input to the HEC-HMS model. These data are required on an event basis (covering at least one day, depending on the size of the watershed) and to provide an appropriate calculation resolution between runoff volume, peak discharge and response time of the various drainage basins.

Floods vary greatly in intensity and duration depending on storm patterns, drainage basin characteristics, and other factors. A summer storm on a small drainage basin may generate a flood with a very high peak flow but of short duration. On a large basin, the peak flow from a similar storm may be significantly attenuated by storage and resistance in the catchment before it reaches the basin outlet. Spring rain-on-snowmelt events, on the other hand, are likely to be of lesser intensity but of much greater areal coverage and longer duration (days). The runoff volume is the dominant factor resulting in flood flows for this type of flood event. Unused storage capacity in a catchment that may be sufficient to attenuate peak runoff and prevent significant flooding from a summer storm of short duration may be ineffective for a severe event of this type. Both types of flood events need to be analyzed to determine the design flood.

Based on the above, two types of design precipitation events were analyzed and used in the study. The first is the summer/fall design storm event (May to November). The other design event is the rain-on-snowmelt conditions. Data from three meteorological stations, Woodstock (Station 6149625) for the period 1871 to 2002, Stratford (Station 6148105) for the period 1959 to 2002 and London A (Station 6144475) covering the period 1940 to 2002, were available for the analysis. The Thiessen polygon technique was applied to determine the applicable basin rainfall weighting factors, based on the location of the study basin relative to the meteorological stations. The results of the weighting analysis indicated that the single station at Stratford was most representative of the storm events expected for the Harrington basin. The data from the Stratford station were, therefore, analyzed and applied in the simulation model.

6.1.4 Design Storms and Temporal Distributions

A design storm consists of three important factors: storm volume or depth, duration and temporal distribution. The choice of these parameters would significantly affect the shape and peak value of the resulting runoff hydrograph.

Rainfall Depth-Duration-Frequency Relationship

Rainfall depth-duration-frequency (DDF) or intensity-duration-frequency data are available in the form of tables and graphs from the Atmospheric Environment Service (AES), Environment Canada[*]. AES provides both short duration DDF (from 5 minutes to 24 hours) and long duration DDF (from 1-day to 30-day) design storm depths. The DDF data are based on statistical analysis of long-term rain gauge records in the selected region. Maximum cumulative rainfall amounts for 1-day to 30-day events have been fitted to a modified Gumbel extreme value distribution by AES in their supplied data. Total precipitation for any return period could then be obtained from the fitted distribution.

---

[*] The organization Atmospheric Environment Service (AES) is now Meteorological Service Canada (MSC).

Before a design storm can be developed from AES data, two storm parameters must be determined: the duration of the storm and the distribution of the time interval for each rainfall increment in the storm. The storm duration to be applied is directly related to the time of concentration of the basin, as determined from an analysis of recorded data or by computation. The duration should be at least as long as, but preferably longer than the time of concentration of the basin. A duration less than the time of concentration would not allow all parts of the basin to contribute runoff simultaneously at the outlet during the course of the storm. Runoff from the lower parts of the basin would have left the basin before runoff from the upper parts of the basin had reached the outlet and the estimated peak discharge would be too low. A long duration storm is required to capture the attenuation effects of large natural storage areas.

The 6-hr, 12-hr and 24-hr rainfall durations were, therefore, used in the simulations. The longer durations of 1-day, 2-day, 3-day and 5-day storms were also analyzed and their results compared to those above.

The time interval of storm increments should be small enough to accurately define the profile of the flood hydrograph. The selected time interval of storm increments used in the study was 15 minutes.

The results from the rainfall DDF curves for Stratford are presented in Tables 6.1 and 6.2, respectively.

Table 6.1

AES Rainfall Events for Stratford MOE Station 6148105 (1966 to 2002)

Return Period (yrs)	Total Precipitation (mm)		
	6-Hr	12-Hr	24-Hr
2	40.6	46.7	53.1
5	62.9	70.5	77.5
10	77.7	86.3	93.6
25	96.4	106.1	114.0
50	110.2	120.9	129.1
100	124.0	135.5	144.1
250	142.2	154.9	164.1

Table 6.2

AES Rainfall Events for Stratford MOE Station 6148105 (1959 to 2002) - for Summer/Fall (May to November)

Return Period (yrs)	Cumulative Total Precipitation (mm)				
	1-Day	2-Day	3-Day	4-Day	5-Day
2	52.7	58.1	64.0	69.3	74.1
5	77.0	82.8	91.3	98.2	103.3
10	93.2	99.2	109.4	117.3	122.7
25	113.6	119.9	132.3	141.5	147.2
50	128.7	135.3	149.2	159.4	165.3
100	143.7	150.5	166.1	177.2	183.3
250	163.6	170.6	188.2	200.7	207.1

Time Distribution

Various types of rainfall distribution curves have been developed for use in hydrograph calculations. The two main categories of rainfall curves comprise statistically derived distributions and the center-peaking distribution or balanced storm. A design storm developed from AES data is sometimes referred to as a ‘balanced’ storm (Chow et al., 1988) because its rainfall curve is symmetrical in appearance and has the most intense portion of the storm located near the center of the storm. This is preceded and followed by periods of much less intense rainfall. This type of rainfall curve is created from the DDF data. Because the hydraulic structures at damsites are to be evaluated under maximum flow, the storm distribution pattern must be selected to give the maximum hydrograph peak flows into the small reservoirs. Based on our past experience with dam safety analyses, the center-loaded (balanced storm), DDF-based hyetographs generate the highest peak flows. Appendix C provides additional background information pertaining to the use of balanced distributions.

Rainfall curves were derived from the DDF data for storms of various durations and return periods. The distributions of incremental rainfall were adjusted to fit a balanced storm pattern in each case. The total depth of rain in the storm was equal to the corresponding depth of rainfall for a given frequency and storm duration. The patterns were made dimensionless by dividing the total rainfall amounts by the cumulative incremental amounts and the total storm durations by the cumulative time amounts. The dimensionless data was required as the input format for the HEC-HMS model for R. T. Orr.

The balanced distributions for the 12-hr, 24-hr and 3-day storms are plotted in Figure 6.2 based on Stratford rainfall data. Figures 6.3 (a) and 6.3 (b) illustrate the 1:50-yr rainfall hyetographs over a 24-hr duration and a 72-hr duration, respectively. Appendix D summarizes the balanced distributions for the 6-hr, 12-hr, 24-hr, 2-day, 3-day and 5-day storms in Tables D1 to D6, respectively.

AES DDF curves describe the variation of point rainfall with time for a given frequency. The curves do not include an adjustment for the variation with space and area. When simulations are undertaken for watersheds larger than 25 km^2, an areal reduction to point rainfall is required in accordance with the Technical Guidelines for Floodplain Management in Ontario (MNR, 1986). Since the size of the Harrington basin drainage area is 12 km^2, it was not necessary to apply an areal reduction factor for watershed rainfall[*].

Rain-On-Snowmelt Event

The DDF data of rain-plus-snowmelt event were obtained from AES, Environment Canada. These data are derived using AES snowmelt models and the amounts are given in equivalent rainfall (water) amounts. The rain-on-snowmelt design events were derived using daily mean temperatures, daily rainfall total and daily depth of fresh snow measurements by ruler. A snow density of 0.1 was assumed to convert snow depth into its water equivalent. Daily snowmelt estimates were calculated using degree-day type equations. Five different snowmelt models can be used; Model 4, which is suitable for southern Ontario and the Upper Thames River basin, was selected.

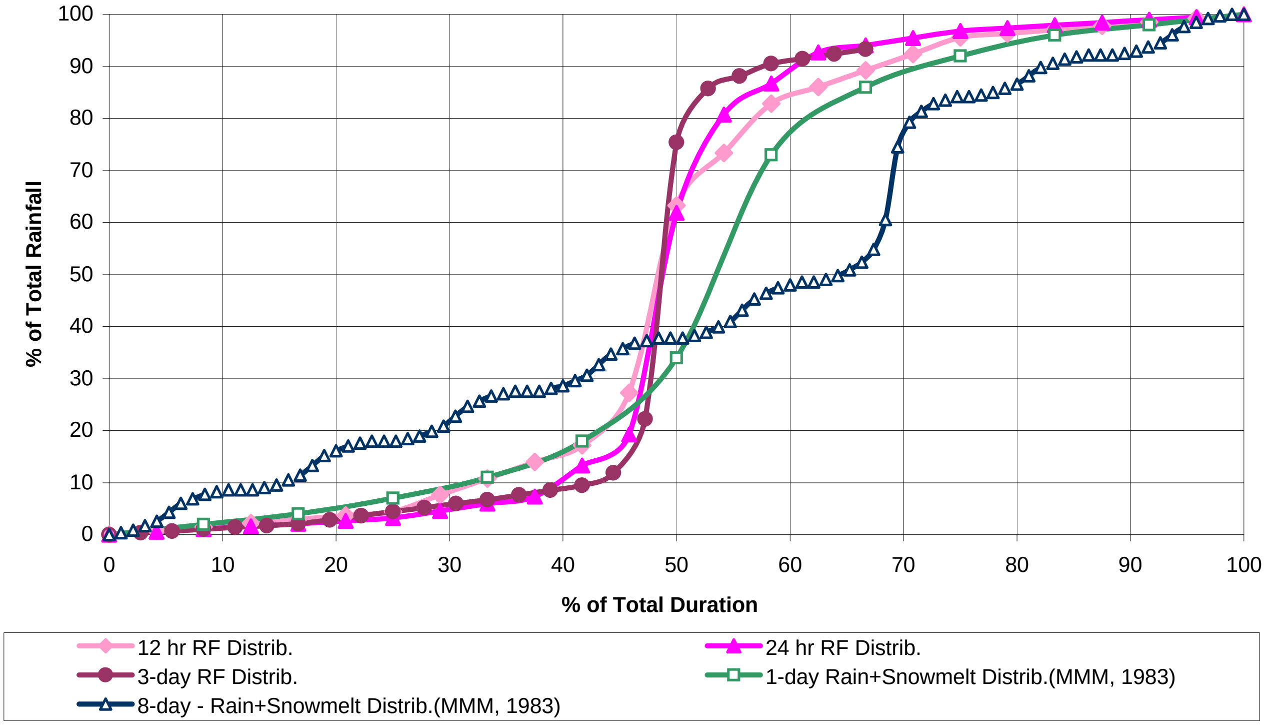
UTRCA has used 8-day rainfall plus snowmelt distributions at four gauge locations in their Visual Otthymo, Version 2 (VO2) modeling for the Upper Thames River basin (MMM, 1983; UTRCA, 1995; M. Wood personal communication, 2003). The rain-on-snowmelt distribution pattern for Gauge A that covers the drainage area of the North Thames River basin below Mitchell was selected and used in the analysis of the Harrington watershed.

The 1-day, 3-day and 8-day rain-plus-snowmelt depths derived from AES data were applied to the above storm distribution patterns for Gauge A. Table D7 in Appendix D summarizes the 1-day, 3-day and 8-day rain-plus-snowmelt distributions. Because these would be longer duration storms (up to 8 days for the Harrington Dam), they are expected to behave differently than the shorter duration storms given in Figure 6.2. The distribution of the rain-on-snowmelt storm extends over an 8-day period with the high intensity portion placed during the sixth day of the storm. The daily hyetograph follows a sinusoidal pattern while the distribution of the peak day follows a winter rainfall distribution (MMM, 1983).

---

[*] Though no areal reduction was necessary, it should be noted that the >25-km^2 threshold is based on MNR guidelines and The World Meteorological Organization (WMO) curves (MNR, 1986; WMO, 1974) parameters not the US National Weather Service curves that are also presented in the MNR guidelines.

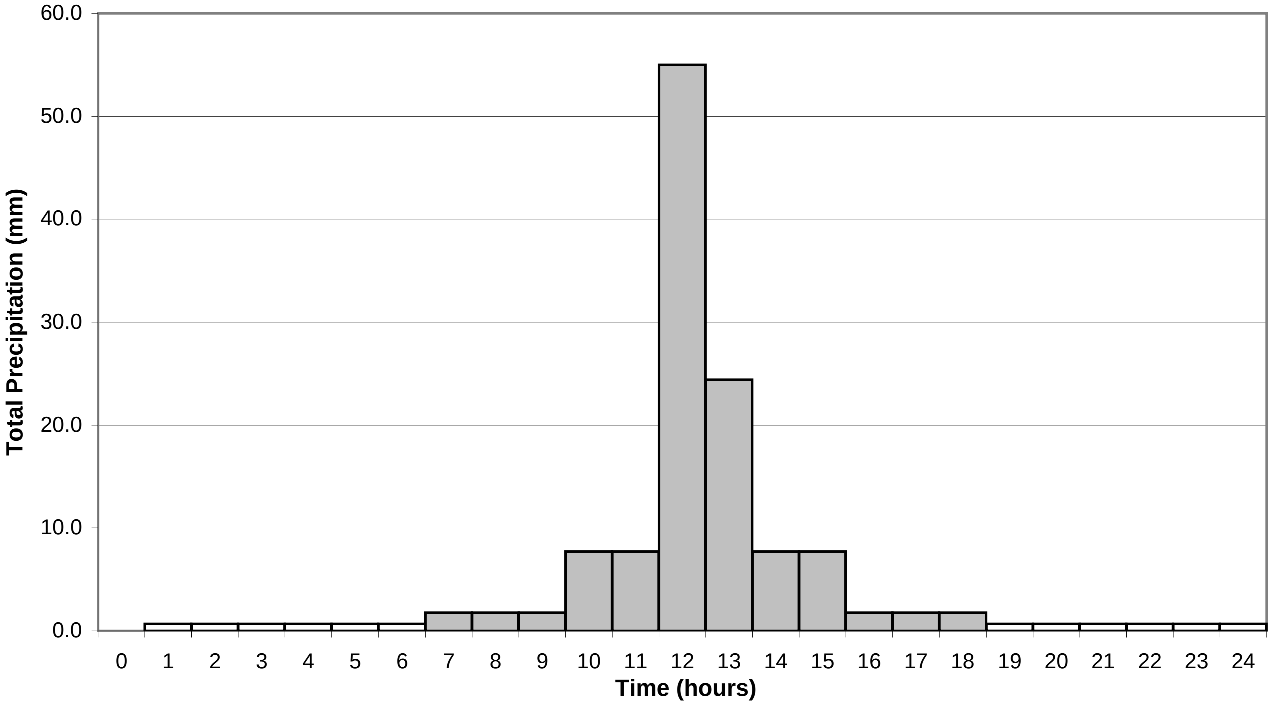
Figure 6.2: Dam Safety Assessment Report - Harrington Dam
Comparison of Rainfall and Snowmelt Plus Rainfall Storm Distributions



Note: Rainfall and Rainfall-Plus-Snowmelt Depths based on the analysis results for Stratford MOE, Meterological Station (6148105); 1959 to 2002 (1 day, 2 days, etc) and 1966 to 2002 (6 hours, 12 hours, 24 hours).

FIGURE 6.2 BACK

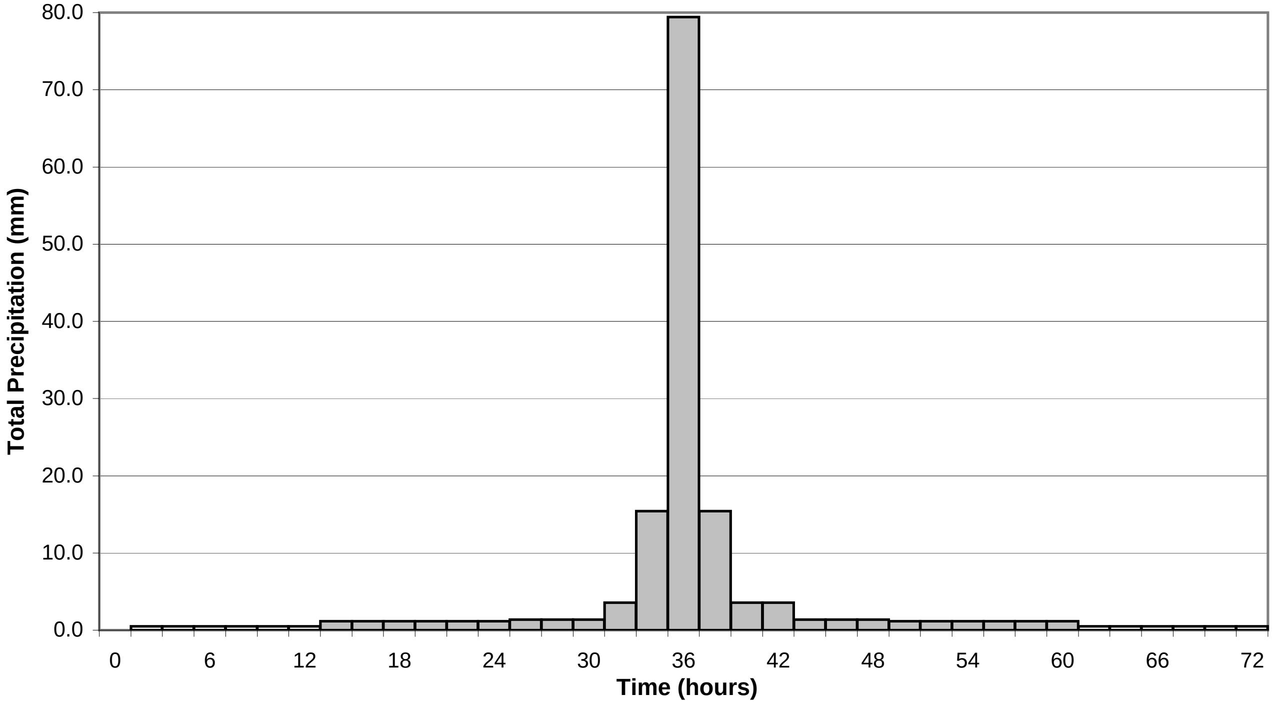
Figure 6.3 (a): Dam Safety Assessment Report - Harrington Dam
50-Yr, 24-Hr Rainfall Distribution



Note: Rainfall hyetograph is based on Stratford RF distribution, as shown in Figure 6.2.

FIGURE 6.3 (A) BACK

Figure 6.3 (b): Dam Safety Assessment Report - Harrington Dam
50-Yr, 3-Day Rainfall Distribution



Note: Rainfall hyetograph is based on Stratford RF distribution, as shown in Figure 6.2.

FIGURE 6.3 (B) – BACK

The rainfall-plus-snowmelt distributions for 1 day and 8 days are denoted in Figure 6.2. Figures 6.4 (a) and 6.4 (b) illustrate the 1:50-yr rainfall-plus-snowmelt hyetographs for a 1-day and 8-day duration, respectively. The rain-plus-snowmelt event DDF data for Stratford is summarized in Table 6.3.

Table 6.3

AES Rainfall and Snowmelt Events for Stratford MOE Station 6148105 (1959 to 2002)

Return Period (yrs)	Total Precipitation (Rainfall and Snowmelt) (mm)							
	1-Day	2-Day	3-Day	4-Day	5-Day	6-Day	7-Day	8-Day
2	31.2	44.1	53.9	62.3	69.6	77.2	83.2	88.6
5	41.2	55.7	68.8	79.0	88.9	99.5	108.9	117.0
10	47.8	63.4	78.7	90.1	101.7	114.3	125.9	135.9
25	56.1	73.2	91.1	104.1	117.8	133.0	147.5	159.7
50	62.3	80.4	100.3	114.5	129.8	146.8	163.4	177.3
100	68.4	87.6	109.5	124.8	141.7	160.6	179.3	194.8
250	76.6	97.1	121.4	138.2	157.2	178.8	200.0	218.0

6.1.4.1 Regional Storm

The regional storm for the study area is the Hurricane Hazel storm based on the Floodplain Management Guidelines (MNR, 1986).

This 12-hr design storm (37 to 48 hours) was developed from rainfall gauge data located at Snelgrove just north of Brampton, Ontario. It is the largest recorded rainfall for any location within Ontario.

During a 48-hr period on October 15 and 16, 1954, the remnants of Hurricane Hazel dumped over 285 mm of rain in the Toronto area. The heaviest rains fell on the watershed during the final 12 hours of the storm when 212 mm of rain was recorded on saturated ground surface. Towards the end of the storm, 53 mm of rain fell in one hour while 91 mm was recorded during a 2-hr period.

6.1.4.2 Event Modeling

The HEC-HMS model was used to evaluate the Harrington basin discharge behavior under a wide range of precipitation events, with return periods of 2, 5, 10, 25, 50, 100 and 250 years. The Hurricane Hazel storm (with appropriate areal reduction factors) was also modeled. The dam and outlet structure are used directly to regulate a relatively small storage lake. This makes the volume component of a storm event more important, in comparison to the peak flow generated by the event. It is possible that a precipitation event, with a given return period, may yield different flood flow conditions with the same probability of occurrence depending on the reservoir starting water level and discharge facilities setting, the storm durations, the temporal patterns and intensities of the storms.

6.2 Hydrological/Hydraulic Assessment

6.2.1 Rainfall-Runoff Modeling

6.2.1.1 General

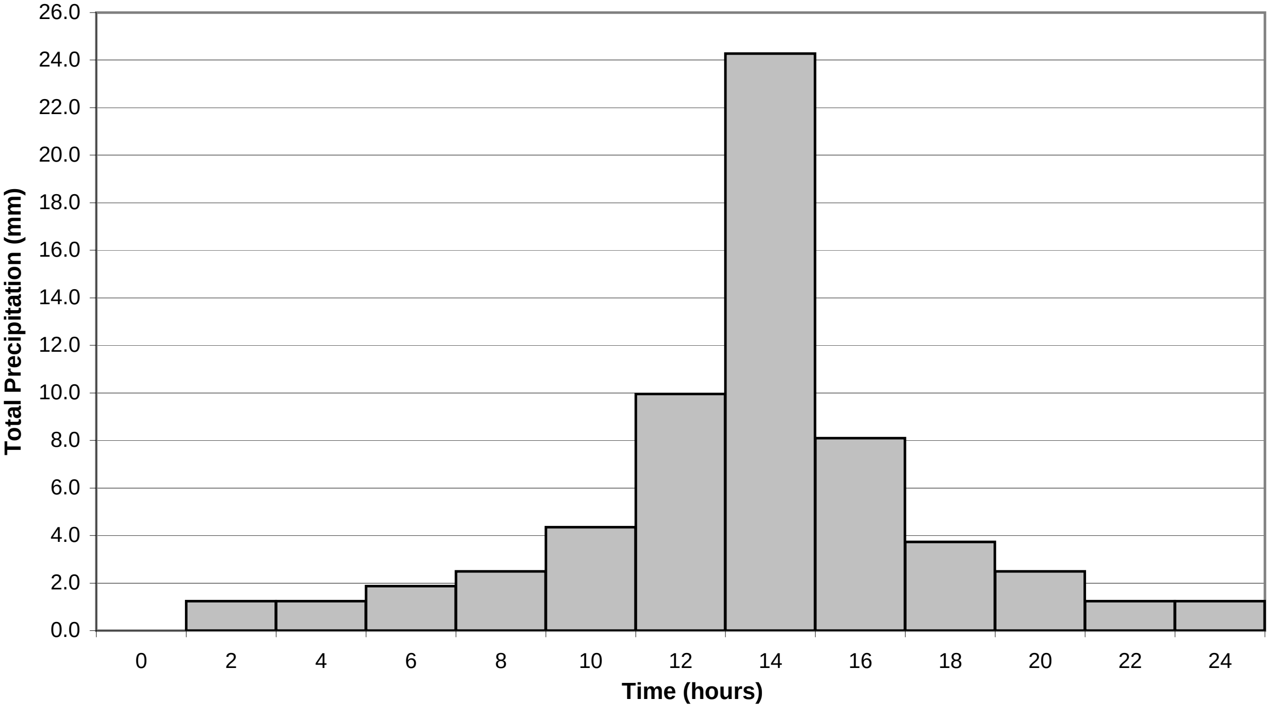
Hydrologic analysis of potential flood events at the damsite included the assessment of regional flood frequency characteristics along with deterministic rainfall-runoff modeling using the HEC-HMS simulation package, as described in Section 6.1.

6.2.1.2 Model Setup

(a) Basin Physiographic and Hydrologic Characteristics

Input to the HEC-HMS model as described previously, consisted of physiographic characteristics for the damsite basin and the storm distribution curve. Physiographic parameters were determined from topographic and soil maps and UTRCA data files. These parameters consisted of catchment area, drainage characteristics, lake area and estimates of live storage and main watercourse slope and length. The storm rainfall data comprised historical storms with their temporal distributions covering the summer/fall seasons. These were obtained from AES.

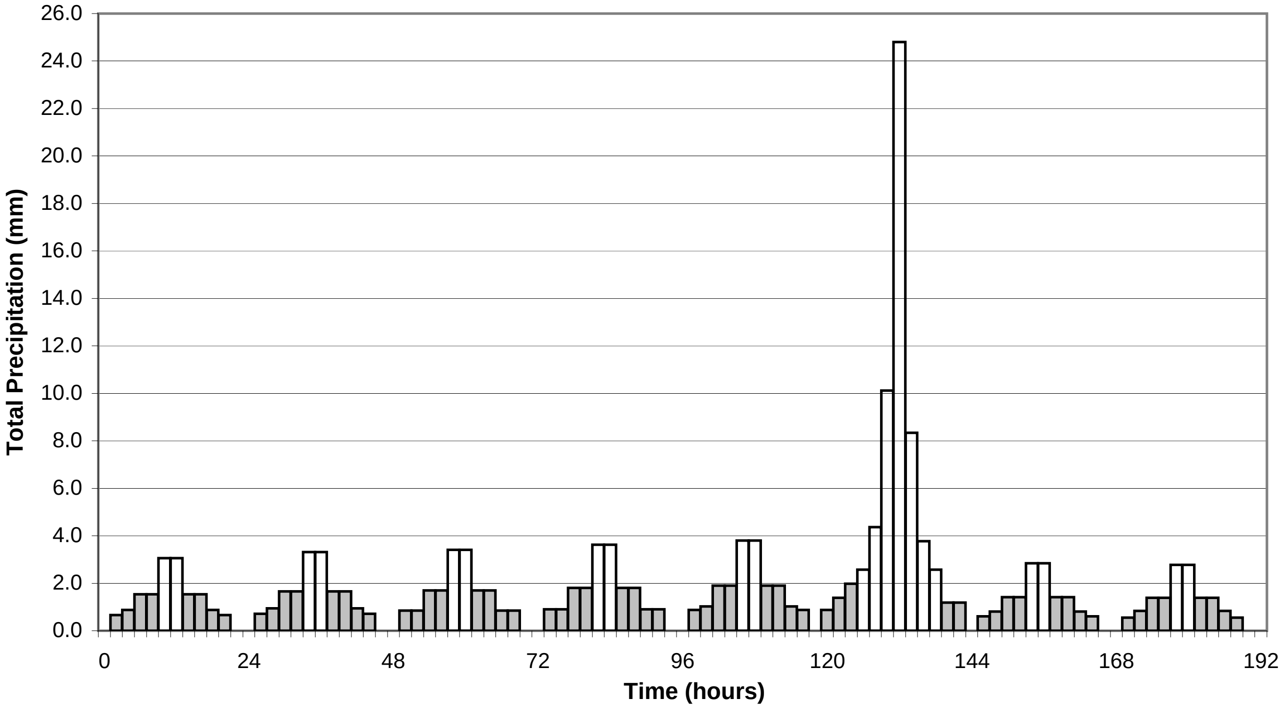
Figure 6.4 (a): Dam Safety Assessment Report - Harrington Dam
50-Yr, 1-Day Rainfall Plus Snowmelt Distribution



Note: Rainfall and snowmelt hyetograph is based on MMM 1983 Study, as shown in Figure 6.2.

FIGURE 6.4 (A) BACK

Figure 6.4 (b): Dam Safety Assessment Report - Harrington Dam
50-Yr, 8-Day Rainfall Plus Snowmelt Distribution



Note: Rainfall and snowmelt hyetograph is based on MMM 1983 Study, as shown in Figure 6.2.

FIGURE 6.4 (B) – BACK

(b) Calibration of HEC-HMS Model

Successful application of the HEC-HMS model depends on the various derived parameters and relationships specific to the basin or river system. Calibration is ideally performed on the study river systems to optimize these parameters and match the model results with recorded data. Since no WSC streamflow stations or UTRCA meteorological monitoring stations were located directly on Harrington Creek, a representative-gauged, unregulated river which had similar runoff characteristics to the Harrington drainage basin was chosen for calibrating the model. The river basin that met these criteria was the Waubuno Creek basin (UTRCA Meteorological Monitoring System station, covering the period 1984 to present). Waubuno Creek basin is between the city of London and the community of Thamesford, and is located adjacent to and south of the study basin. This gauging station was also operated by WSC over the period 1966 to 1999 as Station No. 02GD020.

The calibration procedure in HEC-HMS involves the automatic adjustment of parameters, which affect the transformation of rainfall to runoff in a river catchment in order to achieve a best fit between the simulated flows and the observed discharge in the river. The user may choose to optimize the fit between computed and gauge hydrographs by manipulating any combination of parameters within specified ranges such as the AMC of the basins (the CN value), basin lag time, and initial losses in order to reduce the differences between the simulated and observed flows to acceptable limits. Hourly rainfall and flow data are available for the Waubuno Creek station for a period of record of 20 years, providing a range of rainfall events and catchment’s responses, which permitted accurate parameter optimization.

For application of the HEC-HMS model to river catchments where storage is present at the damsites, considerable attenuation of the inflow hydrograph can occur. This will result in a reduction of the magnitude of the outflow peak discharge in comparison to the peak of the inflow flood. Therefore, good agreement with storm event runoff volume must be considered in the calibration exercise, as well as reasonable correspondence with peak discharge. IDFs, by convention, are associated with a peak flood magnitude. For application to structures associated with little or no upstream storage, peak inflow is the key parameter used to assess their conveyance capacity. This latter condition applies to the Waubuno watershed in this calibration. Therefore, available hourly rainfall and hourly recorded flows were used for the calibration exercise.

Appropriate storm events were selected from the historical rainfall and streamflow database using the following selection criteria.

- The storm event should be a 24-hr or 1-day event occurring in the summer/fall period of the year, such that transformation of rainfall is accomplished with no snowfall or snowmelt present.
- The storm event should be preceded by at least one week of no rainfall such that average AMCs are present in the drainage basin.

Candidate storm events were selected from a review of the joint databases of hourly rainfall totals and hourly average discharge at Waubuno Creek near Dorchester.

A total of three potential storm events were identified for the study site, and these are presented in Table 6.4. These included one fall and two summer events of which two occurred following relatively dry periods, corresponding to an AMC between I and II. The third event occurred following a relatively wet period, corresponding to an AMC between II and III. It proved very difficult to select individual storm events that entirely met the selection criteria given above.

The storm event that occurred on August 27 and 28, 1992 was selected as a summer event. This storm event took place following antecedent rainfall and corresponded to the ideal 24-hr duration target event. This event was selected for calibration at Waubuno Creek because of the strong observed catchment response to the resulting runoff from the storm.

Another summer event, which occurred on June 11, 2000, was also selected on the basis of strong observed catchment response, although it was under the 24-hr duration criterion. This event took place following a relatively dry period without antecedent rainfall.

Table 6.4

Storm Event Candidate Data for HEC-HMS Calibration

Date	Hour	Waubuno Creek		Date	Hour	Waubuno Creek		Date	Hour	Waubuno Creek	
		Rainfall (mm)	Flows (m^3/s)			Rainfall (mm)	Flows (m^3/s)			Rainfall (mm)	Flows (m^3/s)
11-Jun-00	1	0.00	0.4	28-Aug-92	1	0.25	0.8	29-Sep-86	1	0.00	1.9
	2	0.00	0.4		2	0.25	0.8		2	0.00	1.9
	3	0.00	0.4		3	2.00	0.8		3	0.00	1.9
	4	0.00	0.4		4	0.75	0.9		4	0.00	1.8
	5	0.00	0.4		5	0.00	1.0		5	6.50	1.8
	6	0.00	0.4		6	1.75	1.0		6	7.50	1.9
	7	0.00	0.4		7	3.00	1.0		7	0.00	2.5
	8	0.00	0.4		8	16.50	1.3		8	1.75	2.5
	9	0.00	0.4		9	24.75	3.7		9	5.75	2.5
	10	0.00	0.4		10	1.25	8.0		10	0.00	2.7
	11	0.25	0.4		11	0.50	8.2		11	2.00	3.1
	12	23.75	0.5		12	0.25	6.6		12	0.25	3.3
	13	10.00	0.8		13	1.25	6.0		13	23.50	4.2
	14	0.00	1.2		14	0.25	6.8		14	1.00	5.7
	15	18.50	1.7		15	0.25	8.7		15	1.50	7.1
	16	2.00	2.1		16	0.00	11.2		16	0.25	8.5
	17	0.50	1.9		17	0.00	13.0		17	4.00	9.3
	18	6.00	1.9		18	0.25	14.2		18	1.00	10.0
	19	19.25	2.9		19	0.00	15.3		19	0.00	10.7
	20	6.75	6.5		20	0.00	16.3		20	30.50	11.4
	21	22.00	18.8		21	0.00	16.9		21	5.50	13.2
	22	0.00	18.3		22	0.00	17.7		22	0.00	15.1
	23	2.00	15.7		23	0.00	18.1		23	0.00	16.5
	24	0.75	16.4		24	0.50	18.3		24	0.00	17.4
12-Jun-00	25	0.00	17.7	29-Aug-92	25	0.25	18.4	30-Sep-86	25	0.00	18.0
	26	0.00	19.3		26	0.00	18.6		26	3.00	18.4
	27	0.00	21.4		27	0.00	18.5		27	6.50	19.1
	28	0.00	23.3		28	0.00	18.6		28	0.25	19.9
	29	0.00	25.1		29	0.25	18.7		29	0.25	20.3
	30	0.00	26.7		30	0.00	18.7		30	0.25	20.5
	31	0.00	28.7		31	0.00	18.6		31	0.00	20.5
	32	0.00	31.2		32	0.25	18.3		32	0.00	20.5
	33	0.00	33.2		33	0.00	17.7		33	0.25	20.6
	34	0.00	34.6		34	0.25	17.0		34	0.00	20.7
	35	0.00	35.1		35	0.00	15.9		35	1.75	20.8
	36	0.00	33.9		36	0.00	14.9		36	0.50	21.3
	37	0.00	33.3		37	0.00	13.9		37	3.75	22.1
	38	0.00	32.3		38	0.25	12.7		38	2.25	23.3
	39	0.00	31.2		39	0.00	11.7		39	1.25	24.6
	40	0.00	30.1		40	0.00	10.8		40	0.50	25.4
	41	0.00	28.7		41	0.00	10.1		41	0.75	25.8
	42	0.00	27.0		42	0.00	9.3		42	2.75	25.8
	43	0.00	24.9		43	0.00	8.8		43	1.25	23.4
	44	5.25	22.7		44	0.00	8.2		44	0.25	22.4
	45	1.00	20.1		45	0.00	7.9		45	0.00	21.5
	46	0.00	17.3		46	0.00	7.5		46	0.75	20.9
	47	0.00	15.0		47	0.00	7.2		47	0.25	20.5
	48	0.25	13.7		48	0.00	6.8		48	0.00	20.0
								1-Oct-86	49	0.00	19.8
									50	0.00	19.5
									51	0.00	19.2
									52	0.00	18.8
									53	0.25	18.0
									54	0.50	17.2
									55	0.00	16.4
									56	0.00	15.5
									57	0.00	14.7
									58	0.00	14.1
									59	0.00	13.5
									60	0.00	12.8
									61	0.00	12.2
									62	0.00	11.6
									63	0.00	11.0
									64	0.00	10.4
									65	0.25	9.8
									66	0.00	9.3
									67	0.00	8.8
									68	0.00	8.3
									69	0.00	8.0
									70	0.50	7.6
									71	0.00	7.3
									72	0.50	7.0

Note:
Source data form UTRCA's HEC-DSS database.

The selected fall storm, which occurred on September 29 and 30, 1986, consisted of a large 24-hr rainfall event followed by a well-developed runoff hydrograph at the Waubuno Creek site.

The above-selected storm events formed the basis of the calibration of the HEC-HMS model and concentrated on obtaining an acceptable agreement between the simulated and observed storm event volume and the average hourly recorded flows.

The HEC-HMS model calibration required the following key parameters.

- The contributing river basin drainage area. Verification of the WSC drainage area for Waubuno Creek of 108 km^2 was performed by digitizing the delineated drainage area off 1:50 000-scale topographic mapping.
- The basin response to rainfall, which is referred to as basin lag. This is defined as the elapsed time from the center of mass of the rainfall event to the peak outflow of the runoff hydrograph. This is typically a function of basin area and slope, and can be calculated from a number of empirical equations or determined from storm event analysis. Basin lag for the selected calibration basin was determined from the storm event analysis as discussed in the section below, Waubuno Creek Calibration Results.
- An initial estimate of potential runoff potential of the catchment based on the relationship between CN value and hydrologic soil-cover complexes and soil group designation. This was estimated using the Soil Map of Middlesex County, Ontario (UTRCA). The CN value for AMC II condition was estimated to be 77 for this basin.
- Base flow amounts that reflect the antecedent flow conditions in the river and watershed, prior to a response to the storm event.

(c) Waubuno Creek Calibration Results

Results of the Waubuno Creek basin calibration are presented as follows.

The Waubuno Creek watershed was modeled as a single basin. Catchment parameters are summarized in Table 6.5. The optimization utility in HEC-HMS was used to fine-tune the estimated CN values, initial losses, and the computed basin lag to achieve the best agreement between observed and calculated flood event hydrographs. Initially, basin lag was established using an empirical relationship. However, empirical formulae such as Kirpich's equation severely underestimated basin lag, as observed in the recorded hydrographs.

Table 6.5

Summary of HEC-HMS Input Data and Calibrated Parameters

Basin Name	Input Data							Calibration						
	Drainage Area	Basin Lag	Stream Length	Average Slope	Base Flow	Event Year	Total Rainfall	Storm Event	Curve Number (CN)	AMC Conditions	Peak Flow		Discharge Volume	
											Observed	HEC-HMS	Observed	HEC-HMS
	(km^2)	(hrs)	(km)	(m/m)	(m^3/s)		(mm)				(m^3/s)	(m^3/s)	(mm)	(mm)
Waubuno Creek near Dorchester	108 [*]	17 [**]	31.0	0.0043	0.38	2000	112	Summer	60.5	I	35.1	37.5	27.1	27.8
					0.60	1992	55	Summer	81.5	II	18.7	20.7	22.6	19.0
					1.80	1986	118	Fall	60.5	I	25.8	27.6	32.4	32.6

---

[*] Drainage area from WSC.

[**] Basin lag was calibrated from observed basin rainfall and discharge.

The June 2000 event calibration yielded a CN value of 60.5, a basin lag of 17 hours, and an initial loss of 25 mm. The comparison between observed flow peak and event volume is given in Table 6.5. These results showed good agreement; the antecedent flows in the river prior to this event represent normal summer flow conditions and antecedent rainfall was low, suggesting a low AMC condition between I and II.

The August 1992 storm event occurred during a wetter than usual period with antecedent flows in Waubuno Creek well above the long-term average flow for this time of year, and was used for verification of the basin lag parameter. The calibration yielded a CN value of 81.5 and initial losses of 30 mm. This event yielded good agreement between simulated and recorded flows, with the basin lag of 17 hours obtained from the calibration of the June 2000 event, as shown in Table 6.5.

The fall event of September 1986 followed a very dry month of August. Calibration using the basin lag of 17 hours yielded a CN value of 60.5 and an initial loss of 30 mm, consistent with antecedent soil moisture conditions.

Results of the calibration are presented in Figures 6.5, 6.6 and 6.7. The HEC-HMS computed hourly outflow has been plotted beside the recorded flow for the storm events to provide a graphical comparison.

Generally, the storm volumes agreed quite well. There were some variations between the hourly average flows from the computed output hydrographs and the recorded flows. The computed peak discharges of the three storms used in the calibrations were within 7% and 10.4% of the recorded peaks while the computed runoff volumes were within 2.6% of the measured runoff volumes. In one event, this variation was about 15% for a low value input rainfall hyetograph. The CN value of 77 for AMC II conditions is within the expected values based on the soil and land-use cover in the area. It is, therefore, concluded that the calibration of the Waubuno Creek catchment falls within acceptable limits and can be appropriately applied to the Harrington basin.

(d) Storm Event Precipitation

Summer/fall storm rainfall amounts corresponding to the Stratford station for the shorter durations (6 hours, 12 hours and 24 hours) and the longer durations (2 days, 3 days and 5 days) were used in the HEC-HMS model. Summer/fall rainfall storm depths for the required frequencies are summarized in Tables 6.1 and 6.2. Spring snowmelt-plus-rainfall events for 1-day, 3-day and 8-day durations at Stratford were also used in the HEC-HMS model and are summarized in Table 6.3, over the required range of frequencies. Each precipitation event was assumed to apply individually and entirely on the study basin, and no area reduction factor was applied to the point rainfall amounts.

For the summer/fall storm event analysis, average AMC II CN conditions were adopted. Spring snowmelt-plus-rainfall events were initially evaluated under AMC III CN conditions to account for ground conditions being partially or completely frozen.

Figure 6.5: Dam Safety Assessment Report - Harrington Dam
HEC-HMS Model Event Calibration Waubuno Creek
Period 11-June-2000 to 13-June-2000

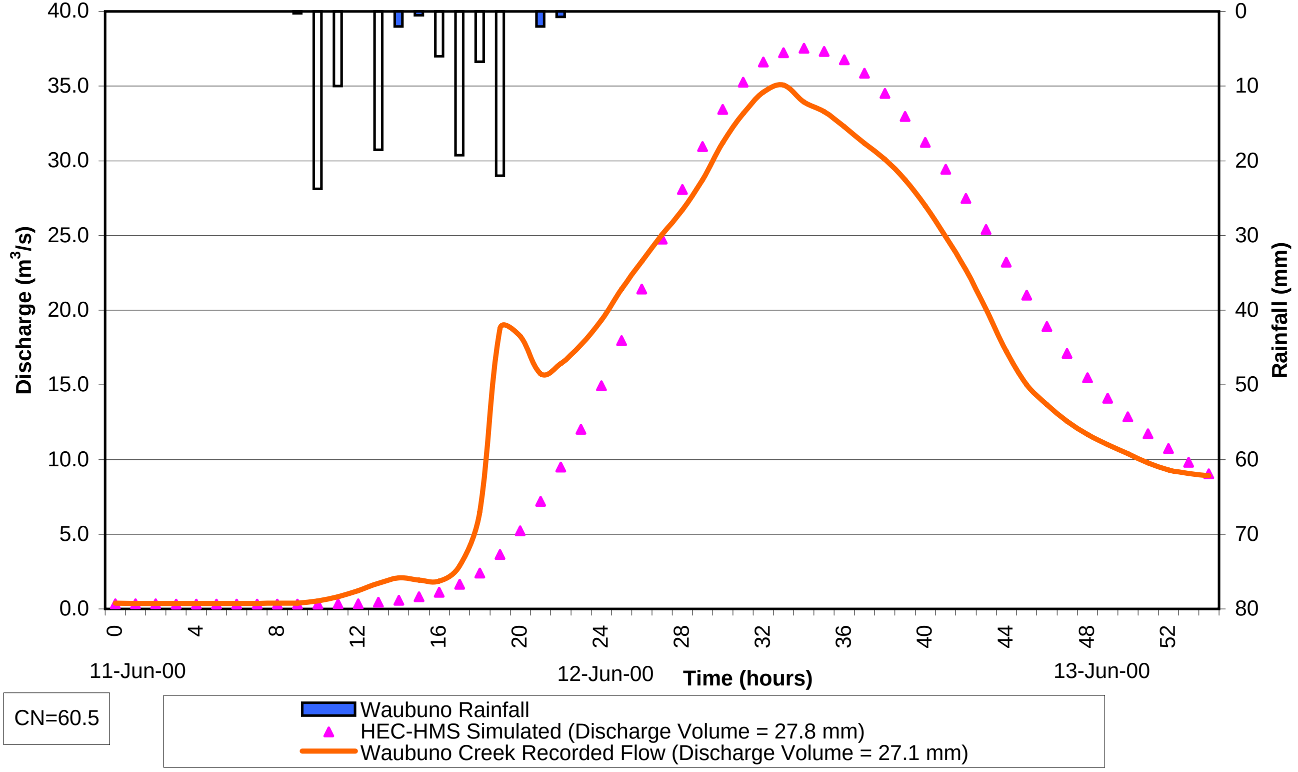


FIGURE 6.5 – BACK

Figure 6.6: Dam Safety Assessment Report - Harrington Dam
HEC-HMS Model Event Calibration Waubuno Creek
Period 28-August-1992 to 30-August-1992

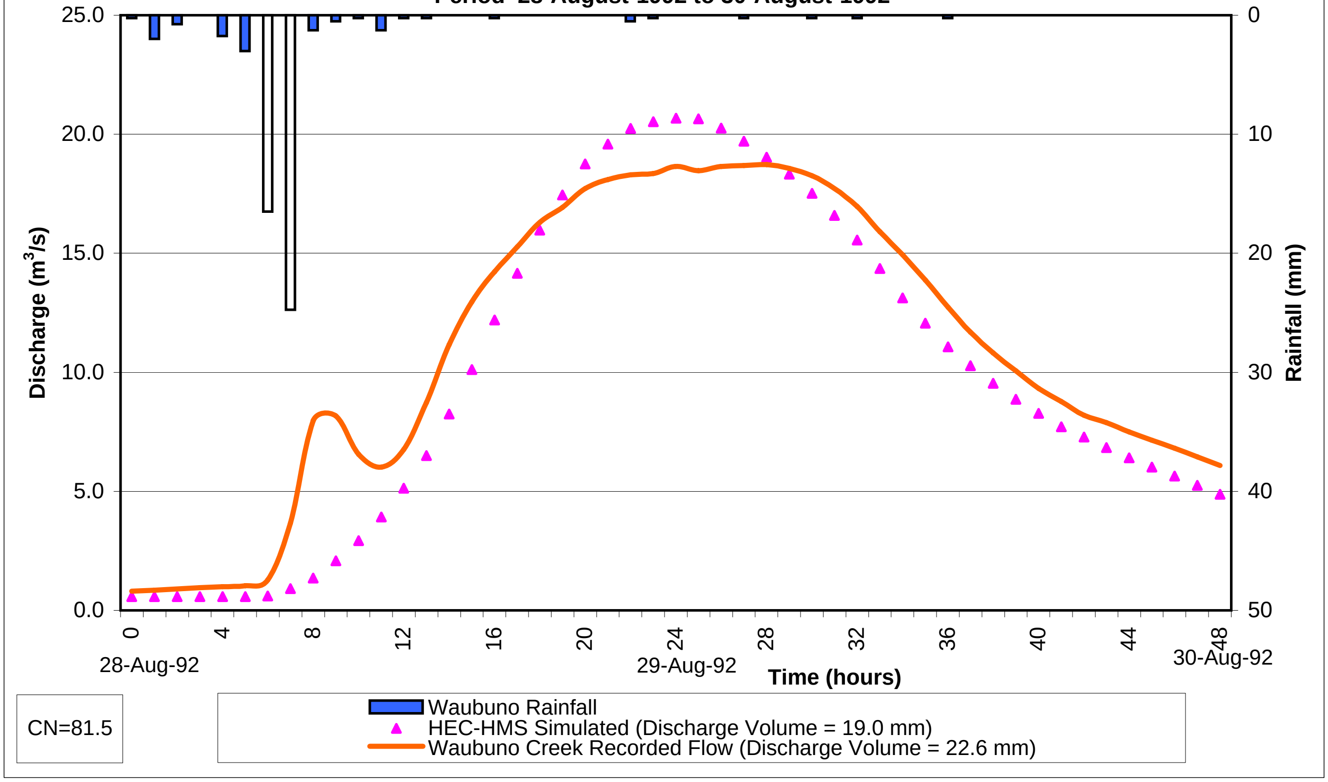


FIGURE 6.6 – BACK

Figure 6.7: Dam Safety Assessment Report - Harrington Dam
HEC-HMS Model Event Calibration Waubuno Creek
Period 29-September-1986 to 01-October-1986

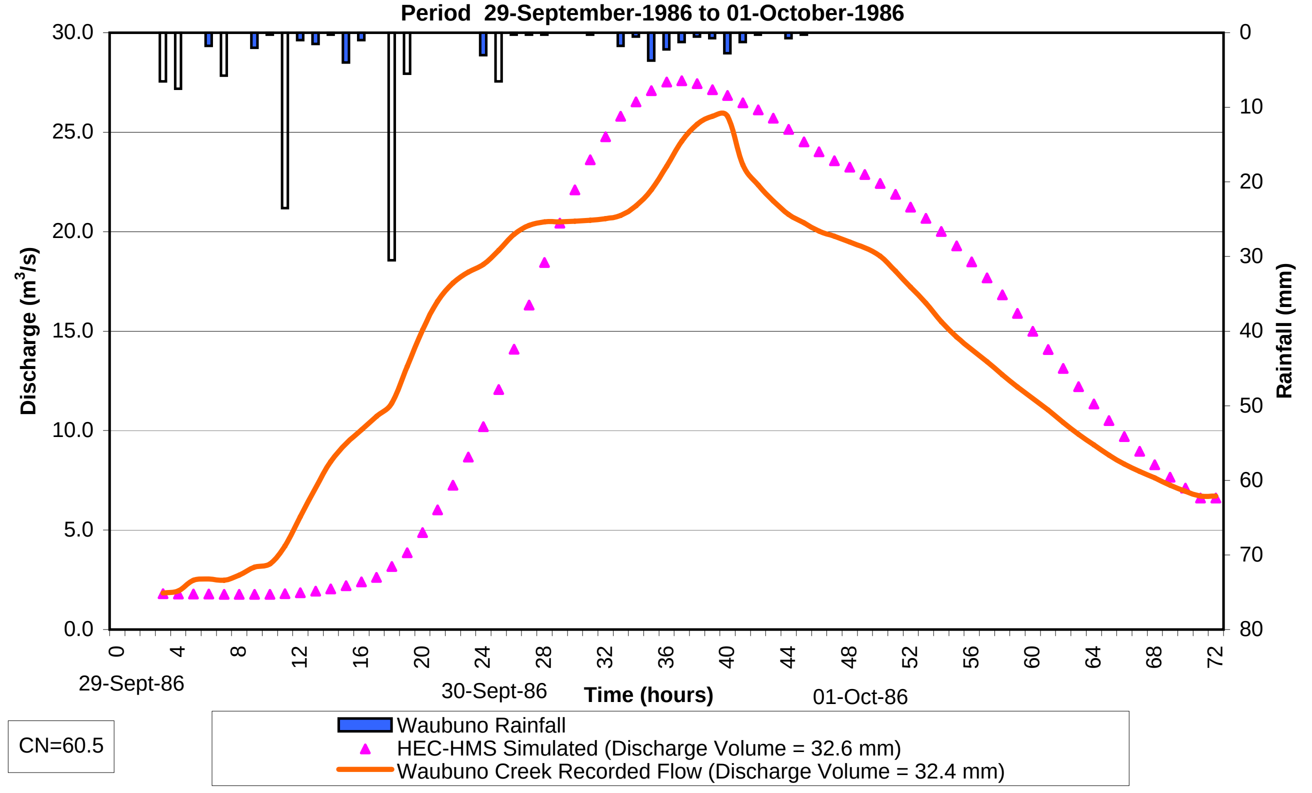


FIGURE 6.7 - BACK

(e) Regional Flood (Hurricane Hazel)

Although the IHP of the Harrington Dam is classified as VERY LOW with the corresponding 50-yr flood assigned as the IDF, the regional flood was routed through the watershed as required in the terms of reference of this study. The regional flood designation for the study dam, which lies within the Regional Storm - Zone 1 is the Hurricane Hazel storm. This storm is a 12-hr summer precipitation event with temporal distribution documented in the MNR guidelines. Areal reduction of the total event precipitation, which is dependent on the size of the study drainage basin, was derived by applying either the circular area-watershed length method or the elliptical area technique. The drainage area of Harrington Dam is smaller than 25 km^2; therefore, no areal reduction was required.

AMC III CN conditions were applied to account for ground conditions being saturated at the beginning of the regional storm.

(f) Site Datum

UTRCA provided Acres with a drawing of Harrington Dam, which was part of the Dam Hazard Identification studies in July 2001. The elevations given on this drawing are to a local datum. A field survey was subsequently performed by Acres in June 2003, in which all elevations were referred to Canadian Geodetic Datum (CGD). The survey covered the downstream discharge channel environment to Road 96 and all dwelling foundations located downstream of the damsite.

(g) Model Setup and Initial Conditions – Study Basin

The HEC-HMS model was set up for Harrington Dam to allow transformation of storm precipitation into runoff. The watershed was modeled as a single basin. The contributing drainage area, along with basin parameters pertaining to watercourse length and slope, were determined from both 1:50 000-scale topographical maps and 1:10 000 OBMs of the catchment. These values are summarized in Table 6.6.

Table 6.6

Summary of HEC-HMS Input Data for Harrington Dam

Watershed	Local Drainage Area (km^2)	Total Drainage Area (km^2)	Pond Area (km^2)	Basin Lag[*] (hrs)	Curve Numbers (CN)		Stream Length (km)	Average Slope (m/m)	Storm Event	Base Flow (m^3/s)
					II	III[**]				
Harrington Creek	12.0	12.0	0.026	3.7	70	85	5.4	0.0061	Spring Fall	0.36 0.03

---

[*] Basin lag was computed based on the following formula after Watt/Chow. Reference: Canadian Flood Hydrology, 1995.
Basin lag = C1 $[L/(S)^{0.5}]^{C2}$ where,

L is the length of the flow path from basin divide to the outlet in metres

S is the average channel slope in metres per metre

C1 = 0.000559, C2 = 0.790; C1 and C2 are calibrated constants to yield basin lag in hours.

[**] Reference: National Engineering Handbook. NEH 4 Hydrology. Soil Conservation Service. March 1985.

Basin lag was computed for the study basin based on the adjusted Watt/Chow empirical relationship and adopted values are given in Table 6.6. CNs were assigned to the basin based on the HEC-HMS calibration results and corresponded to the antecedent conditions specified for the storm event being analyzed. Assigned values are summarized in Table 6.6. Weighted CN values were determined based on an assessment of hydrologic soil-cover complexes and soil group designation. These were estimated from the Soil Map of Oxford County, Ontario and mapping units' properties supplied by UTRCA.

Initial base flow in the study basin was set in accordance with average runoff conditions for the time of year during which the storm event was most likely to occur. For the spring storm events, which typically occur in early April, long-term average monthly discharge for March was adopted. The averaged discharge of August and September was used for the fall storm events. For the study basin, the average flow value for the Waubuno Creek gauged catchment was reduced to a specific runoff (cubic metres per second per square kilometres), then applied to the study basin. Adopted base flow values for Harrington are summarized in Table 6.6.

The elevation-volume relationship for the Harrington storage pond was derived from field survey data completed by Acres in June 2003 and used in the HEC-HMS modeling. The discharge capacity of the dam was input to the HEC-HMS model as an elevation-discharge rating curve reflecting the current stop log settings; two stop logs in each of the three discharge bays. At present, the stop logs are not manipulated at the Harrington Dam; therefore, the same log settings were adopted for both spring and summer/fall storm events. Any additional spillway capacity at the dam, such as the embankment sections, was factored into the rating curves. The low-level outlet valve on the left-hand side of the dam was assumed to be inoperable during storm simulations and was, therefore, not included in the rating curve. A description of the discharge facilities and storage relationship for the site is given in Section 6.2.2. Initial water levels that corresponded to the base flow discharges for both the spring and summer/fall events are given in Table 6.7.

Table 6.7

Initial Water Levels for HEC-HMS Analysis

Dam Name	Name of Pond	Spring		Fall	
		Level (m)	Stop Log Settings[*]	Level (m)	Stop Log Settings[*]
Harrington	Harrington	330.09	all logs in	330.01	all logs in

Note: All elevations referred to Canadian Geodetic Datum (CGD).

---

[*] Top of stop logs, el 329.99 m.

6.2.1.3 Model Flood Results

(a) Storm Event Flood Results

The results of the HEC-HMS simulations are presented in Tables 6.8 (a) and 6.8 (b). The storm rainfall return period values, the corresponding total precipitation and the peak inflows and outflows resulting from the rainfall transformation are summarized in these tables. The resulting peak water levels at the damsite, as the routed

Table 6.8 (a)

HEC-HMS Simulation Results for Harrington Creek Subbasin

Event Duration	Event Timing	Storm Return Period (yrs)	Harrington Dam			
			Total Precipitation (mm)	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
1-Day (Rain-on-Snowmelt- AMC III)	Spring	2	31.2	3.4	3.3	330.41
		5	41.2	6.0	5.8	330.61
		10	47.8	7.9	7.8	330.69
		25	56.1	10.6	10.5	330.78
		50	62.3	12.6	12.5	330.85
		100	68.4	14.7	14.6	330.90
		250	76.6	17.6	17.5	330.96
3-Day (Rain-on-Snowmelt- AMC III)	Spring	2	53.9	8.1	8.0	330.70
		5	68.8	11.7	11.6	330.82
		10	78.7	14.1	14.0	330.88
		25	91.1	17.2	17.1	330.95
		50	100.3	19.5	19.4	331.00
		100	109.5	21.8	21.7	331.04
		250	121.4	24.7	24.7	331.07
8-Day (Rain-on-Snowmelt- AMC III)	Spring	2	88.6	9.4	9.3	330.75
		5	117.0	13.4	13.3	330.86
		10	135.9	16.1	16.0	330.93
		25	159.7	19.4	19.3	331.00
		50	177.3	21.9	21.8	331.04
		100	194.8	24.3	24.3	331.07
		250	218.0	27.5	27.5	331.10

Notes:
All elevations referred to CGD.
Top of spillway bridge deck = 330.525 m.
Mean crest elevation of left embankment section = 331.0 m.
Mean crest elevation of right embankment section = 330.5 m.

Table 6.8 (b)

HEC-HMS Simulation Results for Harrington Creek Subbasin

Event Duration	Event Timing	Storm Return Period (yrs)	Harrington Dam			
			Total Precipitation (mm)	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
6-Hr Rainfall (AMC II)	Summer	2	40.6	1.7	1.5	330.24
		5	62.9	6.7	6.4	330.63
		10	77.7	11.2	11.1	330.80
		25	96.4	18.0	17.9	330.97
		50	110.2	23.5	23.4	331.06
		100	124.0	29.4	29.3	331.12
		250	142.2	37.5	37.5	331.19
12-Hr Rainfall (AMC II)	Summer	2	46.7	2.4	2.3	330.32
		5	70.5	8.0	7.8	330.69
		10	86.3	12.8	12.7	330.85
		25	106.1	19.8	19.7	331.01
		50	120.9	25.6	25.5	331.08
		100	135.5	31.6	31.5	331.14
		250	154.9	39.9	39.9	331.21
24-Hr Rainfall (AMC II)	Summer	2	53.1	3.3	3.2	330.40
		5	77.5	9.3	9.1	330.74
		10	93.6	14.2	14.1	330.88
		25	114.0	21.3	21.2	331.03
		50	129.1	27.0	26.9	331.09
		100	144.1	32.9	32.9	331.15
		250	164.1	41.2	41.1	331.22
(AMC III)		Hazel	285.0	76.7	76.7	331.45
2-Day Rainfall (AMC II)	Summer (May to November)	2	58.1	4.1	3.8	330.45
		5	82.8	10.3	10.1	330.77
		10	99.2	15.3	15.2	330.91
		25	119.9	22.4	22.3	331.05
		50	135.3	28.2	28.1	331.10
		100	150.5	34.1	34.0	331.16
		250	170.6	42.2	42.2	331.23
3-Day Rainfall (AMC II)	Summer (May to November)	2	64.0	4.7	4.5	330.50
		5	91.3	11.6	11.4	330.81
		10	109.4	17.1	17.0	330.95
		25	132.3	24.8	24.8	331.07
		50	149.2	30.9	30.9	331.13
		100	166.1	37.3	37.2	331.19
		250	188.2	45.8	45.8	331.25
5-Day Rainfall (AMC II)	Summer (May to November)	2	74.1	5.8	5.4	330.59
		5	103.3	12.3	12.1	330.83
		10	122.7	17.2	17.1	330.95
		25	147.2	23.9	23.9	331.06
		50	165.3	29.1	29.1	331.12
		100	183.3	34.5	34.4	331.17
		250	207.1	41.7	41.7	331.22

Notes:
All elevations referred to CGD.
Top of spillway bridge deck = 330.525 m.
Mean crest elevation of left embankment section = 331.0 m.
Mean crest elevation of right embankment section = 330.5 m.

floods pass through the outlet structures, are also included in these tables.

(b) Comparison of HEC-HMS Floods With Regional Flood Estimates

The deterministic flood estimates from the HEC-HMS analysis for the ungauged river basin can be compared with regional flood estimates. The regional analysis consists of an examination of flood frequency characteristics for the basin using the Index Flood Method, as outlined in Appendix 5, MNR Technical Guidelines (MNR, 1986)*. The study dam is located in Region 4, as defined in the Technical Guidelines. The index flood or 2-yr flood can be computed as a function of the drainage area of the damsite. Regional flood indices are then applied to the 2-yr flood to estimate floods of greater return periods. The regional flood estimates are summarized in Table 6.9 for the Harrington Dam. It is cautioned that while the parameters used for the regional analysis are based on historical flow data from a number of area gauging stations, the range of drainage basin sizes and their degree of regulation are very variable.

---

[*] The primary reference is Moin and Shaw, "Regional Flood Frequency Analysis for Ontario Streams", 1986.

Table 6.9

Summary of Flood Regional Frequency Analysis Region 4 – Southcentral Ontario[*]

Return Period (yrs)	Regional Index Flood[*]	Flood Peak (m^3/s) Harrington Subbasin
2	1.00	5.8
5	1.32	7.6
10	1.57	9.0
20	1.80	10.4
50	2.13	12.3
100	2.37	13.6
200	2.60	15.0
500	2.92	16.8
Drainage Area (km^2)		12.0
Regional Q2y		5.8
Unit Runoff for the 1:2-yr flood ($m^3/s/km^2$)		0.4795

---

[*] MNR Technical Guidelines.

The results of the computed peak floods and those from the Index Flood Method are compared in Figure 6.8. Generally, the comparison shows that computed floods from the 24-hr and 3-day summer rainfall storms are lower than the regional peak flood estimates for the 2-yr return period. However, this situation reverses for computed summer floods with return periods equal to and greater than 5 years. In all cases, these are significantly higher than the regional estimates. The 3-day summer rainfall storm yields the most severe flood conditions at the dam in terms of water level rise and outflows. Due to the inherent variation in drainage basin morphology and degree of both natural and regulated storage, deviations about the regional estimates are expected. This is very pronounced in the case of Harrington and is likely to be caused by the high rainfall figures centered around this basin. An examination of the mean annual runoff map for southern Ontario indicates that the annual runoff for the area around Stratford is approximately 21% higher than the runoff in the London area. This pronounced increase in the runoff characteristic of the Stratford area is depicted in the computed peak flows for Harrington Dam and may account for the peaks being higher than the regional flood estimates as shown in Figure 6.8.

6.2.2 Hydraulic Analysis

6.2.2.1 Discharge Capabilities

A hydraulic analysis of the Harrington damsite was performed to evaluate its existing spillway capacity and check on tailwater levels. The present spillway capacity at the site was reviewed using a field survey drawing completed by Acres in June 2003. The impacts of any upstream or downstream hydraulic conveyance constraints were also evaluated.

The details of the pond impounded behind the Harrington Dam were reviewed based on the recent field survey. An elevation-volume curve was developed using the water surface area of the pond along with surveyed contour levels below the water surface area.

The spillway capacities for two stop log setting configurations along with the respective reservoir elevation-volume relationship are summarized in Table 6.10 and depicted in Figure 6.9.

6.2.2.2 Tailwater Levels

Six cross sections of the downstream discharge channel reach (between the dam and the Road 96 bridge crossing) were extracted from the Acres 2003 survey information and used to calculate the water surface profile for the IDF conditions. The sections were used in the HEC-RAS computer model to derive the water surface profile and establish the tailwater level downstream of the Harrington outlet structure. Placement of the HEC-RAS cross sections is given in Figure 6.10. HEC-RAS output results have been provided as a generated report in Appendix E. A digital copy of the model can be found on the project CD.

Figure 6.8: Dam Safety Assessment Report - Harrington Dam
Flood Estimate Using Regional Index Flood Versus Deterministic Modeling

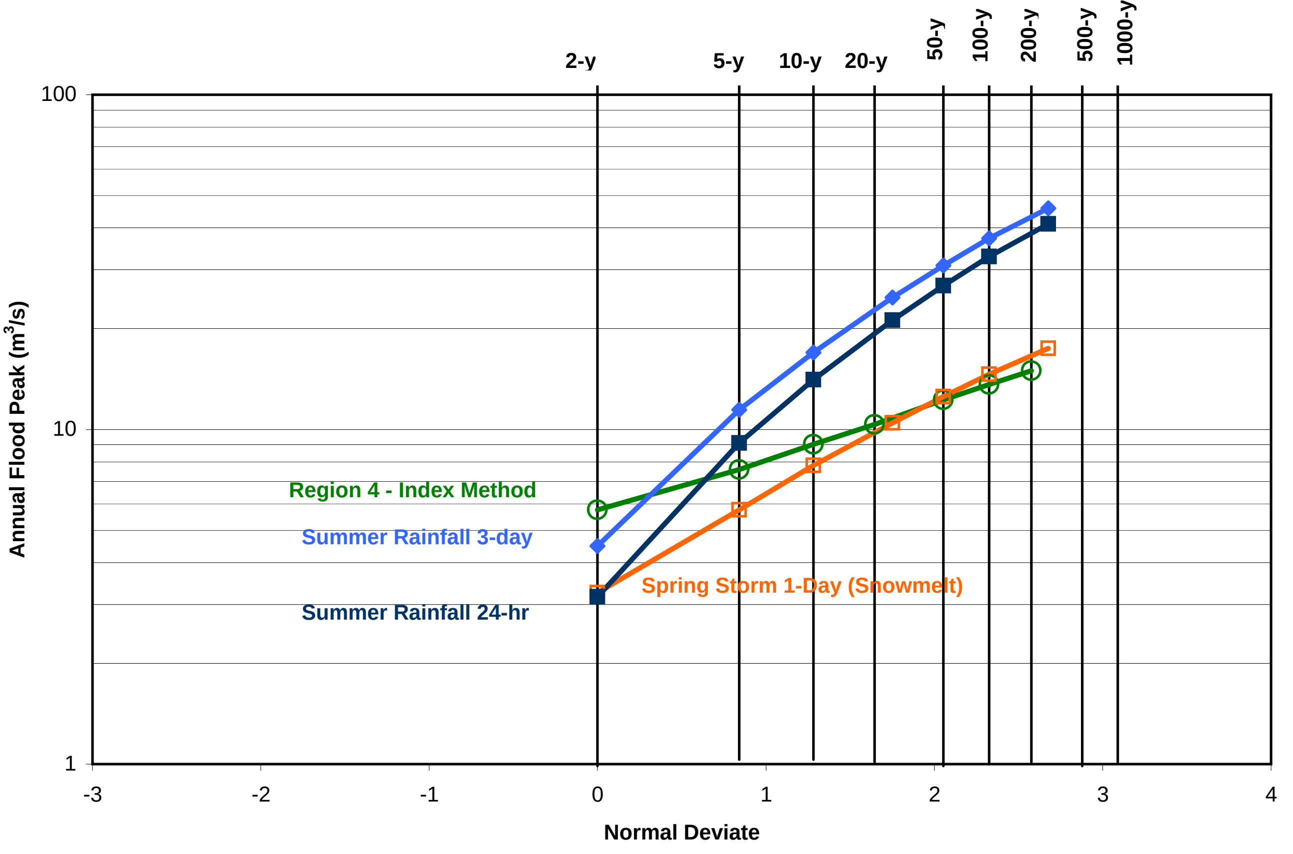


FIGURE 6.8 – BACK

Table 6.10

Harrington Dam – Spillway Capacity and Storage Relationship

Bays 1 to 3 All Logs In		Harrington Pond Storage	
Elevation (m)	Discharge (m^3/s)	Elevation (m)	Storage (m^3x10^6)
329.99	0.00	327.75	0.000
330.03	0.08	329.00	0.004
330.06	0.23	330.00	0.022
330.10	0.43	330.50	0.037
330.13	0.66	331.00	0.058
330.17	0.92		
330.20	1.21		
330.24	1.52		
330.28	1.86		
330.31	2.22		
330.35	2.59		
330.38	2.99		
330.42	3.41		
330.45	3.84		
330.49	4.30		
330.52	4.76[*]		
330.56	5.05[*]		
330.60	5.59[*]		
330.63	6.28[*]		
330.67	7.10[*]		
330.70	8.04[*]		
330.74	9.07[*]		
330.77	10.19[*]		
330.81	11.40[*]		
330.85	12.68[*]		
330.88	14.04[*]		
330.92	15.47[*]		
330.95	16.96[*]		
330.99	18.52[*]		
331.02	20.53[*]		
331.06	23.38[*]		
331.09	26.72[*]		
331.13	30.46[*]		
331.17	34.54[*]		
331.20	38.93[*]		

Notes:
All elevations referred to CGD.
Rating curves plotted in Figure 6.9.

---

[*] Includes flow over embankment sections and top of main dam.

6.3 Assessment and Confirmation of the Final IHP and IDF Assessment

6.3.1 General

The consequences of a dam failure were assessed in terms of the incremental hazard posed by the dam structure, based on guidelines and procedures given in the draft ODSG (MNR, 1999). The hazard potential can be defined as the potential for increase in loss of life, property, and ecological damage and disruption of social and economic activities caused by failure of the dam structure, above that which would have occurred without failure of the dam. The IHP classification is generally determined by simulating dam break floods and assessing the effects of the resultant downstream flood inundation.

For this study, a preliminary IHP classification at the damsite was initially selected on the basis of available information. The information consisted of the characteristics of the dam, reservoir, watershed, discharge facilities, downstream development and ecology, recreational activities, historical flooding, and supplemental data gained from the site visits. This preliminary IHP was assessed using the selection criteria summarized in Table 1.1, which was then used to determine the IDF for a particular site considering the guidelines presented in Table 1.2.

6.3.2 Harrington Dam – Preliminary IHP and IDF

The Harrington Dam and reservoir is located within the town of Harrington. The dam is located at the northern end of the reservoir, which has a surface area of 0.03 km^2. It controls a total drainage area of 12 km^2. Outflow through the dam is controlled by a concrete-gravity outlet structure comprised of three stop log bays with sloping faces to the downstream channel. Flow releases discharge into Harrington Creek below the dam and then passes through a double-reinforced concrete box culvert (2 x 2.2 H x 4.75 W) under Road 96 approximately 100 m downstream. This creek eventually joins Trout Creek, approximately 300 m downstream of the Road 96 culvert crossing. The dam is approximately 4.0 m high and impounds a total estimated storage volume of 0.02 x 10^6 m^3. This classifies the structure as a SMALL dam on the basis of height and a SMALL dam on the basis of storage impounded.

Figure 6.9: Dam Safety Assessment Report - Harrington Dam
Outlet Structure Rating Curve and Reservoir Elevation/Volume Curve
Rating Curve for 3 Stop Log Bays and Embankment Sections

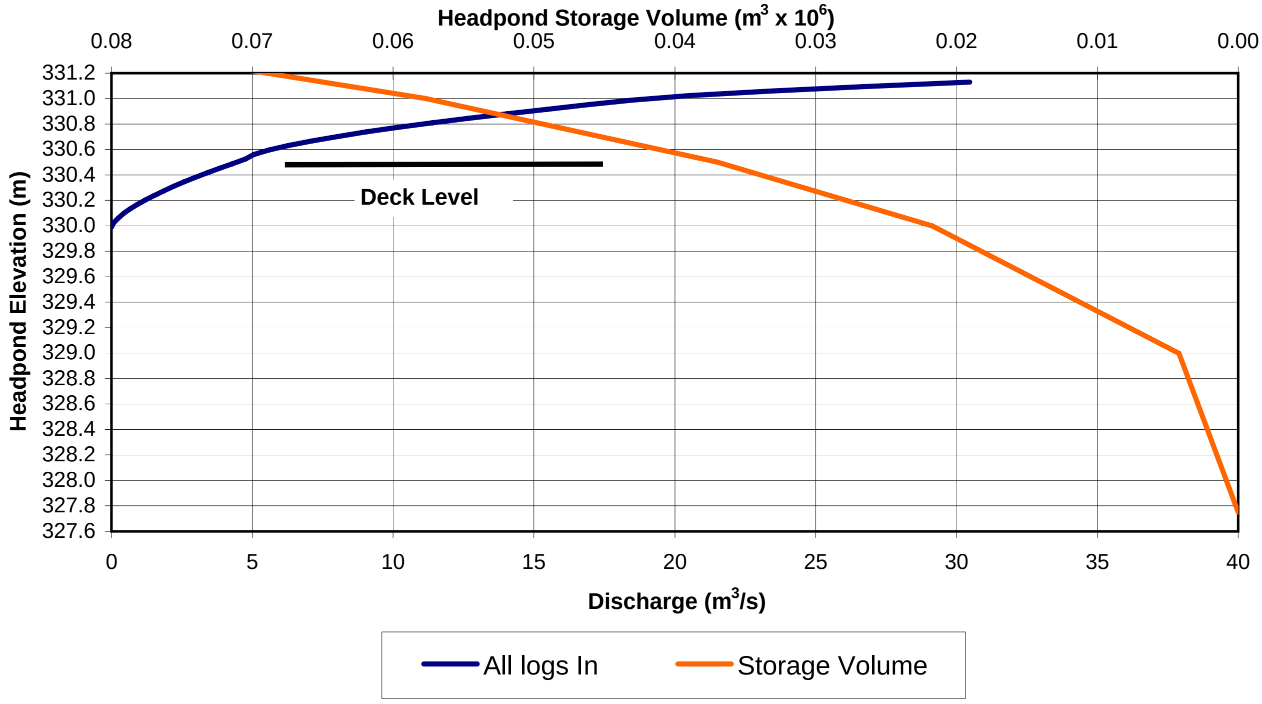


FIGURE 6.9 – BACK OF PAGE

R:\P14504\Civil\Harrington-Figure.DWG

PLOT SCALE 1=1

Plot Date Jul 21, 2003 - 15:03:32

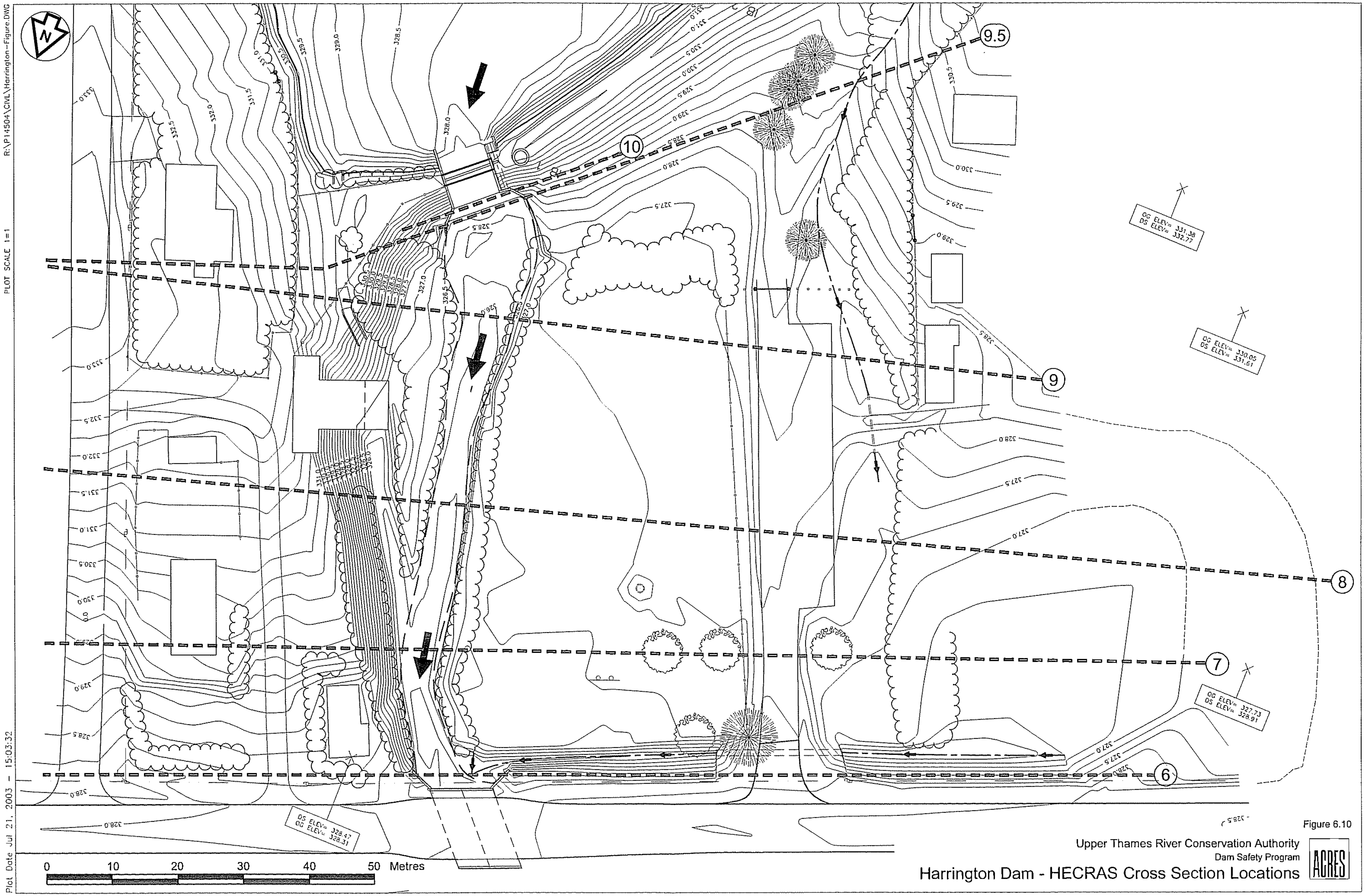


Figure 6.10

Upper Thames River Conservation Authority
Dam Safety Program

Harrington Dam - HECRAS Cross Section Locations

ACRES

FIGURE 6.10 – BACK OF PAGE

There are permanent dwellings located on both sides of the downstream creek banks. The houses located on the right bank, including the old mill, are set at higher elevations compared to those of the left bank and floodplain. One house on the left bank is located at or near the same elevation as the floodplain. Despite the ‘SMALL’ structure classification of the dam, it was felt that overtopping of the downstream channel could result in the overbank flows entering the residence located on the left bank/floodplain. This meant that occupants of the house would be at risk, and there would be a potential for loss of life. In such a case, the required IHP would be HIGH and the associated IDF would be a PMF.

In order to evaluate this potential hazard classification, an approximate analysis of a sunny day failure of the dam was simulated to determine approximate peak water levels in the downstream residential area. A breach in the left embankment comparable to a sunny day failure was estimated. Potential dam break breach flow of the left embankment section was computed based on the breach parameters estimated by guidelines in OPG’s Procedure for Hydraulic Design Reviews, January 2001. This yielded an effective dam height of 2.25 m and a breach top width of 10 m and resulted in an estimated peak outflow of approximately 55 m^3/s. Tailwater conditions at Harrington Dam were evaluated from a HEC-RAS computer model of this channel reach as described in Section 6.2.2.3. Using the HEC-RAS model results, the corresponding water level to a flow of 55 m^3/s in the vicinity of the affected house would rise to approximately 327.8 m. This dwelling has its ground elevation at 327.73 m and the door sill at el 328.91 m. The flood water level would rise only to the ground elevation of the house, and this would not be likely to create a life-threatening situation within this dwelling. Because there would not be loss of lives for the sunny day failure condition, the HIGH hazard classification cannot be applied to Harrington Dam. The available flow passage area of the downstream culvert provides adequate conveyance capacity and would not constrict flow during this high flood discharge. Overall, no potential incremental loss of life under flood conditions is expected. Incremental economic, social and environmental losses are not expected to exceed the VERY LOW category. Therefore, the dam has been designated as a VERY LOW IHP structure and the corresponding IDF lies between 1:25 years to 1:50 years.

Deterministic rainfall/runoff modeling results have established that the 50-yr, 3-day summer storm event is the governing flood for this site. This flood event has been used to assess the adequacy of the existing discharge facilities at the damsite to meet dam safety requirements. The salient features of the damsite, along with a summary of the preliminary IHP and IDF classification parameters according to dam height and reservoir volume, are given in Table 6.11.

Table 6.11

Preliminary IHP and IDF Classifications for Harrington Dam

	Description						Preliminary IHP and IDF					
	Drainage Area						Dam Class		Potential Dam Failure Impacts			
Watercourse	Local (km^2)	Total (km^2)	Reservoir Area (km^2)	Dam Height (m)	Storage (m^{3}x10^6)	Spillway Facilities	By Height	By Storage	Loss of Life	Economic, Social & Environmental	IHP	IDF
Harrington Creek	12.0	12.0	0.026	4.0	0.02	3 stop log bays	SMALL	SMALL	None expected	Minor flood damages downstream	VERY LOW	25-yr flood to 50-yr flood

6.3.3 Harrington Dam – Final IHP and IDF Assessment

The results of the hydrologic and hydraulic assessments for the study damsite verified the preliminary IHP and IDF classifications in Section 6.3.2. During passage of the 50-yr, 3-day summer storm IDF event, the discharge would be conveyed through the 3-bay stop log spillway and over the right and left embankment sections of the dam. The inflow flood for this frequency was estimated at 30.9 m^3/s, while the peak outflow was also 30.9 m^3/s due to negligible attenuation by the Harrington pond. The dam discharge facilities would not be able to pass this flood at an upstream water level of 331.13 m. The deck elevation and right embankment section of the main dam are at el 330.5 m, while the left embankment section is at el 331.0 m. Approximately 16% of the IDF flow would go through the three spillway bays, while 84% or 36.1 m^3/s would overtop the embankments. About 20% of the total embankment flow would be over the left embankment, while the remaining 80% or 20.8 m^3/s would overtop the right embankment.

Based on the above results, the dam does not have adequate spillway capacity to pass the IDF, on the basis of two logs left in each of the three bays. Presently, the Harrington Dam is confirmed as a VERY LOW hazard structure, and the corresponding IDF is the 50-yr, 3-day summer storm event. The final IHP and IDF classifications are presented in Table 6.12.

Table 6.12

Final IHP and IDF Assessments for Harrington Dam

Watercourse	Final		Event Duration and Timing	Start W.L. Condition (m)	Inflow (m^3/s)	Outflow (m^3/s)	Maximum Water Level (m)	Change in W.L. from Start W.L. (m)	Tailwater Level (m)
	IHP	IDF							
Harrington Creek	VERY LOW	1:50-yr	Summer (rainfall) 3-day	330.01	30.9	30.9	331.13	1.12	328.4

Note: All elevations referred to CGD.

6.3.4 Freeboard

Freeboard at the dam was estimated by calculating wind setup, wave height and wave run-up for IDF conditions. Wind setup was computed using the procedure outlined in the US Department of the Interior Freeboard Criteria (USBR, 1981). Design wave heights were determined using the procedures in the US Army Corps of Engineers Shore Protection Manual (SPM) (US Army, 1984). To obtain conservative estimates of freeboard requirements, the effective fetch in the reservoir was calculated with the primary wind direction aligned with the longest fetch length or radial in the vicinity of the dam structure. Since the reservoir is relatively small, no corrections were made from overland to overwater wind speeds.

A Gumbel extreme value extrapolation of the wind frequency data (NRC-CNRC, 1995) for the station at Embro was used to estimate both the 100-yr and 1000-yr wind speeds. Because the reservoir is relatively small, the wave height would have a limited fetch and not be restricted by wind duration. The wind durations at either 104 km/h (100 years) or 127 km/h (1000 years would both be long enough to establish steady-state wind/wave conditions in the headpond.

The computed effective fetch length for the Harrington pond is 0.13 km. The effective fetch at the dam center was computed by

$$F_e = \sum X_i \text{ Cos } a_i$$

where,

a_i = the angle between the central radial and radial ‘i’
X_i = the projection of radial ‘i’ on the central radial.

The resulting calculated wind setups were negligible in both cases. The significant wave height was calculated as a function of effective fetch and wind speed. The design wave was taken as the average of the highest 10% of waves (H_{10}), and was determined from the significant wave height from the SPM ($H_{10} \approx 1.27$ Hs). Nonbreaking wave forces against vertical wall structures were also computed using the method described in the SPM. The resulting wave heights and wave run-ups for the 100-yr and 1000-yr wind speeds are summarized in Table 6.13. The computed wave forces on the vertical stop logs for the structure were found to be negligible. Wave forces computed did not include the force due to the hydrostatic pressure distribution below the still water level.

Minimum freeboard requirements were assessed in accordance with MNR guidelines (MNR, 1999).

- Under maximum normal headpond water levels and 1000-yr wind condition, normal freeboard requirements at the damsite are given in Table 6.13.
- Under peak IDF water level conditions, minimum freeboard requirements at the damsite have been conservatively established for specified 100-yr wind conditions. Minimum freeboard requirements are given in Table 6.13.

These results show that, during passage of the IDF, the dam would be overtopped and freeboard is not adequate. If additional spill capacity is installed, the IDF water level would decrease. It has been assumed that the embankments would have to be raised by approximately 0.5 m. The concrete spillway section would have to be raised during rehabilitation by approximately 1 m.

Table 6.13

Freeboard Requirements for Harrington Dam

				1:1000 Wind				1:100 Wind			Available Freeboard		
											Normal Freeboard	Minimum Freeboard	
Type	Abutment Conditions	Crest Elevation (m)	Normal Water Level (m)	Design Wave Height (m)	Wind Setup (m)	Wave Run-Up (m)	IDF Water Level (4) (m)	Design Wave Height (m)	Wind Setup (m)	Wave Run-Up (m)	Crest (1) Normal (m)	Crest (2) IDF (m)	Remarks
Main Spillway	Concrete	330.53	330.0	0.39	0.03	0.50 (3)	331.13	0.34	0.02	0.44 (3)	0.00	-1.07	Overtopped during IDF
Left Embankment	Earth fill	331.00	330.0	0.39	0.03	0.28 (3)	331.13	0.34	0.02	0.23 (3)	0.69	-0.38	Overtopped during IDF
Right Embankment	Earth fill	330.50	330.0	0.39	0.03	0.28 (3)	331.13	0.34	0.02	0.23 (3)	0.19	-0.88	Overtopped during IDF

Notes:

(1) Crest elevation - (NWL + 1:1000-yr wind setup + 1:1000-yr wave run-up).
(2) Crest elevation - (IDF + 1:100-yr wind setup + 1:100-yr wave run-up).
(3) Conservatively estimated as the design wave height; waves expected to break before reaching the structure.
(4) Water level based on all logs in each of the three stop log bays.

All elevations referred to CGD.

6.3.5 Recommendations

Based on the results of the IDF in Section 6.3.3 and the freeboard assessment in Section 6.3.4, the spillway structure at Harrington is not adequate to ensure safe passage of the IDF. This will require future modifications to the spillway which could involve the removal of the stop logs, modifications to the emergency spillway or provision of an auxiliary spillway.

Acres has reviewed several preliminary options to upgrade the spillway structure at Harrington to pass the IDF in a separate study to UTRCA. At this time, we recommend that more detailed work be carried out to refine the IDF based on a more in-depth analysis of basin topography with detailed maps of the study basin. This could possibly lower basin parameters that influence the magnitude of the IDF. A lower IDF would have corresponding lower costs in upgrading the spillway structure at the Harrington damsite.

7 Civil/Structural Assessment

7 Civil/Structural Assessment

7.1 Introduction

Stability analyses were performed using the parameters and the general methods described herein. In performing these analyses, maps and photographs produced during the site inspection phase of the work, as well as site-specific geologic data, were used to assist in the assessment of the structure. These site-specific data obtained during the site visit are described in Section 4 of this report. The results of the stability analyses were used to determine if the Harrington Dam satisfies current draft Ontario Dam Safety Criteria, according to the criteria provided in Sections 6.0 and 7.0 of the draft ODSG. The results from these analyses, together with the results obtained from the various other assessments prepared as part of this study, form the basis of the recommendations for remedial work as detailed in Section 11 of this report.

7.2 Methods of Analysis

The dam safety analyses involved the assessment of the ability of the structure to resist

- sliding at the dam-foundation interface, within the dam and at any plane in the foundation under all loading conditions
- overturning
- overstressing of the concrete dam or foundation.

The analyses were based on ‘rigid body’ limit equilibrium method with the various load combinations treated as static because of the relatively sustained nature of loads involved.

For critical representative sections of the structures, sliding stability in the upstream-downstream direction, the compressive and bearing stresses in the concrete and the location of the resultant were determined. Where the location, magnitude, direction and duration of computed tensile stresses were such that the stresses would be likely to produce cracking, the extent of cracking was evaluated.

Seismic analyses are typically performed at different levels of sophistication depending on the hazard potential rating of the dam and the probability of unacceptable performance. For the low earthquake potential in southwestern Ontario, pseudostatic methods of analysis are used.

7.3 Selection of Loads and Load Combinations

The following loads were considered in the assessment of the concrete structure:

- dead loads of permanent structures, rock or soil backfill, silt deposited against the structure and any significant equipment loads
- the maximum flood headwater level based on the IDF with corresponding tailwater levels
- internal water pressure and foundation uplift
- static thrust created by an ice sheet
- MDE.

7.3.1 Ice Loads

The thermally driven, static, ice loads used in the design review were assessed by taking into consideration site-specific characteristics and operating information.

For ice loadings, it was assumed that horizontal thrust created by thermal expansion of ice sheets would occur 0.3 m below the headpond level. Research by OPG, Manitoba Hydro, Fleet Technology and others has shown that the magnitude of this ice thrust depends on factors such as the thickness of the sheet of ice, the average ambient temperature, the rate of temperature change in the ice, fluctuations in the water surface, reservoir characteristics and wind drag.

The temperature data required as part of the ice load assessment was established by considering the January 1% temperature (see Table 7.1 for the definition of this term) from the OBC. For the Harrington Dam, the closest geographically available weather station reports were at Stratford and St. Marys. The average January 1% temperature was found to be -20°C.

Table 7.1

Thermal Ice Loads on Concrete Dams

Reservoir Shoreline Characteristics	Winter Air Temperature (January 1% Temperature* from OBC)		
	Mild **0° to -20°C**	**Average** **-21° to -29°C**	**Severe** **-30°C and Lower**
Flat shore (<20° slope)	58.4 kN/m (4 kips/ft)	80.2 kN/m (5.5 kips/ft)	102.1 kN/m (7 kips/ft)
Steeper shore (20° to 45° slope)	73.0 kN/m (5 kips/ft)	87.5 kN/m (6 kips/ft)	116.7 kN/m (8 kips/ft)
Steep rocky shore (>45° slope)	87.5 kN/m (6 kips/ft**)	116.7 kN/m (8 kips/ft**)	145.9 kN/m (10 kips/ft**)

Notes:

1 * The January 1% temperature is defined as the lowest temperature at or below which only 1% of the hourly exterior air temperatures in January occur. The January 1% temperature for selected locations in Ontario is tabulated in the Ontario Building Code (OBC).

2 ** For steep rocky shoreline, careful study of the site-specific condition with regard to the shape of the headpond, snow cover data and temperature records is required to determine the design ice load magnitude, as the ice load can be larger than the values shown in the table.

3 Ice load for steel gates = 50% of the values shown in the table.

4 Ice load for timber logs = 29.2 kN/m (2.0 kips/ft).

5 Ice load reduction where timber crib remains exist at or above the waterline shall be based on the location, top elevation, and flexibility of the subject timber crib structure.

6 Minimum ice load where ice sheet existed against the structure = 29.2 kN/m (2.0 kips/ft).

7 Maximum water level in January from past records (from 30 to 80 years) shall be considered for the ‘winter operating condition’ in the design review. However, this water level may not be much different from the maximum headwater level given for the summer condition.

8 Site-specific conditions based on the design review inspection shall be used in selecting the appropriate design ice load.

Headpond shoreline characteristics, such as slope, were measured from the topographic details established during the site survey. On the basis of procedures for estimating ice loads presented by OPG at a workshop on ice held at the annual Canadian Dam Association conference in 2000 as detailed in Table 7.1, the resulting ice thrust values were estimated. The results of this assessment showed that the following ice loads should be considered at the Harrington Dam:

• ice load on concrete	73.0 kN/m.
• ice load on stop logs	29.2 kN/m.

7.3.2 Hydrostatic Uplift

Hydrostatic pressures within the dam and foundation are considered as follows.

- **Case 1:** For dams with no foundation drains or pressure relief systems, full uplift, varying linearly from 100% headwater pressure at the upstream face to 100% tailwater pressure at the downstream face, is assumed to act on the entire base area of the dam.

- **Case 2:** For dams equipped with an effective drainage and/or pressure relief system (based on field investigations and/or monitoring data), reduced uplift is used. The reduced uplift varies from 67% of upstream headwater pressure to 100% tailwater pressure, only if the actual recorded uplift is less.

At the Harrington Dam, Case 1 applies. Due to the presence of the steel sheetpiling, additional analysis using flownets were performed to provide a more accurate estimate of the uplift force and location of the resultant.

The uplift assumption corresponds to the design water levels and does not consider any ‘locked in’ pressures. If base tensions exceed allowable limits (typically assumed to be one half of the threshold shear strength), it is assumed that tension cracking of the base occurs at the level which allows full uplift pressures to be transmitted along the crack for cases not involving earthquake loadings. In the case of earthquakes, it is assumed that the motions are of such a short duration that uplift pressures will not be increased within any crack that may be theoretically induced from the earthquake loadings.

The uplift assumption corresponds to the design water levels and does not consider any ‘locked in’ pressures. If base tensions exceed allowable limits (typically assumed to be one half of the threshold shear strength), it is assumed that tension cracking of the base occurs at the level which allows full uplift pressures to be transmitted along the crack for cases not involving earthquake loadings. In the case of earthquakes, it is assumed that the motions are of such a short duration that uplift pressures will not be increased within any crack that may be theoretically induced from the earthquake loadings.

7.3.3 Seismic Loads

Probabilistic earthquake parameters for the damsite was established based on data obtained from the Geological Society of Canada, as summarized in Table 7.2.

Table 7.2

Probabilistic Earthquake Parameters

Peak Horizontal Ground Acceleration (*g*)				
Probability of Exceedance per Year	**0.010**	**0.005**	**0.0021**	**0.001**
Harrington Dam	0.021	0.029	0.039	0.051

These seismic loads were considered to act in a horizontal direction (increasing the driving force) and a vertical upwards direction (decreasing the horizontal resisting force). In the pseudostatic method of analysis, two thirds of the peak ground acceleration (PGA) is used to simulate the sustained ground motion in combination with two thirds of that value acting in a vertically upward direction.

The draft ODSG require that dams

> *". . . be designed and evaluated to withstand ground motions associated with a Maximum Design Earthquake (MDE), without release of the reservoir*"

with the selection of the MDE for a dam being based on the hazard potential classification and consequences of dam failure. As shown in Table 1.3, for any given site, the MDE increases with increasing hazard potential due to dam failure.

For the case of the Harrington Dam, an IHP classification of VERY LOW/ VERY LOW (flood/sunny day) was established. A 1:100-yr earthquake event was selected as the design load case for stability assessment.

7.3.4 Hydrostatic Loads

Water levels used in the assessment of the various load cases were derived for the various load cases based on the IHP classification of the dam and the IDF equivalent to the PMF event. These levels were determined to be as follows:

- normal summer
  headwater level = 330.01 m
  tailwater level = 326.81 m

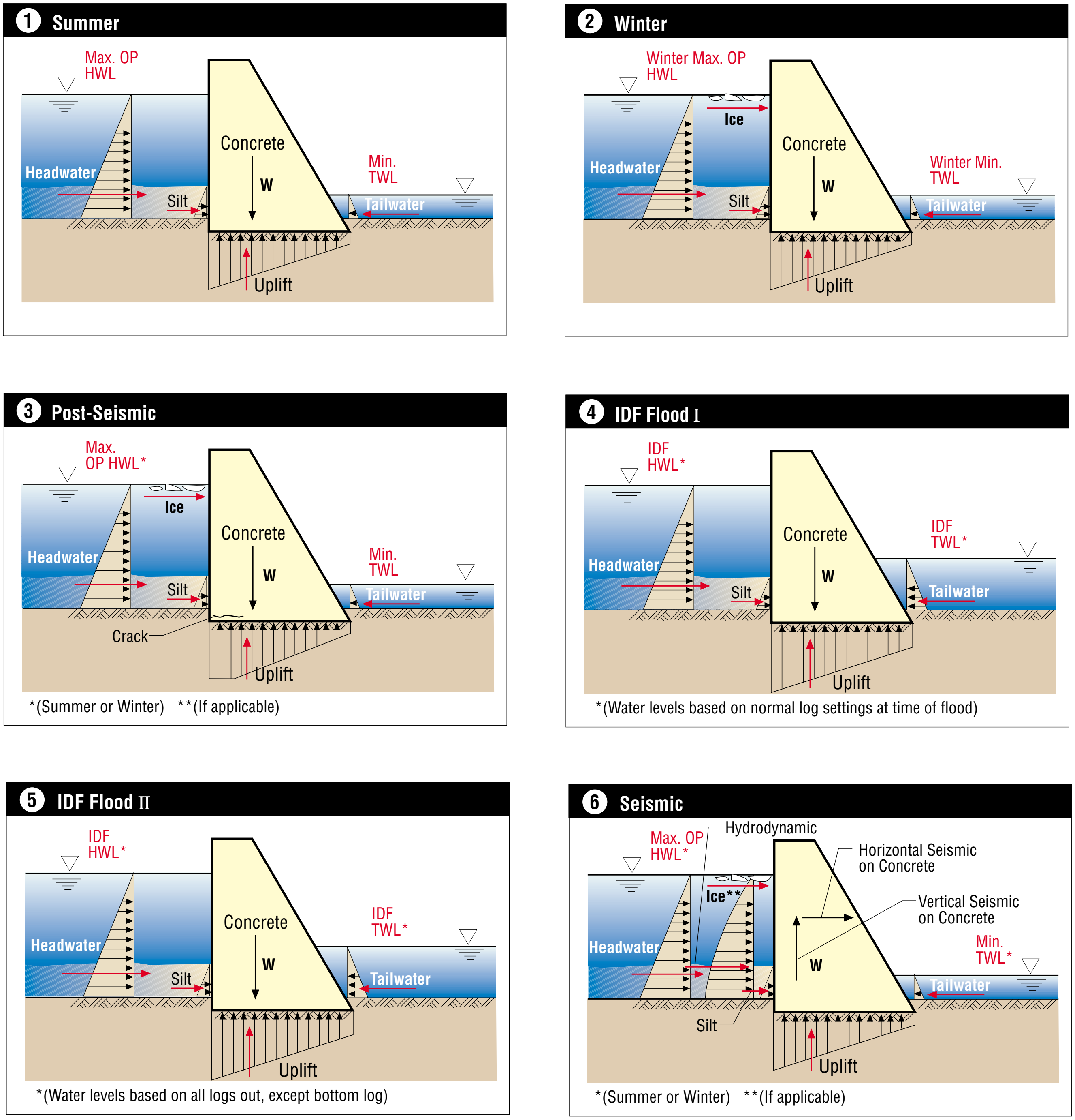
- normal fall/winter
  headwater level = 330.01 m
  tailwater level = 326.81 m

- PMF Flood I and PMF Flood II
  headwater level = 331.13 m
  tailwater level = 328.40 m.

7.3.5 Load Combinations

The various loading combinations are shown schematically in Figure 7.1 and are described as follows. Numbers in parenthesis refer to the numbers in Figure 7.1.

Usual Loading (1) and (2)
Permanent and operating loads were considered for both summer and winter conditions, including self-weight, ice, silt, earth pressure, and the



① Summer

② Winter

③ Post-Seismic

*(Summer or Winter) **(If applicable)

④ IDF Flood I

*(Water levels based on normal log settings at time of flood)

⑤ IDF Flood II

*(Water levels based on all logs out, except bottom log)

⑥ Seismic

*(Summer or Winter) **(If applicable)

Legend

OP	Operating
HWL	Head Water Level
TWL	Tail Water Level
IDF	Inflow Design Flood

Figure 7.1
Upper Thames River Conservation Authority
Dam Safety Assessment Report
Schematic of Load Cases

ACRES
International

FIGURE 7.1 – BACK OF PAGE

normal maximum operating water level with appropriate uplift pressures and tailwater level.

Unusual Loading (3)
Where earthquake-induced cracking at the rock concrete interface or any weak section was identified, a stability analysis was carried out to determine the stability of the structure, in its post-earthquake condition, under the effects of the usual loading conditions that could include concurrent ice loadings in areas where appropriate. Full reservoir pressure within the earthquake-induced cracks is assumed for the post-earthquake case.

Flood Loading (4)
Permanent and operating loads of the usual loading case, except for ice loading, were considered in conjunction with reservoir and tailwater levels and uplift resulting during the passage of the IDF. The effect of ice loads was not considered simultaneously with design flood conditions in accordance with the requirements of the draft ODSG.

Flood Loading (5)
For the Harrington Dam, this case is identical to Flood Loading I as the stop logs are not manipulated.

Seismic Loading (6)
Permanent and operating loads from the usual loading were considered in conjunction with the seismic loads that would be generated during the MDE. During this extreme load case, ice loads are also considered. Uplift pressures were assumed to be those corresponding to the normal loadings, and were not modified during the seismic event.

7.4 Performance Indicators

The assessment of the suitability of the concrete structures was based on the following performance indicators:

- position of resultant force
- normal stresses at the heel and the toe

- calculated sliding factors and strength factors.
- overturning factors.

7.4.1 Position of Resultant Force

The draft ODSG indicate that the position of the resultant should be within the middle third of the base for normal loading conditions and within the base for other load cases. Therefore, the intent of the guidelines is that this is a desirable, but not mandatory, requirement for the evaluation of concrete dams. On this basis, dams that satisfy the following conditions:

- existing structure with a history of service and no signs of significant distress
- low incremental consequence category
- satisfy sliding stability criteria
- satisfy compressive strength criteria

were considered to meet the intent of the dam safety requirements even if the position of the resultant was outside the middle third of the base for the normal case.

7.4.2 Tensile Stresses

Within the dam, tensile stresses are acceptable so long as the stresses remain within 0.1 f_c' to 0.05 f_c' (where f_c' is the compressive strength of concrete) within the mass concrete and at lift joints, respectively.

7.4.3 Sliding Factor

The resistance of a gravity dam against sliding on any surface is designed or assessed by comparing the net driving force with its available shear strength. The ratio of these components is the factor of safety (FOS) against sliding or sliding factor (SF).

$$\text{SF} = \frac{\text{Available Shear Strength}}{\text{Net Driving Force}}$$

The draft ODSG recognizes two states of available shear strength: ‘peak’ and ‘residual’.

(a) Peak shear strength is based on the following components:

$$\text{Available Peak Shear Strength } = \sum A_c\{(\sigma_n)\tan(\phi'') + \tau_o\}$$

where,

σ_n = normal stress
ϕ'' = peak angle of internal friction ‘a’
A_c = area of compression
τ_o = the available peak shear strength at zero normal stress.

(b) The residual or post-peak strength is defined as

$$\text{Available Residual Shear Strength } = \sum \mathrm{A_c}\{(\sigma_n)\tan(\phi')+\tau_n\}$$

where,

ϕ' = residual angle of sliding friction
τ_n = nominal residual shear strength value at zero normal stress. According to the MNR guidelines, this value may range up to 100 kPa (15 lb/in.^{2}), if supported by tests.* Without tests, it is assumed to be zero. For this study, the residual value was assumed to be zero for all structures since no test data was available.

7.5 Acceptance Criteria

Acceptance criteria used in the analysis of concrete structures are as listed in Tables 7.3 to 7.5.

---

* As discussed, it is not strictly correct to assume a cohesive strength when considering residual shear strength, as concrete-to-bedrock bonds are broken at very small strains. For the so-called ‘residual’ shear resistance, it is better to consider all bonding to be lost and any apparent cohesion to be a function of roughness.

Table 7.3

Acceptable Sliding Factors for Gravity Dams

Type of Analysis [(a)] [(f)]	**Load Case**			
	Usual	**Unusual (Post-Earthquake)**	**Earthquake (MDE)** [(b)]	**Flood (IDF)**
Peak sliding factor (PSF) - no tests	3.0	2.0	1.3	2.0
Peak sliding factor (PSF) - with tests [(c)]	2.0	1.5	1.1	1.5
Residual sliding factor (RSF) [(d)] [(e)]	1.5	1.1	1.0	1.3
Concrete strength factor [(g)]	3.0	1.5	1.1	2.0

Notes:

(a) PSF is based on the peak shear strength. RSF is based on the residual or post-peak strength. See Section 6.4.1 for details.

(b) The stated value under the MDE load case is based on pseudostatic analysis. Performance evaluation of the dam should also take into consideration the time-dependent nature of earthquake excitations and the dynamic response of dam.

(c) Adequate test data must be available through rigorous investigation carried out by qualified professionals.

(d) If PSF values do not meet those listed above, the dam stability is considered acceptable provided the RSF values exceed the minimum.

(e) The minimum values of RSF may be reduced for low hazard potential dams provided data is available to support such reduction.

(f) For low hazard potential dams, if they are judged to be performing satisfactorily, based on an inspection and review of available data, and if conditions are expected to be no less favorable in the future, stability analysis may not be necessary.

(g) These values are recommended where test data is not available.

Table 7.4

Load Cases

Load Case	Description	Minimum FOS	
		No 'Cohesion'	With 'Cohesion'*
1	Normal reservoir loading	1.5	3.0
2	Normal winter reservoir levels + ice	1.5	3.0
3	IDF Flood I	1.3	2.0
4	IDF Flood II	1.3	2.0
5	Earthquake	1.0	3.0
6	Post-earthquake loading	1.1	2.0

---

* With no supporting tests.

Table 7.5

Acceptance Criteria

Dam Safety Indicator	Acceptance Criteria
Location of resultant	Within middle third for normal load cases and within the base for all other load cases.
Bearing stresses	Below allowable bearing capacity limits.
Sliding stability	Above minimum requirements for given load case (see above).
FOS against overturning	This parameter was calculated, but there are no specific criteria given in the draft ODSG (acceptance governed by position of resultant).

7.6 Results of Analyses Performed for the Harrington Dam

7.6.1 Assumptions

The Harrington Dam has an overall IHP rating of VERY LOW and is founded on the nonorganic silt and clay layer as discussed in Section 8.2 of this report. Loads were assumed to be as discussed in Section 7.3. Ice loads were taken as 29.2 kN/m on the stop logs, based on the discussion in Section 7.3.1. It should be noted that the location of the ice force (at el 329.71 m), based on a winter water level of 330.01 m, in the spillway bays, was on the stop logs, but only above the concrete sill by 100 mm. Water levels for the various load cases were as given in Section 7.3.4 under Hydrostatic Loads.

As shown on the drawings, the spillway structure has inclined upstream and downstream concrete rollways with small end walls at each end. There is no base slab connecting the upstream and downstream rollways. Accordingly, the section taken for analysis was a 1-m wide strip of the overflow with the critical sliding section along a plane connecting the end walls of the overflow. Sliding would thus be through the foundation material assumed to consist of inorganic silt and clay.

Analyses were performed using the following assumptions:

• foundation material	inorganic silt and clay
• friction angle	30°
• ultimate bearing pressure	0.580 MPa
• cohesion	0 kPa.

The concrete properties were taken as

f_c' = 20 MPa
γ_{conc} = 23.50 kN/m^3.

7.6.2 Discussion of Results

Detailed results of the stability analysis are found in Appendix F and are summarized in Table 7.6.

The results indicate that the overflow structure does not meet acceptance criteria in sliding during the winter condition and during the IDF case. As this is an overflow structure, it is possible that no ice forms against the stop logs in the winter due to constant flow over the logs. This should be verified.

Based on the results of the three boreholes, it has been assumed that the overflow is founded on the inorganic silt and clay. It is possible that the structure is founded on sand or the glacial till which could have angles of

Table 7.6

Stability Results – Harrington Dam

	Residual	Peak			FOS Against Sliding							
					Residual Case		Peak					
Section	Phi (deg)	c (MPa)	Phi (deg)	Load Case	Req'd	Actual	Req'd	Actual	Location of Resultant	Minimum Base Friction Angle to Satisfy Sliding Criteria (deg)	Minimum % Bonded Area to Satisfy Sliding Criteria	Notes
1-m strip of overflow	30	n/a	n/a	Normal	1.5	2.09	3.0	n/a	Within limits	22.6	n/a	1
				Normal with ice	1.5	1.40	3.0	n/a	Within limits	31.7	n/a	6
				Flood I	1.3	1.19	2.0	n/a	Within limits	32.3	n/a	6
				Flood II	1.3	1.19	2.0	n/a	Within limits	32.3	n/a	6
				Earthquake	1.0	1.30	1.3	n/a	Within limits	24.0	n/a	1
				Post-earthquake	1.1	1.40	2.0	n/a	Within limits	24.4	n/a	1

Notes:

uc = unstable crack
Note 1 = dam section satisfies dam safety criteria.
Note 2 = dam section satisfies dam safety criteria under peak strength assumptions.
Note 3 = dam section deemed to satisfy dam safety criteria for low hazard dams [Figure 7.1, Note (f) of the draft ODSG].
Note 4 = bearing stress at toe of dam exceeds criteria.
Note 5 = position of resultant does not satisfy criteria.
Note 6 = does not satisfy dam safety criteria for sliding stability.
Note 7 = rock anchor taken into account.

internal friction of 36° and 38°, respectively, greater than the required angle of 32.3° required for the structure to meet the acceptance factors of sliding. This should be verified during the proposed reconstruction at the dam to increase the discharge capacity.

Even though the structure is classified in the VERY LOW IHP category, the structure does not meet acceptance criteria during the winter and IDF flood conditions. UTRCA has proposed modifications to the dam to increase the discharge capacity at which time the deficiencies associated with the stability of the structure should be resolved.

8 Geotechnical Assessment

8 Geotechnical Assessment

8.1 Geology

8.1.1 Regional Geology

The upland terrain is rolling, and relief is about 50 m. The regional physiography has developed as a result of the latest glaciation.

According to government geological mapping (Min. Nor. Dev., 1991; Ont. Div. Mines, 1973), the area is characterized by thick deposits of sediments. These were deposited during the Wisconsin glaciation which occurred in the Pleistocene era.

Silty to sandy silt till, known as the Tavistock Till, with minor clay content, predominates on the upland. Deposits of glaciofluvial sand and gravel outwash and ice contact stratified drift, glaciolacustrine silt and clay, and recent streambed alluvium exist throughout the area. These generally overlie the till. End moraines and eskers are also found locally.

Horizontally bedded sedimentary bedrock underlies the region, but is not exposed.

8.1.2 Site Geology

The dam is located in a rolling, cultivated area. Overburden comprising clay, silt, sand and some gravel forms the ground surface. No bedrock is seen in the area.

According to the drilling by Acres, the dam is founded on layers of clay, silt and sand, overlying sand/silt, and overlying silty glacial till in descending order. An artesian well is located just downstream of the dam. It shows a water level about 1.3 m above the ground.

Exploratory drilling was also done on the right bank close to the dam for the grist mill. This work was done in March 2002 by Atkinson, Davies Inc. (see bibliography). These boreholes showed a sequence of materials which generally correlate with Acres findings.

8.2 Spillway Structure

The spillway consists of a concrete-faced embankment. Deck elevation is 330.53. A short concrete apron is provided on the downstream side. The elevation of the top of this apron is at el 327.421 m. Sheetpiling extends to a depth of 0.8 m below the base of the apron. Shear keys exist at the toe of the upstream concrete face and downstream end of the apron.

8.2.1 Foundation and Foundation Shear Strength

The ground/foundation level of the embankment adjacent to the spillway was found to vary between el 326.37 and el 327.55. As discussed in further detail in Sections 5 and 8.4, the foundation stratigraphy comprises the following layers and materials in descending order. Angles of friction have been estimated for each layer. Zero cohesion has been assumed throughout.

Layers/Material	Angle of Friction (deg)
Silt, clay and sand (topsoil, organic)	25
Silt, clay and sand (nonorganic)	30
Sand/silt	36
Silty glacial till	38

In regards to the spillway, reference to old drawings by Kilborn Engineering Co. Limited in 1950 indicates that the original river/stream channel was incised about 1.5 m below the adjacent valley bottom level.

It appears very likely that the natural surface material, i.e., the organic silt, clay and sand (topsoil) which has relatively low shear strength, has been eroded away in the geological past and that the spillway embankment is, therefore, founded on the stronger nonorganic silt, clay and sand layer.

8.2.2 Bearing Capacity

An ultimate bearing capacity of 580 kN/m^2 was calculated for the spillway foundation assuming silt and clay material and a 30° angle of friction (Canadian Geotechnical Society, 1992).

8.3 Embankment Structure

8.3.1 Cross-Section Geometry

The upstream and downstream slopes of the embankment dam have been surveyed by Global Surveying Services. The resulting cross-section geometry is shown on Drawing 14504-HD-002. The downstream slope is noted to be unusually flat.

8.3.2 Foundation Preparation and Characteristics

There are no records of dam construction and of the foundation preparation. Based on the log of the boreholes, the presence of contaminating organics and topsoil indicates that poor quality materials were not removed prior to placement of the embankment fill.

8.3.3 Shear Strength Parameters

Results of the consolidated undrained triaxial shear strength tests indicated an angle of friction of 36° and zero cohesion for the clay, silt and sand embankment fill material.

The shear strength parameters for the main nonorganic silt, clay and sand foundation material were derived from ‘N’ values as per Bowles (1996). The ‘N’ values ranged from 8 to 17; accordingly, an angle of friction of 30° was selected, along with zero cohesion. The uppermost part of this layer, i.e., the surface of the foundation, was found to contain high organic content, particularly in BH-3 (up to 0.9 m). Blow counts (‘N’) varied from 1 to 5. Hence, it was necessary to downgrade the shear strength from that of the nonorganic equivalent. An angle of friction of 25° and zero cohesion were, therefore, estimated.

The shear strength of the sand/silt layer underlying the silt, clay and sand layer was estimated based on the ‘N’ value of 23. An angle of friction of 36° was estimated.

The shear strength of the silty glacial till, the lowermost part of the foundation, was estimated based on Acres experience with southern Ontario tills. An angle of friction of 38° and zero cohesion were selected.

8.3.4 Bearing Capacity

The allowable bearing capacity of the foundation is estimated to be approximately 130 kPa (Canadian Geotechnical Society, 1992). The embankment exerts a maximum total pressure of approximately 75 kPa and, hence, the foundation has adequate bearing capacity.

8.3.5 Settlement and Deformation

Harrington Dam exhibited no signs of settlement, indicating no differential vertical movements since construction. Provided the vertical loads are not significantly increased and given the low seismicity potential of the site area, settlement of the embankment fill is not likely to occur in the future. The same applies to the foundation.

Locally, the downstream slope shows ‘bulging’, i.e., deformation, caused possibly by relatively high groundwater levels in the dam.

8.3.6 Liquefaction

The soils that comprise the embankment and the upper part of the foundation are not considered to be susceptible to liquefaction due to their substantial clay and silt content and well-graded nature (Arumoli et al., 1999). The sand layer and the glacial till are also not considered liquefiable due to their well-graded nature. The low seismicity potential in the site area also reduces the risk of liquefaction to a negligible level.

8.3.7 Seepage and Uplift

The water table in a homogeneous fill dam of this height is normally gently sloping from the reservoir to just above the tailwater. The inspection indicated the downstream slope was soft (mushy) on the left side and groundwater was at the ground surface over a considerable area immediately downstream of the downstream toe. Small ‘boil’ deposits of silt/sand were noted in this area. This water and the artesian condition of the well downstream of the dam suggest that the sand/silt layer in the foundation may be under artesian pressure.

8.3.8 Instrumentation

The only instrumentation in this dam are the piezometers referred to above. These monitor the phreatic surface. No other instrumentation is recommended.

8.3.9 Embankment Stability

8.3.9.1 Left Embankment

8.3.9.1.1 Location of Section

Stability analyses were done for the left earth embankment. The section location taken for the stability analyses is through the highest portion of the dam at about its midpoint. At this section, the embankment is about 3.5 m high. Figure 8.1 shows the section used in the stability analysis.

8.3.9.1.2 Method of Analysis

Stability analyses were performed according to the limit equilibrium method of slope analysis utilizing the proprietary slope stability software SLOPE/W (GEO-SLOPE International Ltd.). All calculations were based on the effective strength method and analysis was performed according to the Morgenstern-Price method of slices with a half-sine function selected for the interslice force function. Several methods exist to perform slope stability calculations; however, the Morgenstern-Price method was selected since the appropriate factor of safety should be obtained from a slope stability method that satisfies both force and moment equilibrium.

8.3.9.1.3 Material Properties

Table 8.1 describes the properties for the various materials used in the stability analyses.

8.3.9.1.4 Phreatic Surface

It was deemed necessary to consider two piezometric pressure lines, as shown in Figure 8.1. A phreatic surface, deduced from piezometric readings, represents pore pressures within the embankment fill and the clay, silt and sand upper foundation material. The second piezometric pressure line applies to the underlying silt/sand layer and reflects its possible artesian condition (Section 8.3.7).

8.3.9.1.5 Seismic Parameters

The draft ODSG requires that dams withstand ground motions associated with a MDE. The MDE is selected based on the hazard potential classification and consequences of dam failure. In the case of the Harrington Dam, an earthquake event with 1:100-yr return period was selected as the design load case for stability assessment. This selection was on the basis that the dam has a VERY LOW IHP classification.

Probabilistic earthquake parameters for the damsite, up to 1:1000-yr return period, were established based on data obtained from the Geological Society of Canada, and are shown in Table 7.2. The horizontal PGA is 0.021 for the 1:100-yr return period.

The pseudostatic method of analysis requires an equivalent sustained ground motion, and hence, two thirds of the PGA is considered appropriate. A ground acceleration of 0.014*g* was, therefore, applied in the stability analysis.

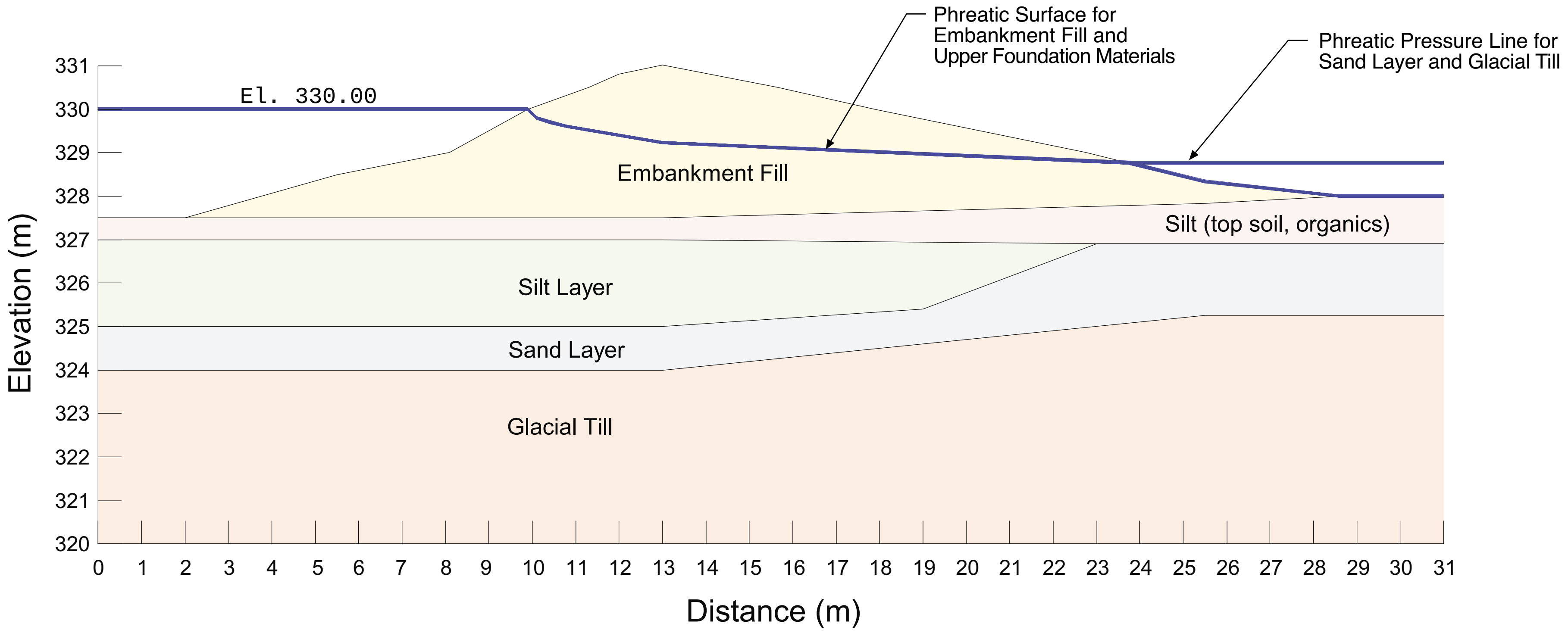


Figure 8.1
Upper Thames River Conservation Authority
Dam Safety Assessment Report - Harrington Dam
Stability Section

ACRES
International

FIGURE 8.1 – BACK OF PAGE

Table 8.1

Stability Analysis of Earth Embankments

Item	Criteria	Calculated	Comments
General			
IHP		Very Low	
Flood Conditions			
IDF		50-yr flood	
Materials			
Embankment			
- embankment fill (CL)			
cohesion (kPa)		0	
ϕ (deg)		36	
moist unit weight (kN/m^3)		17.8	
saturated unit weight (kN/m^3)		19.0	
Foundation			
- silt (top soil, organics)			
cohesion (kPa)		0	
ϕ (deg)		25	
moist unit weight (kN/m^3)		17.8	
saturated unit weight (kN/m^3)		19.0	
- silt layer (nonorganic)			
cohesion (kPa)		0	
ϕ (deg)		30	
moist unit weight (kN/m^3)		18.5	
saturated unit weight (kN/m^3)		20.3	
- sand layer			
cohesion (kPa)		0	
ϕ (deg)		36	
moist unit weight (kN/m^3)		18.2	
saturated unit weight (kN/m^3)		19.5	
- glacial till			
cohesion (kPa)		0	
ϕ (deg)		38	
moist unit weight (kN/m^3)		18.5	
saturated unit weight (kN/m^3)		20.3	
Loads			
Normal water level (NWL)		330.00	
IDF water level		331.13	
Seismic, horizontal (S_h) PGA (*g*)		0.021*	* 2/3, i.e., 0.014*g*, was used in pseudostatic analyses
Load Combinations			
Upstream Slope			
Normal (NWL)	1.50	2.01	
Extreme (NWL, S_h)	1.10	1.85	
Extreme (IDF)	1.30	N/A	
Rapid Drawdown	1.20	N/A	
Downstream Slope			
Normal (NWL)	1.50	1.92	
Extreme (NWL, S_h)	1.10	1.78	
Extreme (IDF)	1.30	N/A	
Rapid Drawdown	N/A	N/A	

8.3.9.1.6 Load Cases

Load cases considered for the upstream and downstream slopes in the stability assessment are summarized in Table 8.1. The cases considered are normal, extreme (normal water level with earthquake) and rapid drawdown. However, the rapid drawdown case was deemed as being not applicable to this site based on the discharge facilities available. The case of the IDF was not considered as a load case in the stability analyses, due to the fact that under this condition the dam will be overtopped.

8.3.9.1.7 Results of Stability Analyses

The results of the stability analyses are provided in Table 8.1, together with the acceptance criteria and calculated factors of stability. Figures 8.2 to 8.5 graphically depict the cross sections analyzed and the minimum factors of safety established for both the upstream and downstream sections.

Both upstream and downstream slopes meet the acceptance criteria for all load cases.

8.3.9.2 Right Embankment

The right embankment downstream slope stands at 2H:1V which is considerably steeper than that for the left abutment. The toe of the downstream slope is supported by gabions and shows no seepage, suggesting the right embankment is in a reasonably drained condition. At the time of the site visit, there was geotextile netting in place on the slope surface in order to encourage vegetation and in turn, improve the slope surface stability. Although stability of the slope was not of immediate concern, the factor of safety of the slope was estimated, assuming dry slope conditions.

$$F.S. = \tan \phi / \tan \alpha$$

where,

ϕ = the angle of friction of the embankment material and was taken as 36°
α = the slope angle.

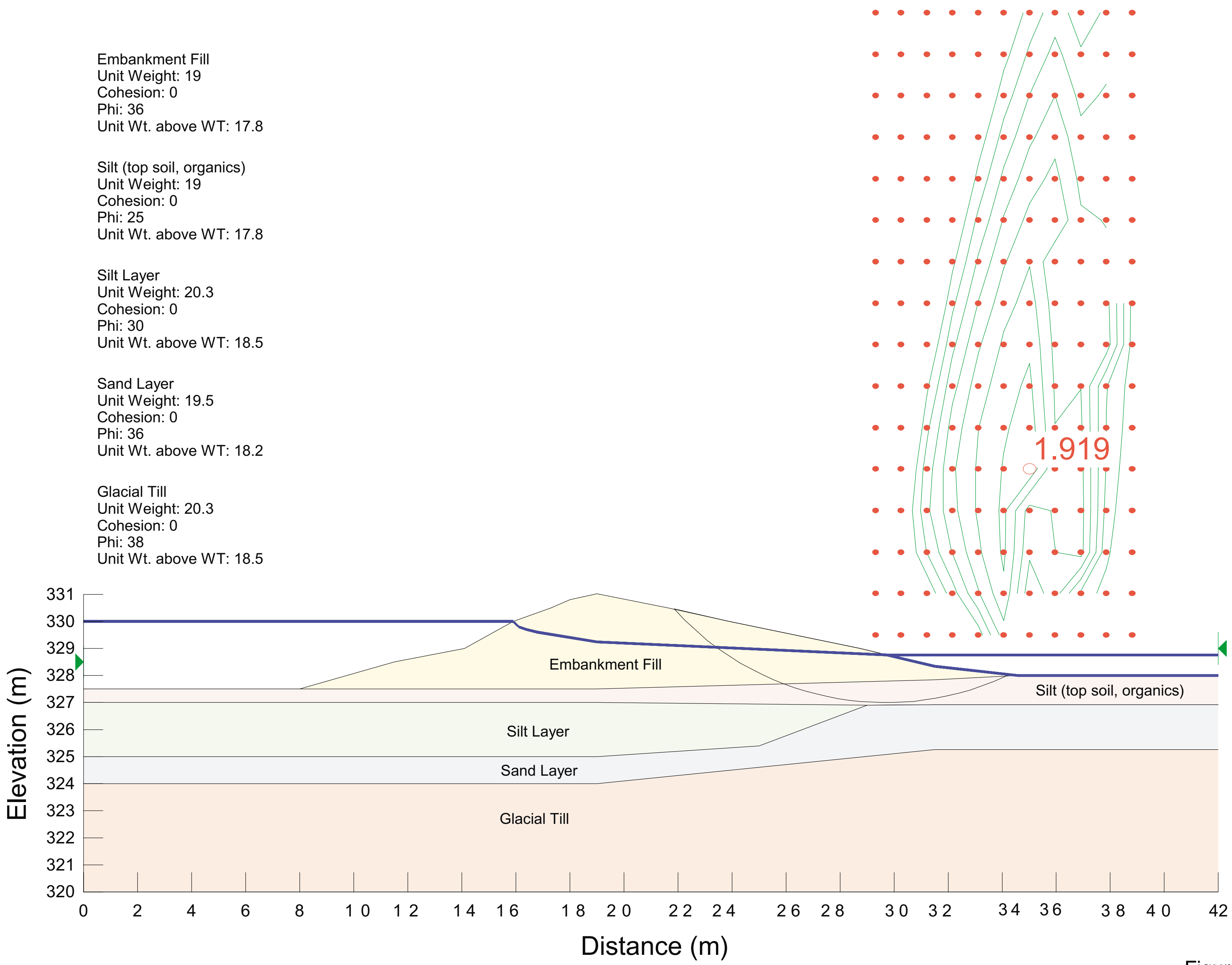
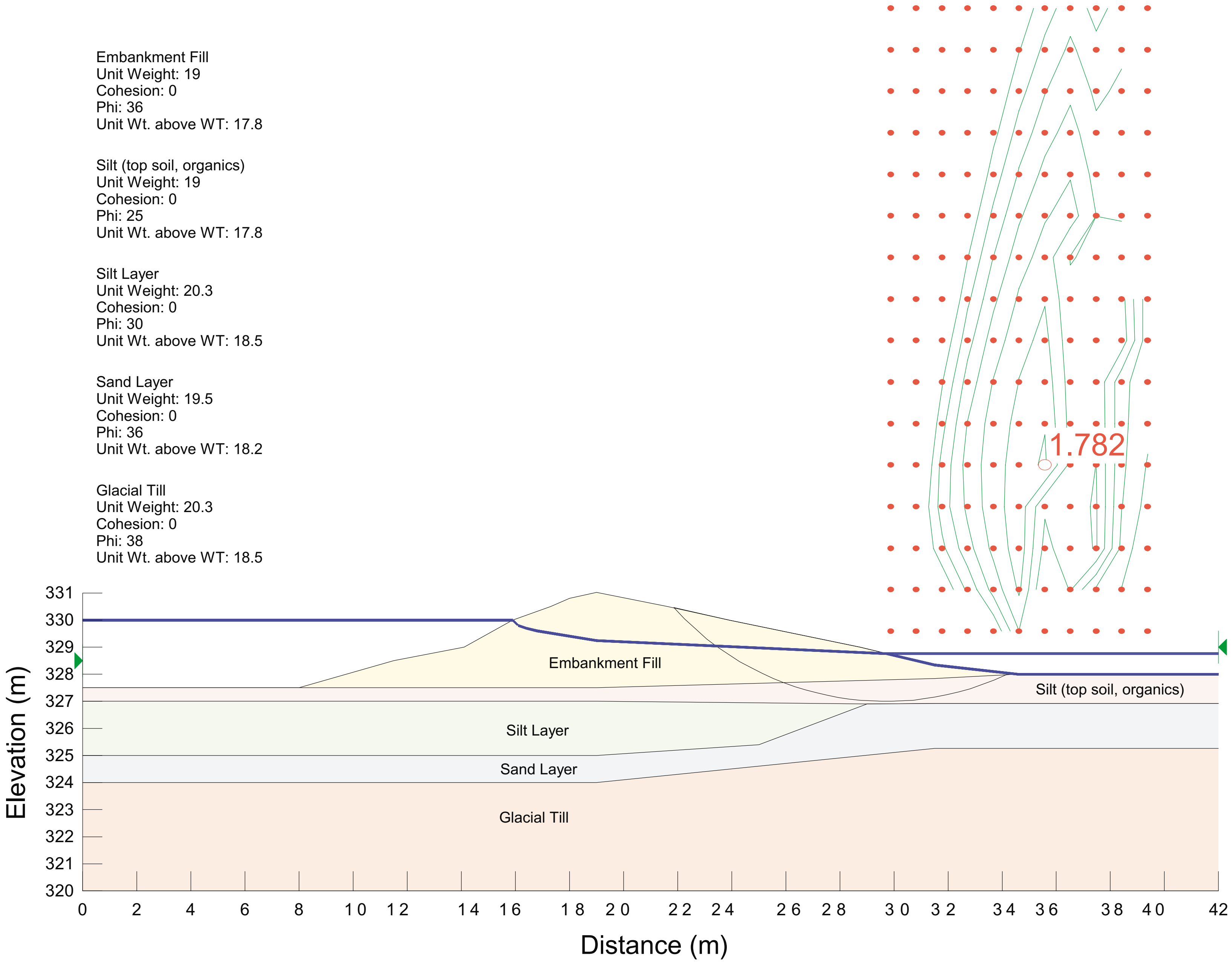


Figure 8.2
Upper Thames River Conservation Authority
Dam Safety Assessment Report - Harrington Dam

Downstream Slope Stability, Normal Load Condition

FIGURE 8.2 – BACK



Embankment Fill
Unit Weight: 19
Cohesion: 0
Phi: 36
Unit Wt. above WT: 17.8

Silt (top soil, organics)
Unit Weight: 19
Cohesion: 0
Phi: 25
Unit Wt. above WT: 17.8

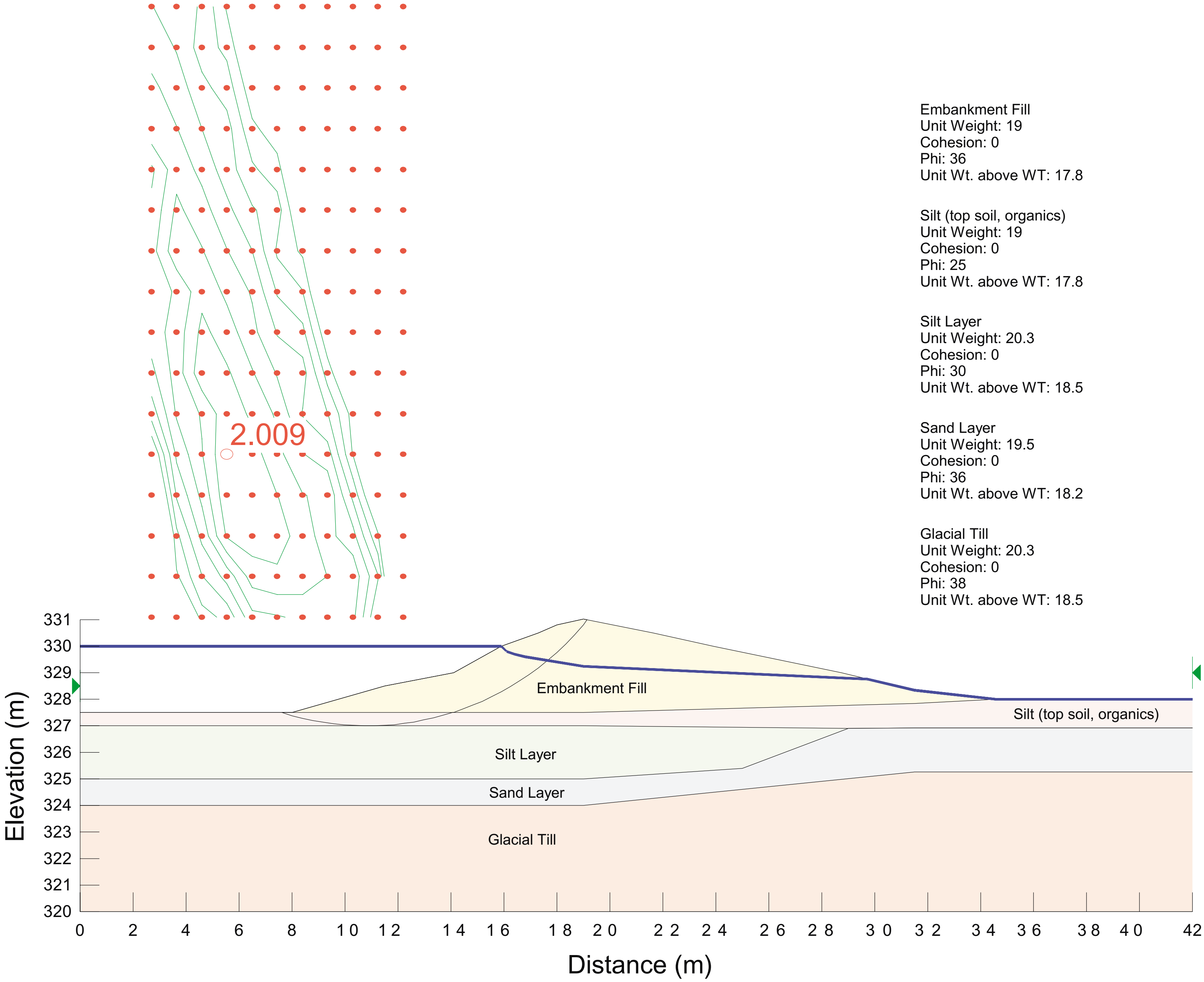
Silt Layer
Unit Weight: 20.3
Cohesion: 0
Phi: 30
Unit Wt. above WT: 18.5

Sand Layer
Unit Weight: 19.5
Cohesion: 0
Phi: 36
Unit Wt. above WT: 18.2

Glacial Till
Unit Weight: 20.3
Cohesion: 0
Phi: 38
Unit Wt. above WT: 18.5

Figure 8.3
Upper Thames River Conservation Authority
Dam Safety Assessment Report - Harrington Dam
Downstream Slope Stability, Extreme Load Condition (NWL, S_h)

FIGURE 8.3 – BACK



Embankment Fill
Unit Weight: 19
Cohesion: 0
Phi: 36
Unit Wt. above WT: 17.8

Silt (top soil, organics)
Unit Weight: 19
Cohesion: 0
Phi: 25
Unit Wt. above WT: 17.8

Silt Layer
Unit Weight: 20.3
Cohesion: 0
Phi: 30
Unit Wt. above WT: 18.5

Sand Layer
Unit Weight: 19.5
Cohesion: 0
Phi: 36
Unit Wt. above WT: 18.2

Glacial Till
Unit Weight: 20.3
Cohesion: 0
Phi: 38
Unit Wt. above WT: 18.5

Figure 8.4
Upper Thames River Conservation Authority
Dam Safety Assessment Report - Harrington Dam

Upstream Slope Stability, Normal Load Condition

FIGURE 8.4 – BACK

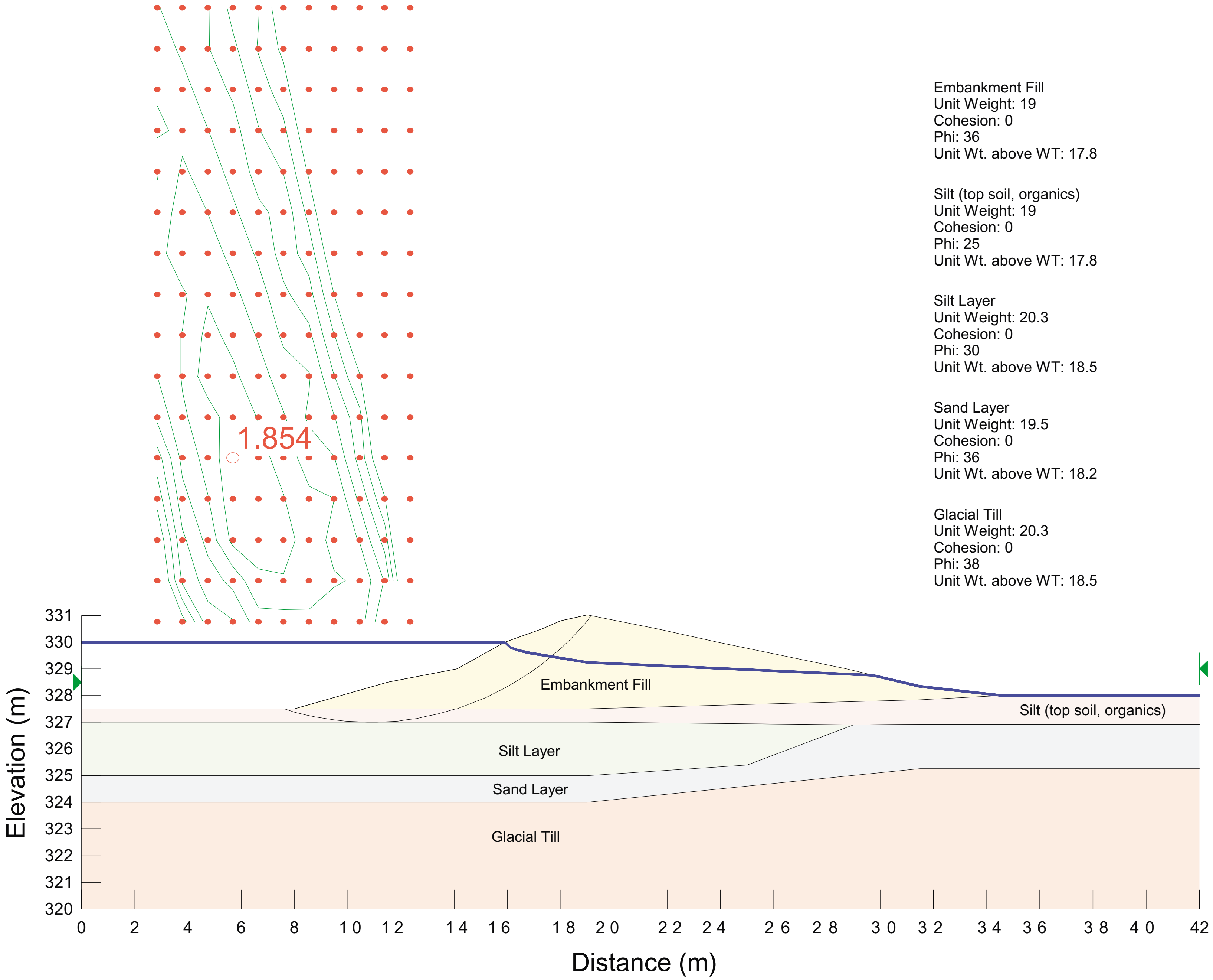


Figure 8.5

Upper Thames River Conservation Authority

Dam Safety Assessment Report - Harrington Dam

Upstream Slope Stability, Extreme Load Condition (NWL, S_h)

FIGURE 8.5 – BACK

> The factor of safety was determined to be 1.45. This value would decrease as the uplift increases. Therefore, although the factor of safety exceeds 1, it is less than the 1.5 value required to meet the compliance criteria.

8.4 Assessment

There is no evidence of settlement, cracking or displacement in the dam or in the abutments, but there is evidence of bulging locally on the downstream slope which is indicative of a high water table and potential instability. There is also evidence of small ‘boils’ on the ground near the downstream toe of the dam, suggesting subsurface seepage and the possibility of artesian pressures (uplift) in the area of the toe of the slope. It is recommended that this condition be remedied. Suggested remedial measures might include a cutoff wall along the crest or a berm on the downstream slope. Some further rehabilitation is required; for example, while there is riprap protection on the upstream slope, some wave-induced erosion has occurred locally.

The left embankment meets all the required stability criteria, but the right embankment does not.

9 Operations, Maintenance and Safety

No OMS manual has been prepared for the Harrington Dam under the current dam safety assessment study.

9.1 Operation

The low-level and 3-bay spillway (not operated) combined with the emergency spillway structure at the Harrington Dam are not adequate to ensure the safe passage of the IDF, and adequate freeboard is not maintained.

9.2 Access and Signage

The public has free access to the structure. Public access should conform to MNR draft Dam Safety Bulletin #3, ‘Public Access to Dams’, found in Appendix G.

At the Harrington Dam, because the public has free access to the dam, there should be “Use At Your Own Risk” signs posted. A sign on the upstream guardrail warning boaters and swimmers to keep away should be posted.

9.3 Fall Protection

Because the Harrington Dam is not operated, fall protection is not required.

9.4 Log Boom

There is no log/debris boom present at this site, and none is required.

Plan

10 Emergency Preparedness Plan

In the event of the failure of the Harrington Dam, the UTRCA is responsible to warn residents of a hazardous situation, linking appropriate dam surveillance with emergency response procedures. The procedures that the dam operator is responsible for are defined in an EPP. The EPP is intended to guide the operator with respect to the procedures that are required to be performed in the event of an emergency. These procedures link with UTRCA's overall emergency response plan (ERP) to allow for planning by parties that might be affected in the event of a dam break flood, and the coordination of efforts between federal, provincial and municipal levels of government.

According to the requirements of the draft ODSG

> *"An EPP shall describe the actions to be taken by the dam owner and operator in an emergency. The EPP shall assign responsibility for each action to be taken by an individual (identified by organizational position) and/or a backup."*

For the dam considered under this study, the EPP is required to include the following procedures and information:

- emergency identification and evaluation
- preventative actions (where available)
- notification procedures
- notification flowchart
- communication systems
- access to site
- response during periods of darkness/adverse weather
- sources of equipment
- stockpiling supplies and materials
- inundation maps (where required).

The EPP for this dam was prepared under separate cover by Acres. For details, the reader is referred to this document.

It should be noted that these plans were prepared using the best information that was available at the time of preparation. These plans are, however, dynamic documents that must be reviewed and updated on an annual basis, particularly with respect to contact names, addresses and telephone numbers, in conjunction with UTRCA’s ERP.   These notifications were summarized in an Emergency Action Table which is attached at the end of this section.

Testing of the EPP should be performed.

Problem	How to Evaluate	Notification	Data to Record	Action
Flooding	• Water level approaching el 330.50m the crest of the right embankment but no waves overtopping the dam.	UTRCA Emergency Response Coordinator	• Water flow discharge, headwater, tailwater elevations and rate of change • Weather conditions • Photographs • Dam and flow control equipment condition	• M itor situation. • R rict access to pa • W n anyone workin ir e grist mill and th ir e left downstrean
	• Waves overtopping crest of dam.	UTRCA Emergency Response Coordinator	• Water discharge, headwater, tailwater elevations and rate of change • Weather conditions • Photographs • Dam and flow control equipment condition	• M itor situation. • Pl e sandbags or fil cr t to increase free • R rict access to pa • W n anyone workin ir e grist mill and th ir e left downstrean
	• Water level exceeds crest of dam and downstream slopes eroding.	UTRCA Emergency Response Coordinator	• Water discharge, headwater, tailwater elevations and rate of change • Weather conditions • Photographs • Dam and flow control equipment condition	• M itor situation. • Fo w procedures fo Da Failure. • Re rict access to cre • W n anyone workin in e grist mill and th in e left downstrean
Imminent Dam Failure	• Slopes of dam severely eroded • Excessive seepage • Whirlpool in headpond • Extensive cracking • Boils or springs downstream • Discharge of fines	UTRCA Emergency Response Coordinator	• Water discharge, headwater, tailwater elevations and rate of change • Weather conditions • Photographs • Dam and flow control equipment condition	• R rict access to cr • W n anyone workin ir e grist mill and th ir e left downstrean
Dam Failure	• Dam breached	UTRCA Emergency Response Coordinator	• Water discharge, headwater, tailwater elevations and rate of change • Weather conditions • Photographs • Description and location of dam breach	• R rict access to cr • W n anyone workin ir e grist mill and th ir e left downstrean
Non-dam Emergency	• Boating accident • Swimming emergency • Personal injury	Emergency Medical Response Team 911 UTRCA Emergency Response Coordinator	• Nature of problem • Photographs • Names • Cause(s) of accident • Length of time for response	• Fo w standard proc fo irst Aid

Harrington Dam
Emergency Action Table

11 Recommendations and Costs

11 Recommendations and Costs

As a result of the 2002/2003 dam safety assessment, a number of recommended actions and maintenance activities were identified that are intended to ensure that the structure will satisfy current dam safety criteria within a 20-yr planning horizon. These ranged from routine monitoring to relatively major concrete rehabilitation works. In each case, an attempt was made to prioritize the remedial work requirements.

For each of the recommended issues, prefeasibility level cost estimates were developed based on an assessment of the general scope of work and typical unit price data from similar projects in Ontario. Note that the cost estimates that were developed were made on the basis of the actual estimated direct construction costs for the individual remedial action identified. As details of the contract packaging for a given dam are not known at this time, other costs (such as mobilization, control of water, increased access costs at remote damsites, contingency and engineering costs) were estimated on the basis of a percentage of the contract price according to the general guidelines summarized in Table 11.1.

Table 11.1

Summary of Additional Costs Associated With a Typical Remedial Repair Project

Item	Cost
Mobilization and demobilization	5% to 7% of capital cost
Control of water during construction	3% to 10% of capital cost (can vary significantly depending on complexity)
Barge access	10% to 15% of capital cost
Contingency	15% to 25% of capital cost
Engineering and supervision	8% to 15% of capital cost

In preparing cost estimates for repairing deteriorating concrete, it was generally anticipated that the scope of the repairs would include all of the deteriorated concrete and at least some of the concrete surrounding the repairs. It was usually assumed that, where necessary, the entire pier, upstream and downstream of the gains, would be repaired at one time. The actual timing of the repairs may, of course, vary. For example, it may be cost-effective where the extent of upstream deterioration is relatively minor to undertake these repairs under a separate, smaller contract, at a later date. There was no attempt made to address the timing of repair issues in this report. It is also noted that costs for repairing areas of relatively minor deterioration, that are not considered to require attention at this time, were not developed.

An explanation of the priority numbers and concrete repair classifications are shown in Tables 11.2 and 11.3. Details of the recommended action and associated costs for the Harrington Dam are summarized in Table 11.4. An overall cost summary of the remedial repairs, including allowances for engineering, permitting and environmental costs, is provided in Table 11.5.

Table 11.2

Explanation of Priority Numbers

Priority	Description
1	Immediate - Corrective action required immediately due to safety concerns.
2	High - Corrective action required within 2 years.
3	Medium - Corrective action required within 5 years.
4	Low - Corrective action required within 10 years.
5	Monitoring - Defect should be monitored with corrective action to be taken only when required.

Note: Each level reflects the relative importance or urgency associated with taking some form of action. In cases in which the defects were observed to be safety related (mostly Priority 1 items), action means actual construction. It is noted that some of the Priority 5 items may need to be reassigned a higher priority once the areas have been monitored and investigated and any defects have been identified.

Table 11.3

Concrete Repair Classification

Description		Area (m^2)	Depth of Repair (mm)	Method
1	Sealing contraction joints (above water)	N/A	N/A	Remove existing cracked caulking by mechanical or other means. Clean joint of dirt and other residue. Apply backer rod if joint is deep. Apply primer. Apply polyurethane elastomeric sealant. Applicable to horizontal and vertical surfaces above waterline.
2	Sealing cracks and contraction joints below waterline	N/A	N/A	Requires diver. Remove existing sealant, if present. Clean joint of algae, etc, by wire brushing. Apply sealant such as Devclad 182 with ethafoam backing rod as required.
3	Bonding cracks (above waterline)	N/A	N/A	Required for structural bonding or to stop water leakage. Use epoxy injection for cracks less than 12 mm, cementitious injection for larger cracks. Where a crack is known to be damp or leaking water, use a water-reactive polyurethane resin.
4.1	Small vertical areas	0 – 2	1 – 50	Remove deteriorated concrete, saw cut, clean, trowel repair mortar
4.2	Horizontal areas	1 – 5	12 – 50	Remove deteriorated concrete, saw cut, pour free-flowing repair mortar
4.3	Large vertical areas	-	12 – 50	Remove deteriorated concrete, saw cut, shotcrete
4.4	Unlimited size vertical surfaces with deep deterioration	-	>75	Chip, saw cut, form and pour concrete. Dowels and rebar may be necessary.
4.5	Vertical areas with exposed rebar	-	12 – 50	Remove deteriorated concrete to 50 mm. Behind rebar, clean rebar of all rust, clean concrete and apply repair material.
4.6	Horizontal overlay with rebar	-	12 – 50	Remove deteriorated concrete to 50 mm. Behind rebar, clean rebar of rust, clean, apply overlay in accordance with manufacturer's directions.
4.7	Large areas of new reinforced facing concrete	-	>150	Roughen old concrete, dowel as required, place new rebar, form and pour concrete
5	Vertical grouting of masonry piers	-	-	Repoint masonry along wall faces. Drill vertically through pier from deck level. Grout using balanced, stable, cement-based suspension grouts to fill all voids and cracks in masonry.

Table 11.4

Estimated Remedial Repair Costs – Harrington Dam

Item No.	Structure	Component	Defect Description	Repair Description	Repair Type	Estimated Quantity	Estimated Construction Cost (2004 $)	Priority	Remarks
1	Embankment	Upstream slope	Some erosion occurring	Install riprap	-	90 m^2	5,000	2	1.5 m x 60 m = 90 m^2
2	Left and right embankments	Crest	Too low	Raise height of crests	-	35 m^3	2,000	1	Crest overtopped during IDF and inadequate freeboard. 0.5 H x 35 L x 2 W = 35
3	Entire dam	-	Lack of signage	Install signs	-	3	1,000	1	Install “Use at Own Risk” signs at each end of dam and “Danger – Keep Away – Fast Water” sign on upstream guardrail.
4	Spillway	Guardrail	Gaps in guardrail do not meet code requirements	Install mesh to reduce openings	-	-	-	1	By UTRCA.
5	Spillway	Low-level outlet	Gate may be inoperable	Repair to make operable	-	-	1,000	2	Contact manufacturer to inspect.
6	Spillway	Deck	Too low	New pedestrian bridge	-	-	5,000	1	Deck needs to be raised by 0.50 m.
7	Spillway	Abutments	Too low	Raise by 0.50 m	-	1 m^3	-	1	6 x 0.3 x 0.5 = 0.9 m^3. Included in Item 14.
8	Spillway	Deck	Excessive deflection	Support grating at closer spacing	-	-	-	2	Included in Item 6 above.
9	Left and right embankments	Adjacent to spillway	Repairs from 2000 flood not completed	Compact material next to spillway	-	-	-	1	Included in Item 2 above.
10	Spillway	Wingwalls and abutments	Freeze-thaw damage	Repair	4.1, 4.2	3 m^3	-	3	Concrete: 20 x 0.3 x 0.5 = 3 m^3. Included in Item 14.

Table 11.4
Estimated Remedial Repair Costs – Harrington Dam – 2

Item No.	Structure	Component	Defect Description	Repair Description	Repair Type	Estimated Quantity	Estimated Construction Cost (2004 $)	Priority	Remarks
11	Spillway	Wingwalls and abutments	Cracks	Bond and seal	3	5 m	-	3	Included in Item 14.
12	Spillway	Wingwalls and abutments	Erosion damage	Chip and trowel repair material	4.1	0.13 m^3	-	3	1.5 x 0.15 x 0.15 + 10 x 0.1 x 0.1= 0.13 m^3. Included in Item 14.
13	Left embankment	Downstream slope	Seepage	Install downstream seepage control	-	350 m^3	50,000	3	Cutoff wall along crest or berm on downstream toe.
14	Spillway	Sluices	Inadequate discharge capacity	Install two overshot gates from Springbank	-	-	70,000	1	Modifications to existing structure. Remote operation included.
15	Spillway	Sluices	Inadequate discharge capacity	Try to reduce the IDF by closer look at basin topographs	-	-	5,000	1	Engineering study using more detailed maps of the area.
16	Spillway	Stilling basin	-	Required downstream of overshot gates	-	-	50,000	1	Required for energy dissipation to prevent erosion.
17	Spillway	Entire structure	Assumed founded on inorganic sill and clay	Additional boreholes	-	2	15,000	2	Should be performed before any remediation work attempted.
18	Right embankment	Downstream slope	Does not meet factor of safety	Perform rigorous stability analysis	-	-	2,500	2	
							206,500		

Table 11.5

Budget Estimate Summary of Construction Costs for Maintenance Repairs for the Harrington Dam

Item No.	Description	Unit	Quantity	Unit Price ($)	Amount ($)
1	Mobilization and demobilization (5%)	LS	1	10,000	10,000
2	Repairs to dam and structures	LS	1	206,500	206,500
3	Control of water during construction	LS	1	20,000	20,000
4	**Subtotal (Construction Costs Without Contingency)**				**236,500**
5	Contingency on Construction Costs (25%)				59,125
6	**Total Estimated Construction Costs**				**295,625**
7	Engineering and Supervision	LS	1	25,000	25,000
8	**TOTAL ESTIMATED COST**				**320,625**

Bibliography

Bibliography

Arumoli, K., et al. **Recommended Procedures for Implementation of DMG Special Publication 117 – Guidelines for Analyzing and Mitigating Liquefaction Hazards in California**. Southern California Earthquake Center. University of Southern California. 1999.

Bowles, J. E. **Foundation Analysis and Design**. 5th Edition. McGraw Hill, Inc. 1996.

Canadian Geotechnical Society. **Canadian Foundation Engineering Manual**. 3rd Edition. 1992.

Chow, V. T., D. R. Maidment, and L. W. Mays. **Applied Hydrology**. McGraw-Hill. 1988. pp 466-467.

GEO-SLOPE International Ltd. SLOPE/W, Version 5. Calgary, Alberta.

Holtz, R. D., and W. D. Kovacs. **Introduction to Geotechnical Engineering**. Prentice Hall. 1981.

Huff, F. A. **Time Distributions of Heavy Rainfall in Illinois**. 1990.

Marshall Macklin Monaghan. **Report No. 9, Hydrologic and Flood Damage Study**. Background report to the Glengowan Environmental Assessment. Upper Thames River Conservation Authority. March 1983.

Ministry of Northern Development and Mines. “Quaternary Geology of Ontario”, Map 2556, Scale 1:1 000 000. 1991.

National Research Council Canada. **National Building Code of Canada**. 1995.

Ontario Division of Mines. “Quaternary Geology, Woodstock, Southern Ontario”, Map 2381, Scale 1:63 360. 1973.

Ontario Ministry of Municipal Affairs and Housing. **Ontario Building Code**. 1997.

Ontario Ministry of Natural Resources. **Ontario Dam Safety Guidelines, Draft Issue**. Lands and Natural Heritage Branch. September 1999.

Ontario Ministry of Natural Resources. **Flood Plain Management in Ontario, Technical Guidelines**. 1986.

US Army Corps of Engineers. **Shore Protection Manual, Volume 2**. 1984.

US Army Corps of Engineers, Hydrologic Engineering Center. "HEC-1 Flood Package, Version 4.1." June 1998.

US Army Corps of Engineers, Hydrologic Engineering Center. **River Analysis System, HEC-RAS, Version 3.1.1**. May 2003.

US Department of the Interior, Bureau of Reclamation. **Design of Small Dams**. 1973.

US Department of the Interior, Bureau of Reclamation. **Freeboard Criteria and Guidelines for Computing Freeboard Allowances for Storage Dams**. 1981.

World Meteorological Organization (WMO). "Guide to Hydrological Practices," **WMP No. 168 Geneva**. 1974.

Appendix A

Photographs

Photo 1 – View of Dam from Right Bank

Photo 2 – Downstream View of Right Embankment

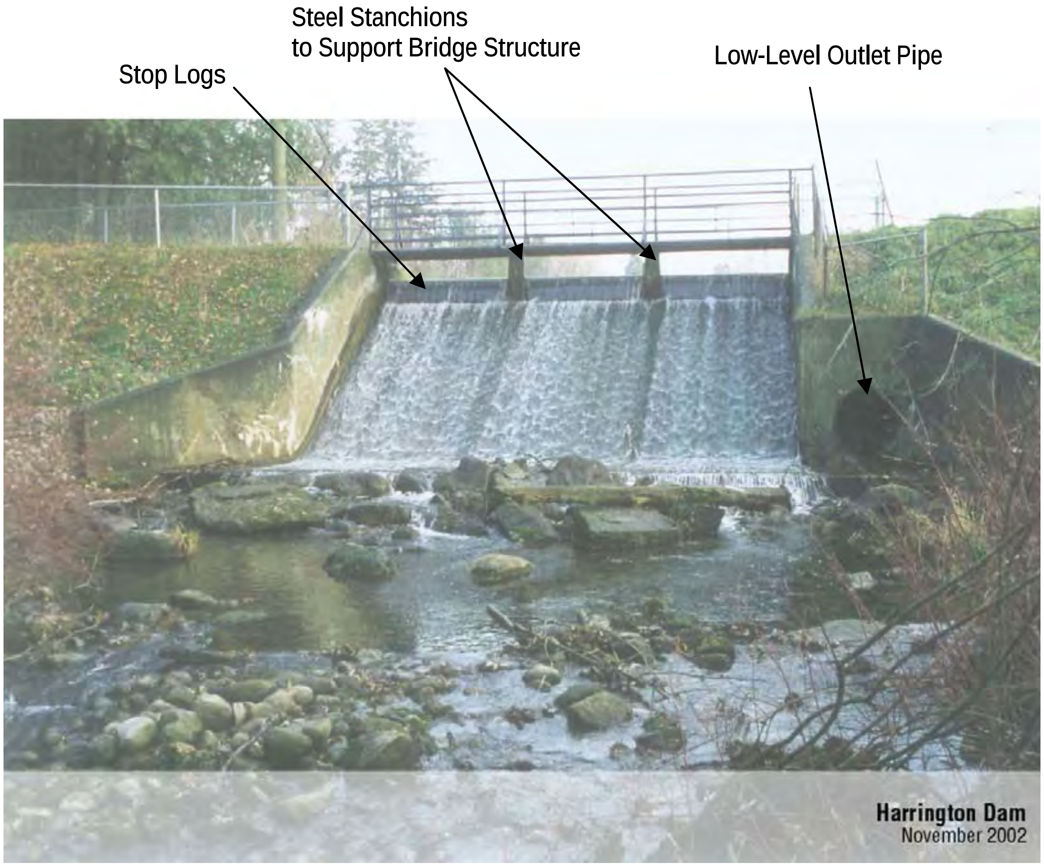


Photo 3 – Downstream View of Spillway

Photo 4 – Abandoned Mill Raceway

Photo 5 – Area Downstream of Dam

Photo 6 – View of Upstream Pond

Photo 7 – Twin Box Culverts Under County Road 96

Left Downstream Wingwall

Photo 8 – Gabion Baskets, Left Downstream Side of Spillway

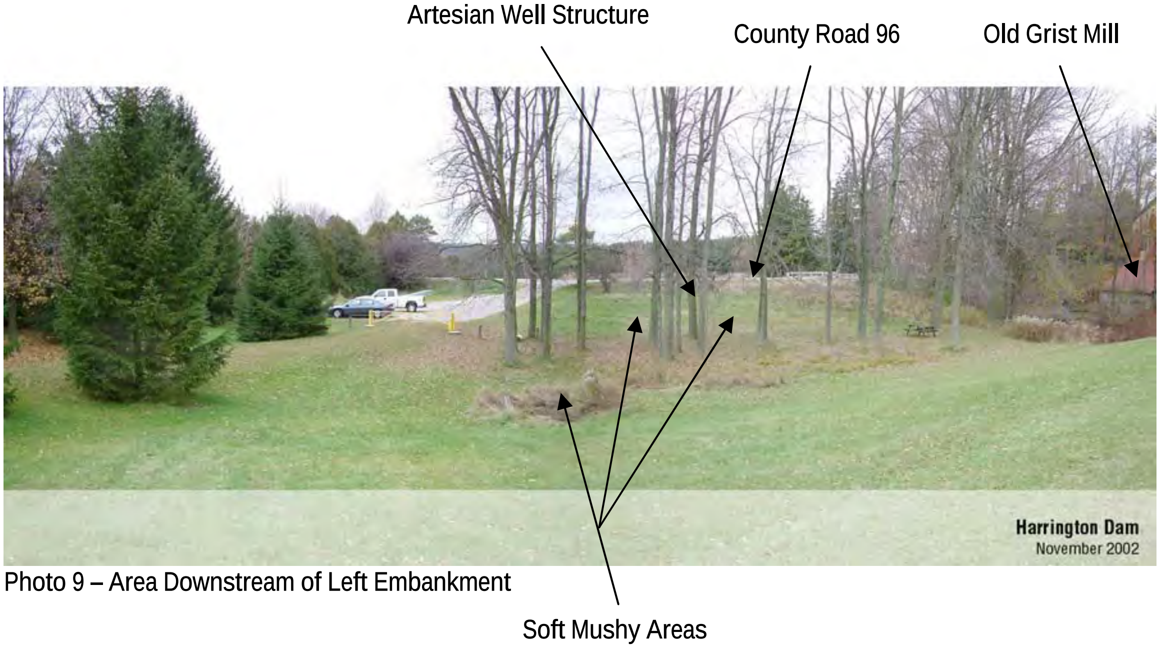


Photo 9 – Area Downstream of Left Embankment

Photo 10 – House in Left Downstream Floodplain

Photo 11 – Upstream Slope and Crest of Left Embankment

Photo 12 – Leakage Area, Left Downstream Slope

Photo 13 – Upstream View of Spillway

Photo 14 – Crest of Right Embankment

Photo 15 – Close-up of Cracking in Right Downstream Wingwall

Photo 16 – Concrete Deterioration, Left Abutment

Photo 17 – Left Downstream Wingwall

Photo 18 – Intermediate Piers of Spillway

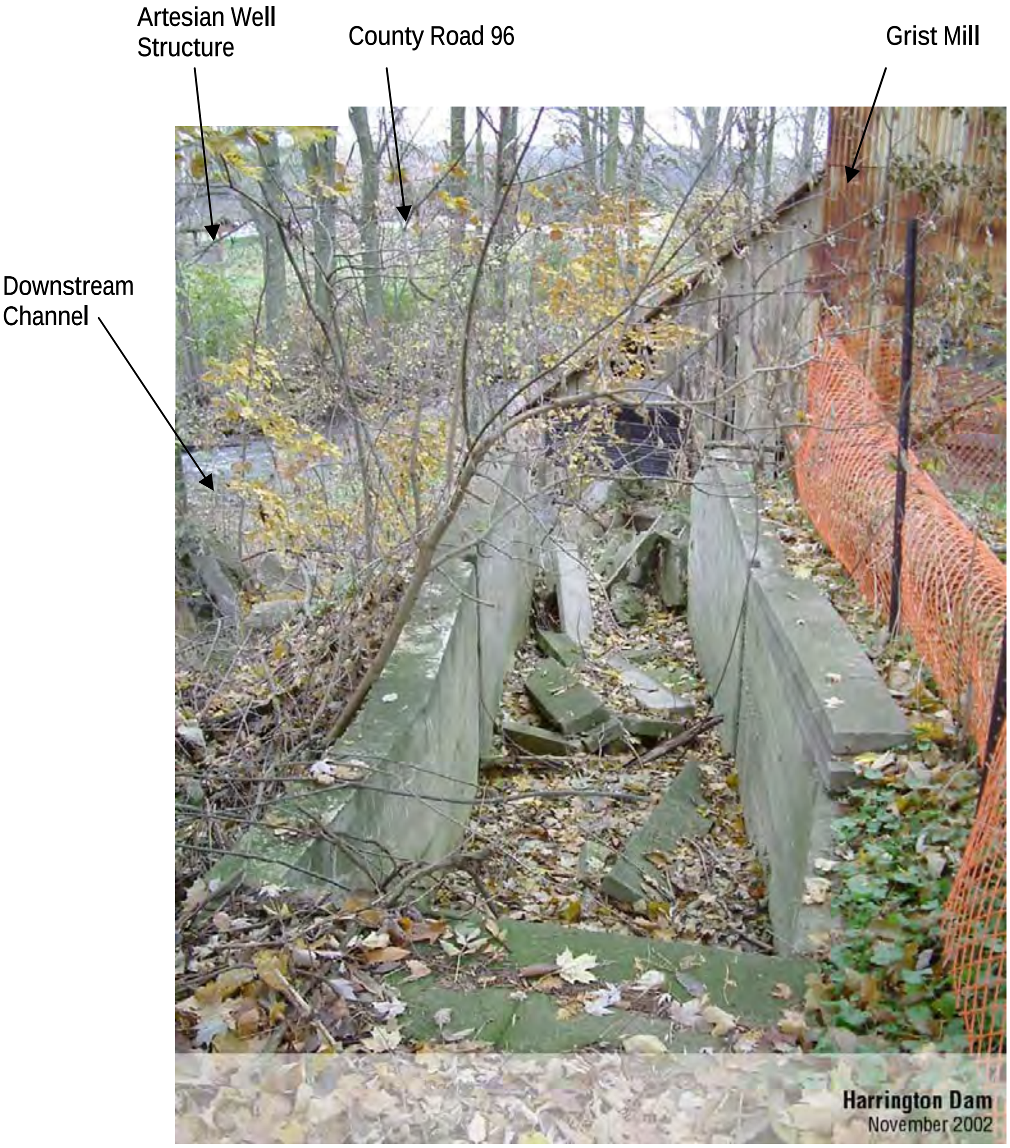


Photo 19 – Concrete Flume Leading to Grist Mill

Appendix B

Forms B1 and B2

Form B1

Pre-Inspection Background Information

Prepared By:	Acres International Limited	
Name of Dam:	Harrington	
Latest Construction:	2000	Repaired erosion damage at downstream east side of dam. Installed gabions and restored slope.
	Summer 1985	Gabion basket repair. Phased removal of trees from embankment initiated. Minor concrete repair at end of wingwall.
Inspection Dates:	July 2001	UTRCA
	July 2000	UTRCA
	August 1985	UTRCA
	May 1982	UTRCA
Access:	Town of Harrington, turn off into Harrington Conservation Area from County Road 96	
Lake Controlled:	Harrington Pond	
Lake Area:	0.03 km^2	
Watershed:	Harrington Creek, tributary of Trout Creek, North Thames River Watershed	
Drainage Area:	12 km^2	
Gauge Info:	None at the dam	
Rule Curves:	Not available	
List of Drawings:	UTRCA:	
	#?	Dam Hazard Identification, Harrington Dam, July 2001

Kilborn Engineering Co. Limited:

54-A-2	Harrington Dam – Spillway, July 1952
54-A-3	Harrington West Dam – Portion of Reservoir, July 1952
54-B-1-1	Harrington Dam General Layout, July 1952

Source: unknown

W-2#54	Harrington Dam – Spillway, No Date

Meteorological and Hydrological Data: The following meteorological data are available from Stratford, Woodstock and London airport:

- daily precipitation amounts
- mean, maximum and minimum daily temperatures.

The closest regional streamflow gauging station are

- Trout Creek (Station No. 02GD009); drainage area = 140 km^2
- Trout Creek near Fairview (Station No. 02GD019); drainage area = 36 km^2.

Both ceased operating in 1991 but Fairview back in operation in 2002.

Topographic Maps: 40 P/2 Woodstock (1:50 000-scale)

Soil and Land-Use Maps: Soil Map of Oxford County, Ontario (digitized, UTRCA) and The Upper Thames River Watershed Report Cards 2001

Dam Height: 4.0 m (from drawings)

Dam Length:
Left embankment – approximately 65 m
Concrete spillway – 7.32 m
Right embankment – approximately 20 m

No. of Sluiceways: Three bays plus one low-level outlet

No. of Stop Logs per Bay: 2 per bay (third row removed in 2000)

Hydrologic Flows: Nothing available in files

Hydraulic Analysis: Nothing available in files

Dam Operation: Dam is not operated

Soils Reports: See Appendix A, Table 4. Soil Type in Upper Thames River Watershed, Report Cards 2001

Underwater Inspections: None available

Property Ownership: UTRCA

CA Maintenance: Harrington Community Club

Dam Maintenance: UTRCA

Divestment Opportunities: Annual agreement for area management

Known Problems: Dam was overtopped twice in 2000. Erosion has occurred between abutments and embankments. Partial repairs have been performed, but more required. Embankment crest is lower at both sides of the spillway structure.

Seepage though left embankment as seen by mushy ground near toe is being monitored.

Invert of millrace is close to elevation of dam crest promoting potential overtopping during flood conditions.

Summary of File: See Table 3.1 documenting all dam safety reference information found in UTRCA files

Form B2

Dam Inspection Report

Date: November 12 and 19, 2002

Structure: Harrington Dam

Municipality: Zorra

Location: Zorra Township, Oxford County, in the town of Harrington

GPS Coordinates: UTM, NAD83: 17 500 642 E, 4 787 565 N
Lat/Long: 43° 14’ 27” N, 80° 59’ 32” W

Inspected By: B. Craig, T. Hartung, P. Last, M. Ragwen and B. Sinclair of Acres International Limited

Weather: Cloudy overcast, air temperature approximately 6°C

---

1. Earth Embankment

For details, see the photographs in Appendix A and the attached drawings.

- Upstream slope of left embankment sparsely protected by cobbles and boulders. Signs of erosion are visible along shore.
- Downstream left embankment shows signs of bulging. Seepage visible below bulging. Evidence of internal erosion along seepage path exists.
- Indication of washout between left embankment and concrete spillway.
- No signs of distress on right embankment. Steep slope on downstream side layered with geotextile netting to promote vegetation growth.
- Invert of millrace seems higher than crest of dam.

---

2. **Concrete Structures** (wingwalls, piers, deck, spillways, apron, etc)

For details, see the photographs in Appendix A and the attached drawings.

- Spalls and cracking over surface of left and right abutment and wingwalls. Potential alkali-aggregate reaction.
- Significant map cracking and spalls at upstream end of left abutment. Steel reinforcement exposed.

- Hydraulic erosion near waterline on left abutment and around low-level outlet.
- Large stress crack in downstream left wingwall at location of low water outlet.

3. **Wooden and Metal Structures** (decks, gains, railings, conduits, etc)

For details, see the photographs in Appendix A and the attached drawings.

- Railings along the top of the bridge deck appear in good condition but require painting. Height meets code requirements; however, openings must be checked since dam has full public access.
- Steel gains are in good condition with light rust.
- The 51-mm deep galvanized steel deck grating is in good condition with minor rust. Significant deflection obtained when standing midspan.
- Steel deck supports appear in good condition with minor rusting.

4. **Gates and/or Stop Logs** (identified looking downstream left to right)

For details, see the photographs in Appendix A and the attached drawings.

Three stop log bays directly below steel decking. Steel decking must be removed for access. Operator survey indicates that logs are left all year and are difficult to remove during flood conditions. Stop logs appear in good condition.

5. **Water Level Gauge** (reading and condition)

For details, see the photographs in Appendix A.

No water level gauge is located on-site. Operator survey indicates that measurements are taken with reference to dam deck.

6. **Winches** (type and number)

For details, see the photographs in Appendix A.

No winches are located on-site. Logs removed manually.

7. **Valves** (type and number)

For details, see the photographs in Appendix A.

One low-level outlet valve in the left abutment. Controls for valve housed in locked wooden box on upstream side of left abutment. Access hatch is located within a locked fenced area. Not operated during inspection. Minor leaking visible from outlet. Operator survey indicates valve may not be operable.

---

8. **Boom** (driftwood, chains, anchors)

For details, see the photographs in Appendix A.

No boom present at this site, and none is recommended.

---

9. **Erosion** (upstream and downstream)

For details, see the photographs in Appendix A and the attached drawings.

Erosion has on the upstream shore of the left abutment.

Washout and erosion between embankments and abutments due to overtopping of dam. Repair has been attempted with gabions and sandbags.

Internal erosion of dam through seepage planes is visible by muddy water emanating from downstream face of left embankment.

---

10. **Seepage or Leaks**

For details, see the photographs in Appendix A.

Seepage through the left embankment seen as wet areas on the downstream face.

---

11. **Access Route** (location of gate keys, winch handles and keys)

Vehicular access is possible to left dam bank via access road from Harrington CA parking lot. UTRCA maintenance has keys to access gate and low flow valve access hatch. Dam within walking distance from Harrington CA parking lot.

12. **Safety Issues** (public and operator)

- No warning signs for boaters or public using the dam.
- Invert of millrace seems higher than dam crest promoting overtopping during flood conditions.

---

13. Signage

For details, see the photographs in Appendix A.

- “Danger, Fast Current, No Boating, No Swimming” sign missing from upstream side of dam.
- No “Use at Own Risk” signs for public using the deck as a pedestrian crossing.

---

14. Divestment and/or Decommissioning Opportunities

Annual agreement for area management.

---

15. General Remarks

The dam is generally in adequate condition but requires further repair and maintenance. Major dam safety deficiencies exist.

---

16. Recommendations

- Install “Use at Own Risk” signs at both ends of the dam.
- Ensure openings in guardrails on deck to conform to code requirements in areas where public access is permitted.
- Check serviceability of bridge deck and modify as required.
- Investigate operational status of low flow valve.
- Regrade millrace to ensure proper diversion during flood conditions.
- Repair cracks and deterioration in dam as required.
- Determine extent of seepage through dam and repair as required.

Appendix C

Appendix C

Discussion on the Balanced Distribution

Appendix C

Discussion on the Balanced Distribution

In the case of dam safety studies, since the variation of rainfall depths in a storm is essentially random then the objective is to come up with a critical storm pattern, produced by re-arranging the rainfall excess pattern into the most critical sequence. There are two ways of approaching this selection. It can be based on either (a) the worst possible storm pattern or (b) an analysis of recorded storm distribution patterns (e.g., the F. A. Huff study in 1990). Acres conducted a brief review that examined the existing reports on the statistics of the frequency of hyetograph shapes that would be applicable to the Upper Thames watershed and its small dams. Acres examined and compared the Huff storm distributions (Huff, 1990), the AES 30% distribution, 6-hr Becker design storm, the 12-hr southern Ontario design storm and the SCS Type II storm distribution. Our proposal did not entail an in-depth study of historical storm patterns to arrive at a storm pattern applicable to dam safety studies. It should be remembered that in December 2002 when Acres received an e-mail containing the UTRCA VO2 model of the Upper Thames watershed there were problems with the VO2 model storm files that precluded their (and the model's) use at the time. As an alternative, it was agreed that the HEC-HMS rainfall-runoff model would be used for the smaller damsites (Dorchester Mill Pond, Dorchester CA, Centreville, Embro, Harrington and Shakespeare dams).

In Acres experience with dam safety studies, one can use a historical storm pattern from a set with a certain frequency of occurrence but there are disadvantages to this method. Consideration has to be given of joint probability and the fact that historical storms rarely repeat themselves. Also, the selection may not turn out to be the critical pattern. In addition, the consequences of climate change are causing significant changes in rainfall patterns (more intense and frequent storms) that would reduce the efficacy of the selection historical storm patterns for peak flows for dam safety assessment.

Because of our long experience with dam safety work, our practice is to use an IDF-generated hyetograph for the critical design storm for the key dam structures. Conservative considerations are made for the time-wise distribution of rainfall depths which must vary from zero at the beginning and end of the storm and rise to a maximum at some intermediate time increment. The smallest increment of rainfall depends upon the time of concentration of the river basin. Acres has found that although the storms are either front-loaded, back-loaded or center-loaded, it is the center-loaded IDF hyetographs that generate the highest peak flows. Because of this, in synthesizing the design hyetograph, the increment of maximum rainfall intensity is generally placed somewhere near the midpoint of the storm and the hyetograph developed using the alternating block method (Chow et al, 1988).

In other studies, Acres analyzed three patterns of hyetographs

(a) center-loaded (derived by the alternating block method)
(b) SCS Type II, and
(c) SCS Type II but with the highest rainfall intensity occurring at the end of the first quartile of the storm duration.

The center-loaded storm pattern produced the highest peak outflow although this was only 0.3% larger than outflow from the SCS Type II storm pattern. For all practical purposes, the center-loaded storm pattern gives the same outflow as the SCS Type II storm. In our view, the use of the SCS Type II storm pattern would have resulted in very similar outflows to the center-loaded storms used in our analysis. The original SCS Type II distribution itself was developed using the ‘balanced’ or ‘alternative block’ method and then made dimensionless by the United States Department of Agriculture. The SCS front end-loaded storm which is similar to the AES storm pattern, produced a peak outflow that was 6% less than the center-loaded distribution.

Acres did examine the 30% AES storm distribution data that UTRCA submitted in 2003. The basic criterion is that the aggregated incremental rainfall in the distribution must be equal to the corresponding value in the AES DDF data. In both the 12-hr and 24-hr 1:50-yr storms using UTRCA percentages, we found that these exceeded the amounts that were in the DDF data and were, therefore, outside of the DDF results. These were amended and the percentages adjusted to conform to the DDF data and the distribution changed accordingly. They were still front end-loaded storms and the resulting flood peaks were lower than the center-loaded storms. The result was expected since the SCS loss function is also front end-loaded. These were not considered appropriate for dam safety assessment of the dams’ discharge capacities.

Appendix D

Appendix D

Balanced Distribution Curves

(Tables D1 to D7)

Table D1

Balanced Distribution
6-Hr Rainstorm Based on Stratford Rainfall Data

Duration (hrs)	Cumulative Percentage of Storm Depth
0.0	0.00
0.3	1.75
0.5	3.49
0.8	5.24
1.0	6.99
1.3	8.73
1.5	10.48
1.8	12.23
2.0	13.97
2.3	19.51
2.5	25.05
2.8	30.76
3.0	57.08
3.3	70.24
3.5	75.77
3.8	81.31
4.0	86.03
4.3	87.77
4.5	89.52
4.8	91.27
5.0	93.01
5.3	94.76
5.5	96.51
5.8	98.25
6.0	100.00

Table D2

Balanced Distribution 12-Hr Rainstorm Based on Stratford Rainfall Data

Duration (hrs)	Cumulative Percentage of Storm Depth
0.0	0.00
0.5	0.74
1.0	1.48
1.5	2.21
2.0	2.95
2.5	3.69
3.0	4.43
3.5	7.61
4.0	10.79
4.5	13.98
5.0	17.16
5.5	27.25
6.0	63.23
6.5	73.33
7.0	82.84
7.5	86.02
8.0	89.21
8.5	92.39
9.0	95.57
9.5	96.31
10.0	97.05
10.5	97.79
11.0	98.52
11.5	99.26
12.0	100.00

Table D3

Balanced Distribution 24-Hr Rainstorm Based on Stratford Rainfall Data

Duration (hrs)	Cumulative Percentage of Storm Depth
0.0	0.00
1.0	0.53
2.0	1.06
3.0	1.59
4.0	2.12
5.0	2.65
6.0	3.18
7.0	4.56
8.0	5.94
9.0	7.32
10.0	13.28
11.0	19.25
12.0	61.85
13.0	80.75
14.0	86.72
15.0	92.68
16.0	94.06
17.0	95.44
18.0	96.82
19.0	97.35
20.0	97.88
21.0	98.41
22.0	98.94
23.0	99.47
24.0	100.00

Table D4

Balanced Distribution 2-Day Rainstorm Based on Stratford Rainfall Data

Duration (hrs)	Cumulative Percentage of Storm Depth
0.0	0.00
2.0	0.38
4.0	0.76
6.0	1.15
8.0	1.53
10.0	1.91
12.0	2.29
14.0	3.30
16.0	4.31
18.0	5.32
20.0	7.96
22.0	19.34
24.0	78.02
26.0	89.41
28.0	92.04
30.0	94.68
32.0	95.69
34.0	96.70
36.0	97.71
38.0	98.09
40.0	98.47
42.0	98.85
44.0	99.24
46.0	99.62
48.0	100.00

Table D5

Balanced Distribution 3-Day Rainstorm Based on Stratford Rainfall Data

Duration (hrs)	Cumulative Percentage of Storm Depth
0.0	0.00
2.0	0.35
4.0	0.69
6.0	1.04
8.0	1.39
10.0	1.73
12.0	2.08
14.0	2.85
16.0	3.63
18.0	4.41
20.0	5.18
22.0	5.96
24.0	6.74
26.0	7.65
28.0	8.57
30.0	9.48
32.0	11.87
34.0	22.20
36.0	75.41
38.0	85.74
40.0	88.13
42.0	90.52
44.0	91.43
46.0	92.35
48.0	93.26
50.0	94.04
52.0	94.82
54.0	95.59
56.0	96.37
58.0	97.15
60.0	97.92
62.0	98.27
64.0	98.61
66.0	98.96
68.0	99.31
70.0	99.65
72.0	100.00

Table D6

Balanced Distribution 5-Day Rainstorm Based on Stratford Rainfall Data

Duration (hrs)	Cumulative Percentage of Storm Depth
0.0	0.00
6.0	0.93
12.0	1.85
18.0	2.79
24.0	3.73
30.0	5.24
36.0	6.75
42.0	8.85
48.0	10.95
54.0	13.43
60.0	80.10
66.0	86.57
72.0	89.05
78.0	91.15
84.0	93.25
90.0	94.76
96.0	96.27
102.0	97.21
108.0	98.15
114.0	99.07
120.0	100.00

Table D7

Rain-on-Snowmelt Distribution Pattern for Gauge A for 1 Day, 3 Days and 8 Days

1 Day		3 Days		8 Days	
Duration (hrs)	Cumulative Percentage of Storm Depth	Duration (hrs)	Cumulative Percentage of Storm Depth	Duration (hrs)	Cumulative Percentage of Storm Depth
0.0	0.00	0.0	0.000	0.0	0.000
1.0	1.00	2.0	0.866	2.0	0.397
2.0	2.00	4.0	1.732	4.0	0.794
3.0	3.00	6.0	3.609	6.0	1.686
4.0	4.00	8.0	5.486	8.0	2.678
5.0	5.50	10.0	9.095	10.0	4.364
6.0	7.00	12.0	12.704	12.0	6.051
7.0	9.00	14.0	14.581	14.0	6.943
8.0	11.00	16.0	16.313	16.0	7.836
9.0	14.50	18.0	17.180	18.0	8.233
10.0	18.00	20.0	18.046	20.0	8.629
11.0	26.00	22.0	18.046	22.0	8.629
12.0	34.00	24.0	18.046	24.0	8.629
13.0	53.50	26.0	18.985	26.0	9.055
14.0	73.00	28.0	19.924	28.0	9.480
15.0	79.50	30.0	21.803	30.0	10.437
16.0	86.00	32.0	23.798	32.0	11.500
17.0	89.00	34.0	27.673	34.0	13.308
18.0	92.00	36.0	31.547	36.0	15.116
19.0	94.00	38.0	33.425	38.0	16.179
20.0	96.00	40.0	35.304	40.0	17.136
21.0	97.00	42.0	36.243	42.0	17.561
22.0	98.00	44.0	37.182	44.0	17.986
23.0	99.00	46.0	37.182	46.0	17.986
24.0	100.00	48.0	37.886	48.0	17.986
		50.0	39.271	50.0	18.466
		52.0	41.249	52.0	18.946
		54.0	43.821	54.0	19.906
		56.0	48.173	56.0	20.866
		58.0	58.261	58.0	22.786
		60.0	82.988	60.0	24.706
		62.0	91.296	62.0	25.666
		64.0	95.055	64.0	26.626
		66.0	97.626	66.0	27.106
		68.0	98.813	68.0	27.586
		70.0	100.000	70.0	27.586
		72.0	100.000	72.0	27.586
				74.0	28.076
				76.0	28.566

Table D7

Rain-on-Snowmelt Distribution Pattern for Gauge A for 1 Day, 3 Days and 8 Days

1 Day		3 Days		8 Days	
Duration (hrs)	Cumulative Percentage of Storm Depth	Duration (hrs)	Cumulative Percentage of Storm Depth	Duration (hrs)	Cumulative Percentage of Storm Depth
				78.0	29.628
				80.0	30.690
				82.0	32.731
				84.0	34.773
				86.0	35.835
				88.0	36.815
				90.0	37.305
				92.0	37.795
				94.0	37.795
				96.0	37.795
				98.0	38.326
				100.0	38.857
				102.0	39.920
				104.0	41.049
				106.0	43.241
				108.0	45.432
				110.0	46.495
				112.0	47.557
				114.0	48.089
				116.0	48.620
				118.0	48.620
				120.0	49.019
				122.0	49.802
				124.0	50.921
				126.0	52.376
				128.0	54.838
				130.0	60.545
				132.0	74.533
				134.0	79.233
				136.0	81.359
				138.0	82.814
				140.0	83.485
				142.0	84.157
				144.0	84.157
				146.0	84.525
				148.0	84.893
				150.0	85.722
				152.0	86.642
				154.0	88.207
				156.0	89.772

Table D7

Rain-on-Snowmelt Distribution Pattern for Gauge A for 1 Day, 3 Days and 8 Days

1 Day		3 Days		8 Days	
Duration (hrs)	Cumulative Percentage of Storm Depth	Duration (hrs)	Cumulative Percentage of Storm Depth	Duration (hrs)	Cumulative Percentage of Storm Depth
				158.0	90.601
				160.0	91.429
				162.0	91.798
				164.0	92.166
				166.0	92.166
				168.0	92.166
				170.0	92.545
				172.0	92.924
				174.0	93.682
				176.0	94.440
				178.0	96.083
				180.0	97.726
				182.0	98.484
				184.0	99.242
				186.0	99.621
				188.0	100.000
				190.0	100.000
				192.0	100.000

Reference:
UTRCA's Visual Otthymo, Version 2 (VO2) modeling for the Upper Thames River basin (MMM, 1983; UTRCA, 1995; M. Wood personal communication, 2003).

Appendix E

Appendix E

HEC-RAS Generated Reports

Table 1 – Harrington Dam Model Results

```
                               Army Corp of Engineers




                  X  XXXXXX    XXXX        XXXX       XX      XXXX
                  X  X        X    X       X   X     X  X    X
                  X  X        X            X   X    X    X   X
                     XXXX     X       XXX  XXXX     XXXXXX    XXXX
                  X  X        X            X  X     X    X        X
HEC-RAS Version 4.0 Beta
                  X  X        X   X        X   X   X     X        X
                  X  XXXXXX    XXXX        X    X  X    X   XXXXX
X
X
U.S.
X
Hydrologic Engineering Center
********************************************************************************
XXXXXXX
X
PROJECT DATA
X
Project Title: Harrington CA Dam - TWL
609 Second Street
Project File : twl_harr.prj
Davis, California
Run Date and Time: 7/18/2003 7:52:34 AM

Project in SI units

********************************************************************************


PLAN DATA

Plan Title: Plan 02
Plan File : C:\harrington\twl_harr.p02






                          : Flow 04
                          : C:\harrington\twl_harr.f04

Geometry Title: Rd 96 culvert crossing to TWL Harring_re
Plan Summary Information:
Geometry File : C:\harrington\twl_harr.g02
Number of:  Cross Sections  =    7    Multiple Openings  =    0
                            =    1    Inline Structures  =    0
Flow Title
                            =    0    Lateral Structures =    0
Flow File
Computational Information
                                              =  0.003
                                                 0.003
Water surface calculation tolerance
Culverts                                      =  20
Critical depth calculation tolerance =
Bridges                                       =  0.1
Maximum number of iterations
Maximum difference tolerance
```

```
                                         =  0.001
 Flow tolerance factor
Computation Options


Critical depth computed only where necessary
Conveyance Calculation Method: At breaks in n values only
                                   Average Conveyance
Friction Slope Method:
                                   Subcritical Flow
Computational Flow Regime:
********************************************************************************

FLOW DATA

Flow Title: Flow 04
Flow File : C:\harrington\twl_harr.f04

Flow Data (m3/s)
*****************************************************************************************************************************************
* River           Reach           RS      *            PF 1            PF 2            PF 3            PF 4            PF 5              PF 6 *
* Harrington Creek1               10      *              .5               1              10              31              50                75 *
*****************************************************************************************************************************************

Boundary Conditions
**************************************************************************************************************
* River           Reach           Profile          *            Upstream                 Downstream    *
**************************************************************************************************************
* Harrington Creek1               PF 1             *                                Normal S = 0.014286 *
* Harrington Creek1               PF 2             *                                Normal S = 0.014286 *
* Harrington Creek1               PF 3             *                                Normal S = 0.014286 *
* Harrington Creek1               PF 4             *                                Normal S = 0.014286 *
**************************************************************************************************************

CROSS SECTION


RIVER: Harrington Creek
REACH: 1                  RS: 10


CROSS SECTION OUTPUT  Profile #PF 1
*****************************************************************************************
* E.G. Elev (m)        *  327.27  * Element             *  Left OB *  Channel * Right OB *
* Vel Head (m)         *    0.04  * Wt. n-Val.          *          *   0.035  *          *
* W.S. Elev (m)        *  327.23  * Reach Len. (m)      *    2.00  *    2.00  *    2.00  *
* Crit W.S. (m)        *  327.23  * Flow Area (m2)      *          *    0.57  *          *
* E.G. Slope (m/m)     *0.028849  * Area (m2)           *          *    0.57  *          *
* Q Total (m3/s)       *    0.50  * Flow (m3/s)         *          *    0.50  *          *
* Top Width (m)        *    7.28  * Top Width (m)       *          *    7.28  *          *
* Vel Total (m/s)      *    0.88  * Avg. Vel. (m/s)     *          *    0.88  *          *
* Max Chl Dpth (m)     *    0.08  * Hydr. Depth (m)     *          *    0.08  *          *
* Conv. Total (m3/s)   *     2.9  * Conv. (m3/s)        *          *     2.9  *          *
```

```
* Length Wtd. (m)      *    2.00  * Wetted Per. (m)      *          *    7.44  *          *
* Min Ch El (m)        *  327.15  * Shear (N/m2)         *          *   21.70  *          *
* Alpha                *    1.00  * Stream Power (N/m s) *          *   19.01  *          *
* Frctn Loss (m)       *    0.06  * Cum Volume (1000 m3) *    0.00  *    0.08  *    0.01  *
* C & E Loss (m)       *    0.00  * Cum SA (1000 m2)     *    0.00  *    0.72  *    0.05  *
*********************************************************************************************

Warning: The energy equation could not be balanced within the specified number of iterations.  The

Warning: The energy loss was greater than 1.0 ft (0.3 m). between the current and previous cross
                   This may indicate the need for additional cross sections.
Warning: During the standard step iterations, when the assumed water surface was set equal to critical
                                                                               This indicates that there
program used critical depth for the water surface and continued on with the calculations.
                                             The program defaulted to critical depth.

section.
CROSS SECTION OUTPUT  Profile #PF 2
*********************************************************************************************
depth, the calculated water surface came back below critical depth.
* E.G. Elev (m)        *  327.34  * Element              *  Left OB *  Channel * Right OB *
is not a valid subcritical answer.
* Vel Head (m)         *    0.06  * Wt. n-Val.           *          *   0.035  *          *
* W.S. Elev (m)        *  327.27  * Reach Len. (m)       *    2.00  *    2.00  *    2.00  *
* Crit W.S. (m)        *  327.27  * Flow Area (m2)       *          *    0.91  *          *
* E.G. Slope (m/m)     *0.025143  * Area (m2)            *          *    0.91  *          *
* Q Total (m3/s)       *    1.00  * Flow (m3/s)          *          *    1.00  *          *
* Top Width (m)        *    7.28  * Top Width (m)        *          *    7.28  *          *
* Vel Total (m/s)      *    1.10  * Avg. Vel. (m/s)      *          *    1.10  *          *
* Max Chl Dpth (m)     *    0.12  * Hydr. Depth (m)      *          *    0.12  *          *
* Conv. Total (m3/s)   *     6.3  * Conv. (m3/s)         *          *     6.3  *          *
* Length Wtd. (m)      *    2.00  * Wetted Per. (m)      *          *    7.53  *          *
* Min Ch El (m)        *  327.15  * Shear (N/m2)         *          *   29.66  *          *
* Alpha                *    1.00  * Stream Power (N/m s) *          *   32.74  *          *
* Frctn Loss (m)       *    0.05  * Cum Volume (1000 m3) *    0.00  *    0.13  *    0.01  *
* C & E Loss (m)       *    0.00  * Cum SA (1000 m2)     *    0.01  *    0.75  *    0.08  *
*********************************************************************************************

Warning: The energy equation could not be balanced within the specified number of iterations.  The

Warning: The energy loss was greater than 1.0 ft (0.3 m). between the current and previous cross
                   This may indicate the need for additional cross sections.
Warning: During the standard step iterations, when the assumed water surface was set equal to critical
                                                                               This indicates that there
program used critical depth for the water surface and continued on with the calculations.
                                             The program defaulted to critical depth.

section.
CROSS SECTION OUTPUT  Profile #PF 3
*********************************************************************************************
depth, the calculated water surface came back below critical depth.
* E.G. Elev (m)        *  328.02  * Element              *  Left OB *  Channel * Right OB *
is not a valid subcritical answer.
* Vel Head (m)         *    0.29  * Wt. n-Val.           *          *   0.035  *          *
* W.S. Elev (m)        *  327.73  * Reach Len. (m)       *    2.00  *    2.00  *    2.00  *
* Crit W.S. (m)        *  327.73  * Flow Area (m2)       *          *    4.19  *          *
* E.G. Slope (m/m)     *0.017730  * Area (m2)            *          *    4.19  *          *
* Q Total (m3/s)       *   10.00  * Flow (m3/s)          *          *   10.00  *          *
* Top Width (m)        *    7.28  * Top Width (m)        *          *    7.28  *          *
```

```
* Vel Total (m/s)      *    2.39  * Avg. Vel. (m/s)      *          *    2.39  *          *
* Max Chl Dpth (m)     *    0.58  * Hydr. Depth (m)      *          *    0.58  *          *
* Conv. Total (m3/s)   *    75.1  * Conv. (m3/s)         *          *    75.1  *          *
* Length Wtd. (m)      *    2.00  * Wetted Per. (m)      *          *    8.43  *          *
* Min Ch El (m)        *  327.15  * Shear (N/m2)         *          *   86.38  *          *
* Alpha                *    1.00  * Stream Power (N/m s) *          *  206.15  *          *
* Frctn Loss (m)       *    0.03  * Cum Volume (1000 m3) *    0.03  *    0.59  *    0.20  *
* C & E Loss (m)       *    0.03  * Cum SA (1000 m2)     *    0.12  *    0.81  *    0.44  *
*******************************************************************************************

Warning: The energy equation could not be balanced within the specified number of iterations.  The

Warning: The energy loss was greater than 1.0 ft (0.3 m). between the current and previous cross
                   This may indicate the need for additional cross sections.
Warning: During the standard step iterations, when the assumed water surface was set equal to critical
                                                                                     This indicates that there
program used critical depth for the water surface and continued on with the calculations.
                                                    The program defaulted to critical depth.

section
CROSS SECTION OUTPUT  Profile #PF 4
*******************************************************************************************
depth, the calculated water surface came back below critical depth.
* E.G. Elev (m)        *  328.99  * Element              *  Left OB *  Channel * Right OB *
is not a valid subcritical answer.
* Vel Head (m)         *    0.60  * Wt. n-Val.           *   0.050  *   0.035  *          *
* W.S. Elev (m)        *  328.39  * Reach Len. (m)       *    2.00  *    2.00  *    2.00  *
* Crit W.S. (m)        *  328.39  * Flow Area (m2)       *    0.11  *    9.01  *          *
* E.G. Slope (m/m)     *0.015539  * Area (m2)            *    0.11  *    9.01  *          *
* Q Total (m3/s)       *   31.00  * Flow (m3/s)          *    0.07  *   30.93  *          *
* Top Width (m)        *    8.17  * Top Width (m)        *    0.89  *    7.28  *          *
* Vel Total (m/s)      *    3.40  * Avg. Vel. (m/s)      *    0.60  *    3.43  *          *
* Max Chl Dpth (m)     *    1.24  * Hydr. Depth (m)      *    0.12  *    1.24  *          *
* Conv. Total (m3/s)   *   248.7  * Conv. (m3/s)         *     0.5  *   248.2  *          *
* Length Wtd. (m)      *    2.00  * Wetted Per. (m)      *    0.92  *    9.51  *          *
* Min Ch El (m)        *  327.15  * Shear (N/m2)         *   18.11  *  144.31  *          *
* Alpha                *    1.02  * Stream Power (N/m s) *   10.91  *  495.68  *          *
* Frctn Loss (m)       *    0.03  * Cum Volume (1000 m3) *    1.66  *    1.12  *    0.48  *
* C & E Loss (m)       *    0.06  * Cum SA (1000 m2)     *    4.80  *    0.83  *    0.56  *
*******************************************************************************************

Warning: The energy equation could not be balanced within the specified number of iterations.  The

Warning: The velocity head has changed by more than 0.5 ft (0.15 m).  This may indicate the need for

Warning: The energy loss was greater than 1.0 ft (0.3 m). between the current and previous cross
                   This may indicate the need for additional cross sections.
program used critical depth for the water surface and continued on with the calculations.
Warning: During the standard step iterations, when the assumed water surface was set equal to critical
                                                                                     This indicates that there
additional cross sections.                          The program defaulted to critical depth.

section
CROSS SECTION OUTPUT  Profile #PF 5
*******************************************************************************************
depth, the calculated water surface came back below critical depth.
* E.G. Elev (m)        *  329.62  * Element              *  Left OB *  Channel * Right OB *
is not a valid subcritical answer.
* Vel Head (m)         *    0.71  * Wt. n-Val.           *   0.050  *   0.035  *   0.050  *
```

```
* W.S. Elev (m)        *  328.92  * Reach Len. (m)       *    2.00  *    2.00  *    2.00  *
* Crit W.S. (m)        *  328.92  * Flow Area (m2)       *    1.08  *   12.86  *    0.37  *
* E.G. Slope (m/m)     *0.012114  * Area (m2)            *    1.08  *   12.86  *    0.37  *
* Q Total (m3/s)       *   50.00  * Flow (m3/s)          *    1.24  *   48.55  *    0.21  *
* Top Width (m)        *   12.90  * Top Width (m)        *    2.79  *    7.28  *    2.82  *
* Vel Total (m/s)      *    3.49  * Avg. Vel. (m/s)      *    1.14  *    3.78  *    0.57  *
* Max Chl Dpth (m)     *    1.77  * Hydr. Depth (m)      *    0.39  *    1.77  *    0.13  *
* Conv. Total (m3/s)   *   454.3  * Conv. (m3/s)         *    11.2  *   441.1  *     1.9  *
* Length Wtd. (m)      *    2.00  * Wetted Per. (m)      *    2.90  *    9.77  *    2.83  *
* Min Ch El (m)        *  327.15  * Shear (N/m2)         *   44.38  *  156.30  *   15.70  *
* Alpha                *    1.14  * Stream Power (N/m s) *   50.68  *  590.14  *    8.97  *
* Frctn Loss (m)       *    0.02  * Cum Volume (1000 m3) *    5.19  *    1.52  *    0.82  *
* C & E Loss (m)       *    0.05  * Cum SA (1000 m2)     *    7.07  *    0.84  *    0.68  *
*******************************************************************************************

Warning: The energy equation could not be balanced within the specified number of iterations.  The

Warning: The velocity head has changed by more than 0.5 ft (0.15 m).  This may indicate the need for

Warning: The energy loss was greater than 1.0 ft (0.3 m). between the current and previous cross
                   This may indicate the need for additional cross sections.
program used critical depth for the water surface and continued on with the calculations.
Warning: During the standard step iterations, when the assumed water surface was set equal to critical
                                                                              This indicates that there
additional cross sections.                          The program defaulted to critical depth.

section.
CROSS SECTION OUTPUT  Profile #PF 6
*******************************************************************************************
depth, the calculated water surface came back below critical depth.
* E.G. Elev (m)        *  330.20  * Element              *  Left OB  *  Channel * Right OB *
is not a valid subcritical answer.
* Vel Head (m)         *    0.74  * Wt. n-Val.           *   0.050  *   0.035  *   0.050  *
* W.S. Elev (m)        *  329.46  * Reach Len. (m)       *    2.00  *    2.00  *    2.00  *
* Crit W.S. (m)        *  329.46  * Flow Area (m2)       *    3.25  *   16.85  *    2.94  *
* E.G. Slope (m/m)     *0.009451  * Area (m2)            *    3.25  *   16.85  *    2.94  *
* Q Total (m3/s)       *   75.00  * Flow (m3/s)          *    4.27  *   67.27  *    3.47  *
* Top Width (m)        *   19.17  * Top Width (m)        *    5.70  *    7.28  *    6.19  *
* Vel Total (m/s)      *    3.25  * Avg. Vel. (m/s)      *    1.31  *    3.99  *    1.18  *
* Max Chl Dpth (m)     *    2.31  * Hydr. Depth (m)      *    0.57  *    2.31  *    0.48  *
* Conv. Total (m3/s)   *   771.5  * Conv. (m3/s)         *    43.9  *   691.9  *    35.7  *
* Length Wtd. (m)      *    2.00  * Wetted Per. (m)      *    5.87  *    9.77  *    6.25  *
* Min Ch El (m)        *  327.15  * Shear (N/m2)         *   51.38  *  159.75  *   43.68  *
* Alpha                *    1.37  * Stream Power (N/m s) *   67.42  *  637.91  *   51.43  *
* Frctn Loss (m)       *    0.02  * Cum Volume (1000 m3) *    7.63  *    1.75  *    1.05  *
* C & E Loss (m)       *    0.02  * Cum SA (1000 m2)     *    7.51  *    0.84  *    0.74  *
*******************************************************************************************

Warning: The energy equation could not be balanced within the specified number of iterations.  The

Warning: The energy loss was greater than 1.0 ft (0.3 m). between the current and previous cross
                   This may indicate the need for additional cross sections.
Warning: During the standard step iterations, when the assumed water surface was set equal to critical
                                                                              This indicates that there
program used critical depth for the water surface and continued on with the calculations.
                                                    The program defaulted to critical depth.

section.

depth, the calculated water surface came back below critical depth.
is not a valid subcritical answer.
```

```
CROSS SECTION


RIVER: Harrington Creek
REACH: 1                  RS: 9.5


CROSS SECTION OUTPUT  Profile #PF 1
*******************************************************************************************
* E.G. Elev (m)        *  326.84  * Element              *  Left OB *  Channel * Right OB *
* Vel Head (m)         *    0.03  * Wt. n-Val.           *          *   0.035  *          *
* W.S. Elev (m)        *  326.81  * Reach Len. (m)       *   18.00  *   15.00  *   12.00  *
* Crit W.S. (m)        *  326.81  * Flow Area (m2)       *          *    0.64  *          *
* E.G. Slope (m/m)     *0.030992  * Area (m2)            *          *    0.64  *          *
* Q Total (m3/s)       *    0.50  * Flow (m3/s)          *          *    0.50  *          *
* Top Width (m)        *   10.50  * Top Width (m)        *          *   10.50  *          *
* Vel Total (m/s)      *    0.78  * Avg. Vel. (m/s)      *          *    0.78  *          *
* Max Chl Dpth (m)     *    0.06  * Hydr. Depth (m)      *          *    0.06  *          *
* Conv. Total (m3/s)   *     2.8  * Conv. (m3/s)         *          *     2.8  *          *
* Length Wtd. (m)      *   15.00  * Wetted Per. (m)      *          *   10.52  *          *
* Min Ch El (m)        *  326.75  * Shear (N/m2)         *          *   18.54  *          *
* Alpha                *    1.00  * Stream Power (N/m s) *          *   14.45  *          *
* Frctn Loss (m)       *    0.39  * Cum Volume (1000 m3) *    0.00  *    0.08  *    0.01  *
* C & E Loss (m)       *    0.00  * Cum SA (1000 m2)     *    0.00  *    0.70  *    0.05  *
*******************************************************************************************

Warning: The energy equation could not be balanced within the specified number of iterations.  The

Warning: The energy loss was greater than 1.0 ft (0.3 m). between the current and previous cross
                   This may indicate the need for additional cross sections.
Warning: During the standard step iterations, when the assumed water surface was set equal to critical
                                                                              This indicates that there
program used critical depth for the water surface and continued on with the calculations.
                                              The program defaulted to critical depth.

section
CROSS SECTION OUTPUT  Profile #PF 2
*******************************************************************************************
depth, the calculated water surface came back below critical depth.
is not a valid subcritical answer.
* E.G. Elev (m)        *  326.90  * Element              *  Left OB *  Channel * Right OB *
* Vel Head (m)         *    0.05  * Wt. n-Val.           *          *   0.035  *          *
* W.S. Elev (m)        *  326.85  * Reach Len. (m)       *   18.00  *   15.00  *   12.00  *
* Crit W.S. (m)        *  326.85  * Flow Area (m2)       *          *    1.03  *          *
* E.G. Slope (m/m)     *0.026516  * Area (m2)            *          *    1.03  *          *
* Q Total (m3/s)       *    1.00  * Flow (m3/s)          *          *    1.00  *          *
* Top Width (m)        *   10.79  * Top Width (m)        *          *   10.79  *          *
* Vel Total (m/s)      *    0.97  * Avg. Vel. (m/s)      *          *    0.97  *          *
* Max Chl Dpth (m)     *    0.10  * Hydr. Depth (m)      *          *    0.10  *          *
* Conv. Total (m3/s)   *     6.1  * Conv. (m3/s)         *          *     6.1  *          *
* Length Wtd. (m)      *   15.00  * Wetted Per. (m)      *          *   10.82  *          *
* Min Ch El (m)        *  326.75  * Shear (N/m2)         *          *   24.77  *          *
* Alpha                *    1.00  * Stream Power (N/m s) *          *   24.04  *          *
* Frctn Loss (m)       *    0.26  * Cum Volume (1000 m3) *    0.00  *    0.13  *    0.01  *
```

```
* C & E Loss (m)       *    0.00  * Cum SA (1000 m2)     *    0.01  *    0.74  *    0.08  *
*******************************************************************************************

Warning: The energy equation could not be balanced within the specified number of iterations.  The

Warning: The conveyance ratio (upstream conveyance divided by downstream conveyance) is less than
             or greater than 1.4.  This may indicate the need for additional cross sections.
Warning: The energy loss was greater than 1.0 ft (0.3 m). between the current and previous cross
                   This may indicate the need for additional cross sections.
program used critical depth for the water surface and continued on with the calculations.
Warning: During the standard step iterations, when the assumed water surface was set equal to critical
                                                                              This indicates that there
0.7
                                                    The program defaulted to critical depth.

section
CROSS SECTION OUTPUT  Profile #PF 3
*******************************************************************************************
depth, the calculated water surface came back below critical depth.
is not a valid subcritical answer.
* E.G. Elev (m)        *  327.39  * Element              *  Left OB *  Channel * Right OB *
* Vel Head (m)         *    0.20  * Wt. n-Val.           *   0.050  *   0.035  *   0.050  *
* W.S. Elev (m)        *  327.18  * Reach Len. (m)       *   18.00  *   15.00  *   12.00  *
* Crit W.S. (m)        *  327.18  * Flow Area (m2)       *    0.02  *    4.96  *    0.07  *
* E.G. Slope (m/m)     *0.016141  * Area (m2)            *    0.02  *    4.96  *    0.07  *
* Q Total (m3/s)       *   10.00  * Flow (m3/s)          *    0.01  *    9.96  *    0.03  *
* Top Width (m)        *   12.92  * Top Width (m)        *    0.18  *   12.00  *    0.74  *
* Vel Total (m/s)      *    1.98  * Avg. Vel. (m/s)      *    0.41  *    2.01  *    0.51  *
* Max Chl Dpth (m)     *    0.43  * Hydr. Depth (m)      *    0.09  *    0.41  *    0.09  *
* Conv. Total (m3/s)   *    78.7  * Conv. (m3/s)         *     0.1  *    78.4  *     0.3  *
* Length Wtd. (m)      *   14.83  * Wetted Per. (m)      *    0.26  *   12.06  *    0.76  *
* Min Ch El (m)        *  326.75  * Shear (N/m2)         *   10.30  *   65.10  *   14.13  *
* Alpha                *    1.02  * Stream Power (N/m s) *    4.23  *  130.69  *    7.17  *
* Frctn Loss (m)       *    0.10  * Cum Volume (1000 m3) *    0.03  *    0.58  *    0.20  *
* C & E Loss (m)       *    0.03  * Cum SA (1000 m2)     *    0.12  *    0.79  *    0.44  *
*******************************************************************************************

Warning: The energy equation could not be balanced within the specified number of iterations.  The

Warning: The conveyance ratio (upstream conveyance divided by downstream conveyance) is less than
             or greater than 1.4.  This may indicate the need for additional cross sections.
Warning: The energy loss was greater than 1.0 ft (0.3 m). between the current and previous cross
                   This may indicate the need for additional cross sections.
program used critical depth for the water surface and continued on with the calculations.
Warning: During the standard step iterations, when the assumed water surface was set equal to critical
                                                                              This indicates that there
0.7
                                                    The program defaulted to critical depth.

section
CROSS SECTION OUTPUT  Profile #PF 4
*******************************************************************************************
depth, the calculated water surface came back below critical depth.
is not a valid subcritical answer.
* E.G. Elev (m)        *  328.05  * Element              *  Left OB *  Channel * Right OB *
* Vel Head (m)         *    0.41  * Wt. n-Val.           *   0.050  *   0.035  *   0.050  *
* W.S. Elev (m)        *  327.64  * Reach Len. (m)       *   18.00  *   15.00  *   12.00  *
* Crit W.S. (m)        *  327.64  * Flow Area (m2)       *    0.21  *   10.48  *    0.81  *
* E.G. Slope (m/m)     *0.012112  * Area (m2)            *    0.21  *   10.48  *    0.81  *
* Q Total (m3/s)       *   31.00  * Flow (m3/s)          *    0.17  *   30.00  *    0.83  *
* Top Width (m)        *   15.10  * Top Width (m)        *    0.64  *   12.00  *    2.45  *
```

```
* Vel Total (m/s)      *    2.70  * Avg. Vel. (m/s)      *    0.82  *    2.86  *    1.02  *
* Max Chl Dpth (m)     *    0.89  * Hydr. Depth (m)      *    0.32  *    0.87  *    0.33  *
* Conv. Total (m3/s)   *   281.7  * Conv. (m3/s)         *     1.5  *   272.6  *     7.5  *
* Length Wtd. (m)      *   14.67  * Wetted Per. (m)      *    0.91  *   12.06  *    2.54  *
* Min Ch El (m)        *  326.75  * Shear (N/m2)         *   27.05  *  103.20  *   37.70  *
* Alpha                *    1.09  * Stream Power (N/m s) *   22.20  *  295.48  *   38.61  *
* Frctn Loss (m)       *    0.12  * Cum Volume (1000 m3) *    1.66  *    1.10  *    0.48  *
* C & E Loss (m)       *    0.04  * Cum SA (1000 m2)     *    4.80  *    0.81  *    0.56  *
*******************************************************************************************

Warning: The energy equation could not be balanced within the specified number of iterations.  The

Warning: The energy loss was greater than 1.0 ft (0.3 m). between the current and previous cross
                   This may indicate the need for additional cross sections.
Warning: During the standard step iterations, when the assumed water surface was set equal to critical
                                                                                    This indicates that there
program used critical depth for the water surface and continued on with the calculations.
                                                    The program defaulted to critical depth.

section
CROSS SECTION OUTPUT  Profile #PF 5
*******************************************************************************************
depth, the calculated water surface came back below critical depth.
* E.G. Elev (m)        *  328.49  * Element              *  Left OB  *  Channel  * Right OB *
is not a valid subcritical answer.
* Vel Head (m)         *    0.54  * Wt. n-Val.           *   0.050  *   0.035  *   0.050  *
* W.S. Elev (m)        *  327.96  * Reach Len. (m)       *   18.00  *   15.00  *   12.00  *
* Crit W.S. (m)        *  327.96  * Flow Area (m2)       *    0.46  *   14.23  *    1.75  *
* E.G. Slope (m/m)     *0.010864  * Area (m2)            *    0.46  *   14.23  *    1.75  *
* Q Total (m3/s)       *   50.00  * Flow (m3/s)          *    0.46  *   47.33  *    2.21  *
* Top Width (m)        *   16.57  * Top Width (m)        *    0.96  *   12.00  *    3.61  *
* Vel Total (m/s)      *    3.04  * Avg. Vel. (m/s)      *    1.01  *    3.33  *    1.26  *
* Max Chl Dpth (m)     *    1.21  * Hydr. Depth (m)      *    0.48  *    1.19  *    0.49  *
* Conv. Total (m3/s)   *   479.7  * Conv. (m3/s)         *     4.4  *   454.1  *    21.2  *
* Length Wtd. (m)      *   14.99  * Wetted Per. (m)      *    1.35  *   12.06  *    3.73  *
* Min Ch El (m)        *  326.75  * Shear (N/m2)         *   36.04  *  125.71  *   50.04  *
* Alpha                *    1.14  * Stream Power (N/m s) *   36.47  *  418.03  *   63.02  *
* Frctn Loss (m)       *    0.06  * Cum Volume (1000 m3) *    5.19  *    1.50  *    0.82  *
* C & E Loss (m)       *    0.12  * Cum SA (1000 m2)     *    7.07  *    0.82  *    0.67  *
*******************************************************************************************

Warning: The energy equation could not be balanced within the specified number of iterations.  The

Warning: The velocity head has changed by more than 0.5 ft (0.15 m).  This may indicate the need for

Warning: The conveyance ratio (upstream conveyance divided by downstream conveyance) is less than
             or greater than 1.4.  This may indicate the need for additional cross sections.
program used critical depth for the water surface and continued on with the calculations.
Warning: The energy loss was greater than 1.0 ft (0.3 m). between the current and previous cross
                   This may indicate the need for additional cross sections.
additional cross sections.
Warning: During the standard step iterations, when the assumed water surface was set equal to critical
                                                                                    This indicates that there
0.7
                                                    The program defaulted to critical depth.

section
CROSS SECTION OUTPUT  Profile #PF 6
*******************************************************************************************
depth, the calculated water surface came back below critical depth.
is not a valid subcritical answer.
```

```
* E.G. Elev (m)        *  328.98  * Element              *  Left OB *  Channel * Right OB *
* Vel Head (m)         *    0.66  * Wt. n-Val.           *   0.050  *   0.035  *   0.050  *
* W.S. Elev (m)        *  328.32  * Reach Len. (m)       *   18.00  *   15.00  *   12.00  *
* Crit W.S. (m)        *  328.32  * Flow Area (m2)       *    1.02  *   18.54  *    3.29  *
* E.G. Slope (m/m)     *0.009603  * Area (m2)            *    1.02  *   18.54  *    3.29  *
* Q Total (m3/s)       *   75.00  * Flow (m3/s)          *    1.03  *   69.16  *    4.81  *
* Top Width (m)        *   19.20  * Top Width (m)        *    2.26  *   12.00  *    4.94  *
* Vel Total (m/s)      *    3.28  * Avg. Vel. (m/s)      *    1.02  *    3.73  *    1.46  *
* Max Chl Dpth (m)     *    1.57  * Hydr. Depth (m)      *    0.45  *    1.55  *    0.67  *
* Conv. Total (m3/s)   *   765.3  * Conv. (m3/s)         *    10.5  *   705.8  *    49.0  *
* Length Wtd. (m)      *   15.16  * Wetted Per. (m)      *    2.72  *   12.06  *    5.11  *
* Min Ch El (m)        *  326.75  * Shear (N/m2)         *   35.21  *  144.78  *   60.63  *
* Alpha                *    1.20  * Stream Power (N/m s) *   35.82  *  539.99  *   88.60  *
* Frctn Loss (m)       *    0.06  * Cum Volume (1000 m3) *    7.62  *    1.71  *    1.04  *
* C & E Loss (m)       *    0.16  * Cum SA (1000 m2)     *    7.50  *    0.82  *    0.73  *
*******************************************************************************************

Warning: The energy equation could not be balanced within the specified number of iterations.  The

Warning: The velocity head has changed by more than 0.5 ft (0.15 m).  This may indicate the need for

Warning: The conveyance ratio (upstream conveyance divided by downstream conveyance) is less than
             or greater than 1.4.  This may indicate the need for additional cross sections.
program used critical depth for the water surface and continued on with the calculations.
Warning: The energy loss was greater than 1.0 ft (0.3 m). between the current and previous cross
                   This may indicate the need for additional cross sections.
additional cross sections.
Warning: During the standard step iterations, when the assumed water surface was set equal to critical
                                                                                    This indicates that there
0.7
                                                    The program defaulted to critical depth.

section.
CROSS SECTION

depth, the calculated water surface came back below critical depth.
is not a valid subcritical answer.
RIVER: Harrington Creek
REACH: 1                  RS: 9


CROSS SECTION OUTPUT  Profile #PF 1
*******************************************************************************************
* E.G. Elev (m)        *  326.16  * Element              *  Left OB *  Channel * Right OB *
* Vel Head (m)         *    0.04  * Wt. n-Val.           *          *   0.035  *          *
* W.S. Elev (m)        *  326.12  * Reach Len. (m)       *   30.00  *   30.00  *   30.00  *
* Crit W.S. (m)        *  326.11  * Flow Area (m2)       *          *    0.55  *          *
* E.G. Slope (m/m)     *0.021869  * Area (m2)            *          *    0.55  *          *
* Q Total (m3/s)       *    0.50  * Flow (m3/s)          *          *    0.50  *          *
* Top Width (m)        *    5.40  * Top Width (m)        *          *    5.40  *          *
* Vel Total (m/s)      *    0.92  * Avg. Vel. (m/s)      *          *    0.92  *          *
* Max Chl Dpth (m)     *    0.12  * Hydr. Depth (m)      *          *    0.10  *          *
* Conv. Total (m3/s)   *     3.4  * Conv. (m3/s)         *          *     3.4  *          *
* Length Wtd. (m)      *   30.00  * Wetted Per. (m)      *          *    5.42  *          *
* Min Ch El (m)        *  326.00  * Shear (N/m2)         *          *   21.62  *          *
* Alpha                *    1.00  * Stream Power (N/m s) *          *   19.79  *          *
```

```
* Frctn Loss (m)       *    0.13  * Cum Volume (1000 m3) *    0.00  *    0.07  *    0.01  *
* C & E Loss (m)       *    0.01  * Cum SA (1000 m2)     *    0.00  *    0.58  *    0.05  *
*******************************************************************************************

Warning: The conveyance ratio (upstream conveyance divided by downstream conveyance) is less than
             or greater than 1.4.  This may indicate the need for additional cross sections.

CROSS SECTION OUTPUT  Profile #PF 2
*******************************************************************************************
* E.G. Elev (m)        *  326.25  * Element              *  Left OB *  Channel * Right OB *
0.7Vel Head (m)        *    0.05  * Wt. n-Val.           *          *   0.035  *          *
* W.S. Elev (m)        *  326.20  * Reach Len. (m)       *   30.00  *   30.00  *   30.00  *
* Crit W.S. (m)        *          * Flow Area (m2)       *          *    1.05  *          *
* E.G. Slope (m/m)     *0.012584  * Area (m2)            *          *    1.05  *          *
* Q Total (m3/s)       *    1.00  * Flow (m3/s)          *          *    1.00  *          *
* Top Width (m)        *    6.42  * Top Width (m)        *          *    6.42  *          *
* Vel Total (m/s)      *    0.95  * Avg. Vel. (m/s)      *          *    0.95  *          *
* Max Chl Dpth (m)     *    0.20  * Hydr. Depth (m)      *          *    0.16  *          *
* Conv. Total (m3/s)   *     8.9  * Conv. (m3/s)         *          *     8.9  *          *
* Length Wtd. (m)      *   30.00  * Wetted Per. (m)      *          *    6.45  *          *
* Min Ch El (m)        *  326.00  * Shear (N/m2)         *          *   20.04  *          *
* Alpha                *    1.00  * Stream Power (N/m s) *          *   19.12  *          *
* Frctn Loss (m)       *    0.12  * Cum Volume (1000 m3) *    0.00  *    0.12  *    0.01  *
* C & E Loss (m)       *    0.01  * Cum SA (1000 m2)     *    0.01  *    0.61  *    0.08  *
*******************************************************************************************

Warning: The conveyance ratio (upstream conveyance divided by downstream conveyance) is less than
             or greater than 1.4.  This may indicate the need for additional cross sections.

CROSS SECTION OUTPUT  Profile #PF 3
*******************************************************************************************
* E.G. Elev (m)        *  326.97  * Element              *  Left OB *  Channel * Right OB *
0.7Vel Head (m)        *    0.10  * Wt. n-Val.           *   0.050  *   0.035  *   0.050  *
* W.S. Elev (m)        *  326.87  * Reach Len. (m)       *   30.00  *   30.00  *   30.00  *
* Crit W.S. (m)        *          * Flow Area (m2)       *    0.39  *    5.69  *    2.26  *
* E.G. Slope (m/m)     *0.003651  * Area (m2)            *    0.39  *    5.69  *    2.26  *
* Q Total (m3/s)       *   10.00  * Flow (m3/s)          *    0.19  *    8.53  *    1.29  *
* Top Width (m)        *   15.40  * Top Width (m)        *    1.47  *    7.00  *    6.94  *
* Vel Total (m/s)      *    1.20  * Avg. Vel. (m/s)      *    0.48  *    1.50  *    0.57  *
* Max Chl Dpth (m)     *    0.87  * Hydr. Depth (m)      *    0.27  *    0.81  *    0.33  *
* Conv. Total (m3/s)   *   165.5  * Conv. (m3/s)         *     3.1  *   141.1  *    21.3  *
* Length Wtd. (m)      *   30.00  * Wetted Per. (m)      *    1.60  *    7.05  *    6.96  *
* Min Ch El (m)        *  326.00  * Shear (N/m2)         *    8.82  *   28.93  *   11.60  *
* Alpha                *    1.36  * Stream Power (N/m s) *    4.19  *   43.32  *    6.61  *
* Frctn Loss (m)       *    0.08  * Cum Volume (1000 m3) *    0.03  *    0.50  *    0.19  *
* C & E Loss (m)       *    0.01  * Cum SA (1000 m2)     *    0.10  *    0.64  *    0.39  *
*******************************************************************************************

CROSS SECTION OUTPUT  Profile #PF 4
*******************************************************************************************
* E.G. Elev (m)        *  327.59  * Element              *  Left OB *  Channel * Right OB *
```

```
* Vel Head (m)         *    0.28  * Wt. n-Val.           *   0.050  *   0.035  *   0.050  *
* W.S. Elev (m)        *  327.31  * Reach Len. (m)       *   30.00  *   30.00  *   30.00  *
* Crit W.S. (m)        *          * Flow Area (m2)       *    1.84  *    8.81  *    5.94  *
* E.G. Slope (m/m)     *0.006252  * Area (m2)            *    1.84  *    8.81  *    5.94  *
* Q Total (m3/s)       *   31.00  * Flow (m3/s)          *    0.88  *   23.11  *    7.01  *
* Top Width (m)        *   27.15  * Top Width (m)        *   11.01  *    7.00  *    9.15  *
* Vel Total (m/s)      *    1.87  * Avg. Vel. (m/s)      *    0.48  *    2.62  *    1.18  *
* Max Chl Dpth (m)     *    1.31  * Hydr. Depth (m)      *    0.17  *    1.26  *    0.65  *
* Conv. Total (m3/s)   *   392.1  * Conv. (m3/s)         *    11.1  *   292.3  *    88.7  *
* Length Wtd. (m)      *   30.00  * Wetted Per. (m)      *   11.17  *    7.05  *    9.23  *
* Min Ch El (m)        *  326.00  * Shear (N/m2)         *   10.12  *   76.68  *   39.50  *
* Alpha                *    1.56  * Stream Power (N/m s) *    4.82  *  201.09  *   46.59  *
* Frctn Loss (m)       *    0.09  * Cum Volume (1000 m3) *    1.64  *    0.95  *    0.44  *
* C & E Loss (m)       *    0.06  * Cum SA (1000 m2)     *    4.69  *    0.66  *    0.49  *
*******************************************************************************************

Warning: The velocity head has changed by more than 0.5 ft (0.15 m).  This may indicate the need for

Warning: The conveyance ratio (upstream conveyance divided by downstream conveyance) is less than
             or greater than 1.4.  This may indicate the need for additional cross sections.

CROSS SECTION OUTPUT  Profile #PF 5
additional cross sections.
*******************************************************************************************
* E.G. Elev (m)        *  328.01  * Element              *  Left OB *  Channel * Right OB *
0.7
* Vel Head (m)         *    0.12  * Wt. n-Val.           *   0.050  *   0.035  *   0.050  *
* W.S. Elev (m)        *  327.88  * Reach Len. (m)       *   30.00  *   30.00  *   30.00  *
* Crit W.S. (m)        *          * Flow Area (m2)       *   22.32  *   12.82  *   11.55  *
* E.G. Slope (m/m)     *0.002219  * Area (m2)            *   22.32  *   12.82  *   11.55  *
* Q Total (m3/s)       *   50.00  * Flow (m3/s)          *   12.83  *   25.70  *   11.47  *
* Top Width (m)        *   68.25  * Top Width (m)        *   50.77  *    7.00  *   10.48  *
* Vel Total (m/s)      *    1.07  * Avg. Vel. (m/s)      *    0.57  *    2.01  *    0.99  *
* Max Chl Dpth (m)     *    1.88  * Hydr. Depth (m)      *    0.44  *    1.83  *    1.10  *
* Conv. Total (m3/s)   *  1061.5  * Conv. (m3/s)         *   272.3  *   545.6  *   243.6  *
* Length Wtd. (m)      *   30.00  * Wetted Per. (m)      *   50.99  *    7.05  *   10.68  *
* Min Ch El (m)        *  326.00  * Shear (N/m2)         *    9.53  *   39.57  *   23.55  *
* Alpha                *    2.07  * Stream Power (N/m s) *    5.47  *   79.36  *   23.38  *
* Frctn Loss (m)       *    0.03  * Cum Volume (1000 m3) *    4.98  *    1.29  *    0.74  *
* C & E Loss (m)       *    0.03  * Cum SA (1000 m2)     *    6.60  *    0.68  *    0.58  *
*******************************************************************************************

Warning: Divided flow computed for this cross-section.
Warning: The conveyance ratio (upstream conveyance divided by downstream conveyance) is less than
             or greater than 1.4.  This may indicate the need for additional cross sections.

CROSS SECTION OUTPUT  Profile #PF 6
*******************************************************************************************
* E.G. Elev (m)        *  328.33  * Element              *  Left OB *  Channel * Right OB *
0.7
* Vel Head (m)         *    0.11  * Wt. n-Val.           *   0.050  *   0.035  *   0.050  *
* W.S. Elev (m)        *  328.22  * Reach Len. (m)       *   30.00  *   30.00  *   30.00  *
* Crit W.S. (m)        *          * Flow Area (m2)       *   42.04  *   15.14  *   15.17  *
* E.G. Slope (m/m)     *0.001893  * Area (m2)            *   42.04  *   15.14  *   15.17  *
```

```
* Q Total (m3/s)       *   75.00  * Flow (m3/s)          *   27.80  *   31.35  *   15.85  *
* Top Width (m)        *   81.26  * Top Width (m)        *   63.00  *    7.00  *   11.26  *
* Vel Total (m/s)      *    1.04  * Avg. Vel. (m/s)      *    0.66  *    2.07  *    1.05  *
* Max Chl Dpth (m)     *    2.22  * Hydr. Depth (m)      *    0.67  *    2.16  *    1.35  *
* Conv. Total (m3/s)   *  1723.7  * Conv. (m3/s)         *   638.8  *   720.5  *   364.3  *
* Length Wtd. (m)      *   30.00  * Wetted Per. (m)      *   63.46  *    7.05  *   11.52  *
* Min Ch El (m)        *  326.00  * Shear (N/m2)         *   12.30  *   39.90  *   24.44  *
* Alpha                *    2.03  * Stream Power (N/m s) *    8.13  *   82.60  *   25.55  *
* Frctn Loss (m)       *    0.02  * Cum Volume (1000 m3) *    7.24  *    1.46  *    0.93  *
* C & E Loss (m)       *    0.03  * Cum SA (1000 m2)     *    6.91  *    0.68  *    0.63  *
*******************************************************************************************

Warning: The cross-section end points had to be extended vertically for the computed water surface.
Warning: The conveyance ratio (upstream conveyance divided by downstream conveyance) is less than
             or greater than 1.4.  This may indicate the need for additional cross sections.

CROSS SECTION


0.7
RIVER: Harrington Creek
REACH: 1                  RS: 8


CROSS SECTION OUTPUT  Profile #PF 1
*******************************************************************************************
* E.G. Elev (m)        *  326.02  * Element              *  Left OB *  Channel * Right OB *
* Vel Head (m)         *    0.01  * Wt. n-Val.           *   0.000  *   0.035  *   0.050  *
* W.S. Elev (m)        *  326.01  * Reach Len. (m)       *   21.00  *   21.00  *   21.00  *
* Crit W.S. (m)        *          * Flow Area (m2)       *    0.00  *    1.04  *    0.27  *
* E.G. Slope (m/m)     *0.001834  * Area (m2)            *    0.00  *    1.04  *    0.27  *
* Q Total (m3/s)       *    0.50  * Flow (m3/s)          *    0.00  *    0.44  *    0.06  *
* Top Width (m)        *    7.10  * Top Width (m)        *    0.02  *    5.00  *    2.09  *
* Vel Total (m/s)      *    0.38  * Avg. Vel. (m/s)      *    0.02  *    0.43  *    0.22  *
* Max Chl Dpth (m)     *    0.26  * Hydr. Depth (m)      *    0.00  *    0.21  *    0.13  *
* Conv. Total (m3/s)   *    11.7  * Conv. (m3/s)         *     0.0  *    10.3  *     1.3  *
* Length Wtd. (m)      *   21.00  * Wetted Per. (m)      *    0.02  *    5.06  *    2.15  *
* Min Ch El (m)        *  325.75  * Shear (N/m2)         *          *    3.69  *    2.22  *
* Alpha                *    1.13  * Stream Power (N/m s) *          *    1.57  *    0.48  *
* Frctn Loss (m)       *    0.10  * Cum Volume (1000 m3) *    0.00  *    0.05  *    0.00  *
* C & E Loss (m)       *    0.00  * Cum SA (1000 m2)     *    0.00  *    0.42  *    0.02  *
*******************************************************************************************

Warning: Divided flow computed for this cross-section.
Warning: The conveyance ratio (upstream conveyance divided by downstream conveyance) is less than
             or greater than 1.4.  This may indicate the need for additional cross sections.

CROSS SECTION OUTPUT  Profile #PF 2
*******************************************************************************************
* E.G. Elev (m)        *  326.11  * Element              *  Left OB *  Channel * Right OB *
0.7
* Vel Head (m)         *    0.01  * Wt. n-Val.           *   0.050  *   0.035  *   0.050  *
* W.S. Elev (m)        *  326.10  * Reach Len. (m)       *   21.00  *   21.00  *   21.00  *
```

```
* Crit W.S. (m)        *           * Flow Area (m2)       *    0.01  *    1.50  *    0.50  *
* E.G. Slope (m/m)     *0.002035  * Area (m2)            *    0.01  *    1.50  *    0.50  *
* Q Total (m3/s)       *    1.00  * Flow (m3/s)          *    0.00  *    0.86  *    0.14  *
* Top Width (m)        *    8.29  * Top Width (m)        *    0.20  *    5.00  *    3.09  *
* Vel Total (m/s)      *    0.50  * Avg. Vel. (m/s)      *    0.11  *    0.57  *    0.29  *
* Max Chl Dpth (m)     *    0.35  * Hydr. Depth (m)      *    0.05  *    0.30  *    0.16  *
* Conv. Total (m3/s)   *    22.2  * Conv. (m3/s)         *     0.0  *    19.0  *     3.2  *
* Length Wtd. (m)      *   21.00  * Wetted Per. (m)      *    0.22  *    5.06  *    3.22  *
* Min Ch El (m)        *  325.75  * Shear (N/m2)         *    0.89  *    5.90  *    3.11  *
* Alpha                *    1.18  * Stream Power (N/m s) *    0.10  *    3.37  *    0.89  *
* Frctn Loss (m)       *    0.10  * Cum Volume (1000 m3) *    0.00  *    0.08  *    0.01  *
* C & E Loss (m)       *    0.01  * Cum SA (1000 m2)     *    0.00  *    0.44  *    0.03  *
*******************************************************************************************

Warning: Divided flow computed for this cross-section.
Warning: The conveyance ratio (upstream conveyance divided by downstream conveyance) is less than
             or greater than 1.4.  This may indicate the need for additional cross sections.

CROSS SECTION OUTPUT  Profile #PF 3
*******************************************************************************************
* E.G. Elev (m)        *  326.88  * Element              *  Left OB *  Channel * Right OB *
0.7
* Vel Head (m)         *    0.06  * Wt. n-Val.           *   0.050  *   0.035  *   0.050  *
* W.S. Elev (m)        *  326.82  * Reach Len. (m)       *   21.00  *   21.00  *   21.00  *
* Crit W.S. (m)        *           * Flow Area (m2)       *    0.52  *    5.09  *    5.69  *
* E.G. Slope (m/m)     *0.001944  * Area (m2)            *    0.52  *    5.09  *    5.69  *
* Q Total (m3/s)       *   10.00  * Flow (m3/s)          *    0.20  *    6.43  *    3.37  *
* Top Width (m)        *   16.36  * Top Width (m)        *    1.54  *    5.00  *    9.82  *
* Vel Total (m/s)      *    0.88  * Avg. Vel. (m/s)      *    0.39  *    1.26  *    0.59  *
* Max Chl Dpth (m)     *    1.07  * Hydr. Depth (m)      *    0.34  *    1.02  *    0.58  *
* Conv. Total (m3/s)   *   226.8  * Conv. (m3/s)         *     4.6  *   145.9  *    76.4  *
* Length Wtd. (m)      *   21.00  * Wetted Per. (m)      *    1.81  *    5.06  *   10.37  *
* Min Ch El (m)        *  325.75  * Shear (N/m2)         *    5.51  *   19.16  *   10.47  *
* Alpha                *    1.47  * Stream Power (N/m s) *    2.12  *   24.22  *    6.19  *
* Frctn Loss (m)       *    0.08  * Cum Volume (1000 m3) *    0.01  *    0.34  *    0.07  *
* C & E Loss (m)       *    0.02  * Cum SA (1000 m2)     *    0.06  *    0.46  *    0.14  *
*******************************************************************************************

Warning: The velocity head has changed by more than 0.5 ft (0.15 m).  This may indicate the need for

Warning: The conveyance ratio (upstream conveyance divided by downstream conveyance) is less than
             or greater than 1.4.  This may indicate the need for additional cross sections.

CROSS SECTION OUTPUT  Profile #PF 4
additional cross sections.
*******************************************************************************************
* E.G. Elev (m)        *  327.43  * Element              *  Left OB *  Channel * Right OB *
0.7
* Vel Head (m)         *    0.07  * Wt. n-Val.           *   0.050  *   0.035  *   0.050  *
* W.S. Elev (m)        *  327.36  * Reach Len. (m)       *   21.00  *   21.00  *   21.00  *
* Crit W.S. (m)        *           * Flow Area (m2)       *   23.19  *    7.81  *   11.26  *
* E.G. Slope (m/m)     *0.001870  * Area (m2)            *   23.19  *    7.81  *   11.26  *
* Q Total (m3/s)       *   31.00  * Flow (m3/s)          *    8.46  *   12.90  *    9.64  *
* Top Width (m)        *  100.84  * Top Width (m)        *   85.11  *    5.00  *   10.73  *
```

```
* Vel Total (m/s)      *    0.73  * Avg. Vel. (m/s)      *    0.36  *    1.65  *    0.86  *
* Max Chl Dpth (m)     *    1.61  * Hydr. Depth (m)      *    0.27  *    1.56  *    1.05  *
* Conv. Total (m3/s)   *   716.9  * Conv. (m3/s)         *   195.7  *   298.3  *   223.0  *
* Length Wtd. (m)      *   21.00  * Wetted Per. (m)      *   85.41  *    5.06  *   11.44  *
* Min Ch El (m)        *  325.75  * Shear (N/m2)         *    4.98  *   28.31  *   18.06  *
* Alpha                *    2.60  * Stream Power (N/m s) *    1.82  *   46.72  *   15.46  *
* Frctn Loss (m)       *    0.03  * Cum Volume (1000 m3) *    1.27  *    0.70  *    0.18  *
* C & E Loss (m)       *    0.01  * Cum SA (1000 m2)     *    3.25  *    0.48  *    0.19  *
*******************************************************************************************

Warning: Divided flow computed for this cross-section.

CROSS SECTION OUTPUT  Profile #PF 5
*******************************************************************************************
* E.G. Elev (m)        *  327.95  * Element              *  Left OB *  Channel * Right OB *
* Vel Head (m)         *    0.02  * Wt. n-Val.           *   0.050  *   0.035  *   0.050  *
* W.S. Elev (m)        *  327.93  * Reach Len. (m)       *   21.00  *   21.00  *   21.00  *
* Crit W.S. (m)        *          * Flow Area (m2)       *   84.97  *   10.64  *   17.65  *
* E.G. Slope (m/m)     *0.000490  * Area (m2)            *   84.97  *   10.64  *   17.65  *
* Q Total (m3/s)       *   50.00  * Flow (m3/s)          *   29.21  *   11.05  *    9.73  *
* Top Width (m)        *  140.72  * Top Width (m)        *  123.87  *    5.00  *   11.86  *
* Vel Total (m/s)      *    0.44  * Avg. Vel. (m/s)      *    0.34  *    1.04  *    0.55  *
* Max Chl Dpth (m)     *    2.18  * Hydr. Depth (m)      *    0.69  *    2.13  *    1.49  *
* Conv. Total (m3/s)   *  2258.4  * Conv. (m3/s)         *  1319.5  *   499.2  *   439.7  *
* Length Wtd. (m)      *   21.00  * Wetted Per. (m)      *  124.21  *    5.06  *   12.70  *
* Min Ch El (m)        *  325.75  * Shear (N/m2)         *    3.29  *   10.11  *    6.68  *
* Alpha                *    1.88  * Stream Power (N/m s) *    1.13  *   10.50  *    3.68  *
* Frctn Loss (m)       *    0.01  * Cum Volume (1000 m3) *    3.37  *    0.94  *    0.30  *
* C & E Loss (m)       *    0.00  * Cum SA (1000 m2)     *    3.98  *    0.50  *    0.25  *
*******************************************************************************************

CROSS SECTION OUTPUT  Profile #PF 6
*******************************************************************************************
* E.G. Elev (m)        *  328.28  * Element              *  Left OB *  Channel * Right OB *
* Vel Head (m)         *    0.02  * Wt. n-Val.           *   0.050  *   0.035  *   0.050  *
* W.S. Elev (m)        *  328.26  * Reach Len. (m)       *   21.00  *   21.00  *   21.00  *
* Crit W.S. (m)        *          * Flow Area (m2)       *  126.36  *   12.30  *   21.69  *
* E.G. Slope (m/m)     *0.000396  * Area (m2)            *  126.36  *   12.30  *   21.69  *
* Q Total (m3/s)       *   75.00  * Flow (m3/s)          *   50.48  *   12.64  *   11.88  *
* Top Width (m)        *  142.52  * Top Width (m)        *  125.00  *    5.00  *   12.52  *
* Vel Total (m/s)      *    0.47  * Avg. Vel. (m/s)      *    0.40  *    1.03  *    0.55  *
* Max Chl Dpth (m)     *    2.51  * Hydr. Depth (m)      *    1.01  *    2.46  *    1.73  *
* Conv. Total (m3/s)   *  3769.5  * Conv. (m3/s)         *  2537.3  *   635.3  *   596.9  *
* Length Wtd. (m)      *   21.00  * Wetted Per. (m)      *  125.60  *    5.06  *   13.44  *
* Min Ch El (m)        *  325.75  * Shear (N/m2)         *    3.91  *    9.43  *    6.26  *
* Alpha                *    1.52  * Stream Power (N/m s) *    1.56  *    9.70  *    3.43  *
* Frctn Loss (m)       *    0.01  * Cum Volume (1000 m3) *    4.71  *    1.05  *    0.38  *
* C & E Loss (m)       *    0.00  * Cum SA (1000 m2)     *    4.09  *    0.50  *    0.27  *
*******************************************************************************************

Warning: The cross-section end points had to be extended vertically for the computed water surface.
```

```
CROSS SECTION


RIVER: Harrington Creek
REACH: 1                  RS: 7


CROSS SECTION OUTPUT  Profile #PF 1
*******************************************************************************************
* E.G. Elev (m)        *  325.92  * Element              *  Left OB *  Channel * Right OB *
* Vel Head (m)         *    0.05  * Wt. n-Val.           *          *   0.035  *          *
* W.S. Elev (m)        *  325.86  * Reach Len. (m)       *   22.00  *   22.00  *   22.00  *
* Crit W.S. (m)        *  325.86  * Flow Area (m2)       *          *    0.49  *          *
* E.G. Slope (m/m)     *0.025815  * Area (m2)            *          *    0.49  *          *
* Q Total (m3/s)       *    0.50  * Flow (m3/s)          *          *    0.50  *          *
* Top Width (m)        *    4.68  * Top Width (m)        *          *    4.68  *          *
* Vel Total (m/s)      *    1.02  * Avg. Vel. (m/s)      *          *    1.02  *          *
* Max Chl Dpth (m)     *    0.11  * Hydr. Depth (m)      *          *    0.11  *          *
* Conv. Total (m3/s)   *     3.1  * Conv. (m3/s)         *          *     3.1  *          *
* Length Wtd. (m)      *   22.00  * Wetted Per. (m)      *          *    4.72  *          *
* Min Ch El (m)        *  325.75  * Shear (N/m2)         *          *   26.38  *          *
* Alpha                *    1.00  * Stream Power (N/m s) *          *   26.81  *          *
* Frctn Loss (m)       *    0.20  * Cum Volume (1000 m3) *          *    0.03  *          *
* C & E Loss (m)       *    0.01  * Cum SA (1000 m2)     *          *    0.32  *          *
*******************************************************************************************

Warning: The energy equation could not be balanced within the specified number of iterations.  The


Warning: The conveyance ratio (upstream conveyance divided by downstream conveyance) is less than
             or greater than 1.4.  This may indicate the need for additional cross sections.
Warning: During the standard step iterations, when the assumed water surface was set equal to critical
program selected the water surface that had the least amount of error between computed and
                                                                                  This indicates that there
assumed values.
                                            The program defaulted to critical depth.

0.7
CROSS SECTION OUTPUT  Profile #PF 2
*******************************************************************************************
depth, the calculated water surface came back below critical depth.
* E.G. Elev (m)        *  326.01  * Element              *  Left OB *  Channel * Right OB *
is not a valid subcritical answer.
* Vel Head (m)         *    0.08  * Wt. n-Val.           *          *   0.035  *          *
* W.S. Elev (m)        *  325.93  * Reach Len. (m)       *   22.00  *   22.00  *   22.00  *
* Crit W.S. (m)        *  325.93  * Flow Area (m2)       *          *    0.80  *          *
* E.G. Slope (m/m)     *0.022803  * Area (m2)            *          *    0.80  *          *
* Q Total (m3/s)       *    1.00  * Flow (m3/s)          *          *    1.00  *          *
* Top Width (m)        *    5.06  * Top Width (m)        *          *    5.06  *          *
* Vel Total (m/s)      *    1.25  * Avg. Vel. (m/s)      *          *    1.25  *          *
* Max Chl Dpth (m)     *    0.18  * Hydr. Depth (m)      *          *    0.16  *          *
* Conv. Total (m3/s)   *     6.6  * Conv. (m3/s)         *          *     6.6  *          *
* Length Wtd. (m)      *   22.00  * Wetted Per. (m)      *          *    5.12  *          *
* Min Ch El (m)        *  325.75  * Shear (N/m2)         *          *   34.90  *          *
* Alpha                *    1.00  * Stream Power (N/m s) *          *   43.65  *          *
```

```
* Frctn Loss (m)       *    0.17  * Cum Volume (1000 m3) *          *    0.05  *          *
* C & E Loss (m)       *    0.02  * Cum SA (1000 m2)     *          *    0.33  *          *
*******************************************************************************************

Warning: The energy equation could not be balanced within the specified number of iterations.  The


Warning: The conveyance ratio (upstream conveyance divided by downstream conveyance) is less than
             or greater than 1.4.  This may indicate the need for additional cross sections.
Warning: The energy loss was greater than 1.0 ft (0.3 m). between the current and previous cross
program selected the water surface that had the least amount of error between computed and
                   This may indicate the need for additional cross sections.
assumed values.
Warning: During the standard step iterations, when the assumed water surface was set equal to critical
                                                                              This indicates that there
0.7
                                                    The program defaulted to critical depth.

section
CROSS SECTION OUTPUT  Profile #PF 3
*******************************************************************************************
depth, the calculated water surface came back below critical depth.
* E.G. Elev (m)        *  326.77  * Element              *  Left OB  *  Channel * Right OB *
is not a valid subcritical answer.
* Vel Head (m)         *    0.29  * Wt. n-Val.           *   0.050  *   0.035  *   0.050  *
* W.S. Elev (m)        *  326.48  * Reach Len. (m)       *   22.00  *   22.00  *   22.00  *
* Crit W.S. (m)        *  326.48  * Flow Area (m2)       *    0.34  *    3.85  *    0.43  *
* E.G. Slope (m/m)     *0.012024  * Area (m2)            *    0.34  *    3.85  *    0.43  *
* Q Total (m3/s)       *   10.00  * Flow (m3/s)          *    0.23  *    9.39  *    0.38  *
* Top Width (m)        *    9.02  * Top Width (m)        *    1.90  *    5.50  *    1.62  *
* Vel Total (m/s)      *    2.17  * Avg. Vel. (m/s)      *    0.68  *    2.44  *    0.88  *
* Max Chl Dpth (m)     *    0.73  * Hydr. Depth (m)      *    0.18  *    0.70  *    0.27  *
* Conv. Total (m3/s)   *    91.2  * Conv. (m3/s)         *     2.1  *    85.6  *     3.5  *
* Length Wtd. (m)      *   22.00  * Wetted Per. (m)      *    1.98  *    5.59  *    1.70  *
* Min Ch El (m)        *  325.75  * Shear (N/m2)         *   20.41  *   81.11  *   29.97  *
* Alpha                *    1.20  * Stream Power (N/m s) *   13.91  *  198.03  *   26.37  *
* Frctn Loss (m)       *    0.11  * Cum Volume (1000 m3) *    0.00  *    0.25  *    0.00  *
* C & E Loss (m)       *    0.06  * Cum SA (1000 m2)     *    0.02  *    0.35  *    0.02  *
*******************************************************************************************

Warning: The energy equation could not be balanced within the specified number of iterations.  The

Warning: The velocity head has changed by more than 0.5 ft (0.15 m).  This may indicate the need for

Warning: The conveyance ratio (upstream conveyance divided by downstream conveyance) is less than
             or greater than 1.4.  This may indicate the need for additional cross sections.
program used critical depth for the water surface and continued on with the calculations.
Warning: The energy loss was greater than 1.0 ft (0.3 m). between the current and previous cross
                   This may indicate the need for additional cross sections.
additional cross sections.
Warning: During the standard step iterations, when the assumed water surface was set equal to critical
                                                                              This indicates that there
0.7
                                                    The program defaulted to critical depth.

section
CROSS SECTION OUTPUT  Profile #PF 4
*******************************************************************************************
depth, the calculated water surface came back below critical depth.
* E.G. Elev (m)        *  327.39  * Element              *  Left OB  *  Channel * Right OB *
is not a valid subcritical answer.
* Vel Head (m)         *    0.03  * Wt. n-Val.           *   0.050  *   0.035  *   0.050  *
* W.S. Elev (m)        *  327.36  * Reach Len. (m)       *   22.00  *   22.00  *   22.00  *
```

```
* Crit W.S. (m)        *           * Flow Area (m2)       *   47.69  *    8.66  *    2.81  *
* E.G. Slope (m/m)     *0.001117  * Area (m2)            *   47.69  *    8.66  *    2.81  *
* Q Total (m3/s)       *   31.00  * Flow (m3/s)          *   18.41  *   11.07  *    1.52  *
* Top Width (m)        *  118.74  * Top Width (m)        *  109.65  *    5.50  *    3.60  *
* Vel Total (m/s)      *    0.52  * Avg. Vel. (m/s)      *    0.39  *    1.28  *    0.54  *
* Max Chl Dpth (m)     *    1.61  * Hydr. Depth (m)      *    0.43  *    1.57  *    0.78  *
* Conv. Total (m3/s)   *   927.4  * Conv. (m3/s)         *   550.8  *   331.2  *    45.4  *
* Length Wtd. (m)      *   22.00  * Wetted Per. (m)      *  109.84  *    5.59  *    3.86  *
* Min Ch El (m)        *  325.75  * Shear (N/m2)         *    4.76  *   16.97  *    7.96  *
* Alpha                *    2.50  * Stream Power (N/m s) *    1.84  *   21.70  *    4.30  *
* Frctn Loss (m)       *    0.04  * Cum Volume (1000 m3) *    0.52  *    0.53  *    0.03  *
* C & E Loss (m)       *    0.01  * Cum SA (1000 m2)     *    1.21  *    0.37  *    0.04  *
******************************************************************************************

Warning: Divided flow computed for this cross-section.
Warning: The conveyance ratio (upstream conveyance divided by downstream conveyance) is less than
             or greater than 1.4.  This may indicate the need for additional cross sections.

CROSS SECTION OUTPUT  Profile #PF 5
******************************************************************************************
* E.G. Elev (m)        *  327.94  * Element              *  Left OB *  Channel * Right OB *
0.7
* Vel Head (m)         *    0.01  * Wt. n-Val.           *   0.050  *   0.035  *   0.050  *
* W.S. Elev (m)        *  327.93  * Reach Len. (m)       *   22.00  *   22.00  *   22.00  *
* Crit W.S. (m)        *           * Flow Area (m2)       *  115.40  *   11.78  *    5.12  *
* E.G. Slope (m/m)     *0.000309  * Area (m2)            *  115.40  *   11.78  *    5.12  *
* Q Total (m3/s)       *   50.00  * Flow (m3/s)          *   38.44  *    9.72  *    1.84  *
* Top Width (m)        *  134.89  * Top Width (m)        *  124.85  *    5.50  *    4.54  *
* Vel Total (m/s)      *    0.38  * Avg. Vel. (m/s)      *    0.33  *    0.83  *    0.36  *
* Max Chl Dpth (m)     *    2.18  * Hydr. Depth (m)      *    0.92  *    2.14  *    1.13  *
* Conv. Total (m3/s)   *  2844.9  * Conv. (m3/s)         *  2187.2  *   553.2  *   104.4  *
* Length Wtd. (m)      *   22.00  * Wetted Per. (m)      *  125.10  *    5.59  *    4.97  *
* Min Ch El (m)        *  325.75  * Shear (N/m2)         *    2.79  *    6.38  *    3.12  *
* Alpha                *    1.56  * Stream Power (N/m s) *    0.93  *    5.27  *    1.12  *
* Frctn Loss (m)       *    0.02  * Cum Volume (1000 m3) *    1.27  *    0.71  *    0.06  *
* C & E Loss (m)       *    0.02  * Cum SA (1000 m2)     *    1.37  *    0.39  *    0.08  *
******************************************************************************************

Warning: The velocity head has changed by more than 0.5 ft (0.15 m).  This may indicate the need for

Warning: The conveyance ratio (upstream conveyance divided by downstream conveyance) is less than
             or greater than 1.4.  This may indicate the need for additional cross sections.

CROSS SECTION OUTPUT  Profile #PF 6
additional cross sections.
******************************************************************************************
* E.G. Elev (m)        *  328.27  * Element              *  Left OB *  Channel * Right OB *
0.7
* Vel Head (m)         *    0.01  * Wt. n-Val.           *   0.050  *   0.035  *   0.050  *
* W.S. Elev (m)        *  328.26  * Reach Len. (m)       *   22.00  *   22.00  *   22.00  *
* Crit W.S. (m)        *           * Flow Area (m2)       *  157.38  *   13.60  *    6.71  *
* E.G. Slope (m/m)     *0.000286  * Area (m2)            *  157.38  *   13.60  *    6.71  *
* Q Total (m3/s)       *   75.00  * Flow (m3/s)          *   60.57  *   11.87  *    2.56  *
* Top Width (m)        *  139.85  * Top Width (m)        *  129.25  *    5.50  *    5.09  *
```

```
* Vel Total (m/s)      *    0.42  * Avg. Vel. (m/s)      *    0.38  *    0.87  *    0.38  *
* Max Chl Dpth (m)     *    2.51  * Hydr. Depth (m)      *    1.22  *    2.47  *    1.32  *
* Conv. Total (m3/s)   *  4438.3  * Conv. (m3/s)         *  3584.4  *   702.7  *   151.2  *
* Length Wtd. (m)      *   22.00  * Wetted Per. (m)      *  129.51  *    5.59  *    5.61  *
* Min Ch El (m)        *  325.75  * Shear (N/m2)         *    3.40  *    6.81  *    3.35  *
* Alpha                *    1.38  * Stream Power (N/m s) *    1.31  *    5.95  *    1.28  *
* Frctn Loss (m)       *    0.02  * Cum Volume (1000 m3) *    1.73  *    0.77  *    0.08  *
* C & E Loss (m)       *    0.05  * Cum SA (1000 m2)     *    1.42  *    0.39  *    0.09  *
*******************************************************************************************

Warning: The velocity head has changed by more than 0.5 ft (0.15 m).  This may indicate the need for

Warning: The conveyance ratio (upstream conveyance divided by downstream conveyance) is less than
             or greater than 1.4.  This may indicate the need for additional cross sections.

CROSS SECTION
additional cross sections.

0.7
RIVER: Harrington Creek
REACH: 1                  RS: 6


CROSS SECTION OUTPUT  Profile #PF 1
*******************************************************************************************
* E.G. Elev (m)        *  325.63  * Element              *  Left OB *  Channel * Right OB *
* Vel Head (m)         *    0.01  * Wt. n-Val.           *          *   0.035  *          *
* W.S. Elev (m)        *  325.62  * Reach Len. (m)       *   16.80  *   16.80  *   16.80  *
* Crit W.S. (m)        *  325.57  * Flow Area (m2)       *          *    1.11  *          *
* E.G. Slope (m/m)     *0.004490  * Area (m2)            *          *    1.11  *          *
* Q Total (m3/s)       *    0.50  * Flow (m3/s)          *          *    0.50  *          *
* Top Width (m)        *    9.74  * Top Width (m)        *          *    9.74  *          *
* Vel Total (m/s)      *    0.45  * Avg. Vel. (m/s)      *          *    0.45  *          *
* Max Chl Dpth (m)     *    0.12  * Hydr. Depth (m)      *          *    0.11  *          *
* Conv. Total (m3/s)   *     7.5  * Conv. (m3/s)         *          *     7.5  *          *
* Length Wtd. (m)      *   16.80  * Wetted Per. (m)      *          *    9.82  *          *
* Min Ch El (m)        *  325.50  * Shear (N/m2)         *          *    5.00  *          *
* Alpha                *    1.00  * Stream Power (N/m s) *          *    2.24  *          *
* Frctn Loss (m)       *          * Cum Volume (1000 m3) *          *    0.02  *          *
* C & E Loss (m)       *          * Cum SA (1000 m2)     *          *    0.16  *          *
*******************************************************************************************

CROSS SECTION OUTPUT  Profile #PF 2
*******************************************************************************************
* E.G. Elev (m)        *  325.70  * Element              *  Left OB *  Channel * Right OB *
* Vel Head (m)         *    0.02  * Wt. n-Val.           *          *   0.035  *          *
* W.S. Elev (m)        *  325.68  * Reach Len. (m)       *   16.80  *   16.80  *   16.80  *
* Crit W.S. (m)        *  325.60  * Flow Area (m2)       *          *    1.77  *          *
* E.G. Slope (m/m)     *0.003935  * Area (m2)            *          *    1.77  *          *
* Q Total (m3/s)       *    1.00  * Flow (m3/s)          *          *    1.00  *          *
* Top Width (m)        *    9.94  * Top Width (m)        *          *    9.94  *          *
* Vel Total (m/s)      *    0.56  * Avg. Vel. (m/s)      *          *    0.56  *          *
```

```
* Max Chl Dpth (m)     *    0.18  * Hydr. Depth (m)      *          *    0.18  *          *
* Conv. Total (m3/s)   *    15.9  * Conv. (m3/s)         *          *    15.9  *          *
* Length Wtd. (m)      *   16.80  * Wetted Per. (m)      *          *   10.06  *          *
* Min Ch El (m)        *  325.50  * Shear (N/m2)         *          *    6.80  *          *
* Alpha                *    1.00  * Stream Power (N/m s) *          *    3.84  *          *
* Frctn Loss (m)       *          * Cum Volume (1000 m3) *          *    0.02  *          *
* C & E Loss (m)       *          * Cum SA (1000 m2)     *          *    0.16  *          *
*******************************************************************************************

CROSS SECTION OUTPUT  Profile #PF 3
*******************************************************************************************
* E.G. Elev (m)        *  326.39  * Element              *  Left OB *  Channel * Right OB *
* Vel Head (m)         *    0.07  * Wt. n-Val.           *          *   0.035  *          *
* W.S. Elev (m)        *  326.32  * Reach Len. (m)       *   16.80  *   16.80  *   16.80  *
* Crit W.S. (m)        *  325.97  * Flow Area (m2)       *          *    8.39  *          *
* E.G. Slope (m/m)     *0.002699  * Area (m2)            *          *    8.39  *          *
* Q Total (m3/s)       *   10.00  * Flow (m3/s)          *          *   10.00  *          *
* Top Width (m)        *   10.67  * Top Width (m)        *          *   10.67  *          *
* Vel Total (m/s)      *    1.19  * Avg. Vel. (m/s)      *          *    1.19  *          *
* Max Chl Dpth (m)     *    0.82  * Hydr. Depth (m)      *          *    0.79  *          *
* Conv. Total (m3/s)   *   192.5  * Conv. (m3/s)         *          *   192.5  *          *
* Length Wtd. (m)      *   16.80  * Wetted Per. (m)      *          *   11.65  *          *
* Min Ch El (m)        *  325.50  * Shear (N/m2)         *          *   19.05  *          *
* Alpha                *    1.00  * Stream Power (N/m s) *          *   22.71  *          *
* Frctn Loss (m)       *          * Cum Volume (1000 m3) *          *    0.11  *          *
* C & E Loss (m)       *          * Cum SA (1000 m2)     *          *    0.18  *          *
*******************************************************************************************

CROSS SECTION OUTPUT  Profile #PF 4
*******************************************************************************************
* E.G. Elev (m)        *  327.35  * Element              *  Left OB *  Channel * Right OB *
* Vel Head (m)         *    0.15  * Wt. n-Val.           *          *   0.035  *          *
* W.S. Elev (m)        *  327.20  * Reach Len. (m)       *   16.80  *   16.80  *   16.80  *
* Crit W.S. (m)        *  326.49  * Flow Area (m2)       *          *   18.08  *          *
* E.G. Slope (m/m)     *0.002493  * Area (m2)            *          *   18.08  *          *
* Q Total (m3/s)       *   31.00  * Flow (m3/s)          *          *   31.00  *          *
* Top Width (m)        *   11.48  * Top Width (m)        *          *   11.48  *          *
* Vel Total (m/s)      *    1.71  * Avg. Vel. (m/s)      *          *    1.71  *          *
* Max Chl Dpth (m)     *    1.70  * Hydr. Depth (m)      *          *    1.57  *          *
* Conv. Total (m3/s)   *   620.9  * Conv. (m3/s)         *          *   620.9  *          *
* Length Wtd. (m)      *   16.80  * Wetted Per. (m)      *          *   13.73  *          *
* Min Ch El (m)        *  325.50  * Shear (N/m2)         *          *   32.21  *          *
* Alpha                *    1.00  * Stream Power (N/m s) *          *   55.21  *          *
* Frctn Loss (m)       *          * Cum Volume (1000 m3) *          *    0.24  *          *
* C & E Loss (m)       *          * Cum SA (1000 m2)     *          *    0.19  *          *
*******************************************************************************************

CROSS SECTION OUTPUT  Profile #PF 5
*******************************************************************************************
* E.G. Elev (m)        *  327.90  * Element              *  Left OB *  Channel * Right OB *
* Vel Head (m)         *    0.23  * Wt. n-Val.           *          *   0.035  *   0.050  *
```

```
* W.S. Elev (m)        *  327.67  * Reach Len. (m)       *   16.80  *   16.80  *   16.80  *
* Crit W.S. (m)        *  326.85  * Flow Area (m2)       *          *   23.66  *    0.12  *
* E.G. Slope (m/m)     *0.002894  * Area (m2)            *          *   23.66  *    0.12  *
* Q Total (m3/s)       *   50.00  * Flow (m3/s)          *          *   49.97  *    0.03  *
* Top Width (m)        *   13.31  * Top Width (m)        *          *   11.93  *    1.39  *
* Vel Total (m/s)      *    2.10  * Avg. Vel. (m/s)      *          *    2.11  *    0.21  *
* Max Chl Dpth (m)     *    2.17  * Hydr. Depth (m)      *          *    1.98  *    0.09  *
* Conv. Total (m3/s)   *   929.4  * Conv. (m3/s)         *          *   929.0  *     0.5  *
* Length Wtd. (m)      *   16.80  * Wetted Per. (m)      *          *   14.68  *    1.40  *
* Min Ch El (m)        *  325.50  * Shear (N/m2)         *          *   45.73  *    2.44  *
* Alpha                *    1.01  * Stream Power (N/m s) *          *   96.60  *    0.51  *
* Frctn Loss (m)       *          * Cum Volume (1000 m3) *          *    0.32  *    0.00  *
* C & E Loss (m)       *          * Cum SA (1000 m2)     *          *    0.19  *    0.01  *
*******************************************************************************************

CROSS SECTION OUTPUT  Profile #PF 6
*******************************************************************************************
* E.G. Elev (m)        *  328.20  * Element              *  Left OB *  Channel * Right OB *
* Vel Head (m)         *    0.49  * Wt. n-Val.           *          *   0.035  *   0.050  *
* W.S. Elev (m)        *  327.71  * Reach Len. (m)       *   16.80  *   16.80  *   16.80  *
* Crit W.S. (m)        *  327.26  * Flow Area (m2)       *          *   24.14  *    0.18  *
* E.G. Slope (m/m)     *0.006111  * Area (m2)            *          *   24.14  *    0.18  *
* Q Total (m3/s)       *   75.00  * Flow (m3/s)          *          *   74.94  *    0.06  *
* Top Width (m)        *   13.68  * Top Width (m)        *          *   11.97  *    1.71  *
* Vel Total (m/s)      *    3.08  * Avg. Vel. (m/s)      *          *    3.10  *    0.35  *
* Max Chl Dpth (m)     *    2.21  * Hydr. Depth (m)      *          *    2.02  *    0.11  *
* Conv. Total (m3/s)   *   959.4  * Conv. (m3/s)         *          *   958.6  *     0.8  *
* Length Wtd. (m)      *   16.80  * Wetted Per. (m)      *          *   14.74  *    1.72  *
* Min Ch El (m)        *  325.50  * Shear (N/m2)         *          *   98.17  *    6.36  *
* Alpha                *    1.01  * Stream Power (N/m s) *          *  304.69  *    2.23  *
* Frctn Loss (m)       *          * Cum Volume (1000 m3) *          *    0.36  *    0.00  *
* C & E Loss (m)       *          * Cum SA (1000 m2)     *          *    0.20  *    0.01  *
*******************************************************************************************

CROSS SECTION


RIVER: Harrington Creek
REACH: 1                  RS: 3


CROSS SECTION OUTPUT  Profile #PF 1
*******************************************************************************************
* E.G. Elev (m)        *  325.50  * Element              *  Left OB *  Channel * Right OB *
* Vel Head (m)         *    0.02  * Wt. n-Val.           *          *   0.035  *          *
* W.S. Elev (m)        *  325.48  * Reach Len. (m)       *          *          *          *
* Crit W.S. (m)        *  325.47  * Flow Area (m2)       *          *    0.78  *          *
* E.G. Slope (m/m)     *0.014297  * Area (m2)            *          *    0.78  *          *
* Q Total (m3/s)       *    0.50  * Flow (m3/s)          *          *    0.50  *          *
* Top Width (m)        *    9.59  * Top Width (m)        *          *    9.59  *          *
* Vel Total (m/s)      *    0.64  * Avg. Vel. (m/s)      *          *    0.64  *          *
```

```
* Max Chl Dpth (m)     *    0.08  * Hydr. Depth (m)      *          *    0.08  *          *
* Conv. Total (m3/s)   *     4.2  * Conv. (m3/s)         *          *     4.2  *          *
* Length Wtd. (m)      *          * Wetted Per. (m)      *          *    9.65  *          *
* Min Ch El (m)        *  325.40  * Shear (N/m2)         *          *   11.35  *          *
* Alpha                *    1.00  * Stream Power (N/m s) *          *    7.26  *          *
* Frctn Loss (m)       *          * Cum Volume (1000 m3) *          *          *          *
* C & E Loss (m)       *          * Cum SA (1000 m2)     *          *          *          *
*******************************************************************************************

CROSS SECTION OUTPUT  Profile #PF 2
*******************************************************************************************
* E.G. Elev (m)        *  325.56  * Element              *  Left OB *  Channel * Right OB *
* Vel Head (m)         *    0.04  * Wt. n-Val.           *          *   0.035  *          *
* W.S. Elev (m)        *  325.52  * Reach Len. (m)       *          *          *          *
* Crit W.S. (m)        *  325.50  * Flow Area (m2)       *          *    1.19  *          *
* E.G. Slope (m/m)     *0.014312  * Area (m2)            *          *    1.19  *          *
* Q Total (m3/s)       *    1.00  * Flow (m3/s)          *          *    1.00  *          *
* Top Width (m)        *    9.69  * Top Width (m)        *          *    9.69  *          *
* Vel Total (m/s)      *    0.84  * Avg. Vel. (m/s)      *          *    0.84  *          *
* Max Chl Dpth (m)     *    0.12  * Hydr. Depth (m)      *          *    0.12  *          *
* Conv. Total (m3/s)   *     8.4  * Conv. (m3/s)         *          *     8.4  *          *
* Length Wtd. (m)      *          * Wetted Per. (m)      *          *    9.78  *          *
* Min Ch El (m)        *  325.40  * Shear (N/m2)         *          *   17.08  *          *
* Alpha                *    1.00  * Stream Power (N/m s) *          *   14.34  *          *
* Frctn Loss (m)       *          * Cum Volume (1000 m3) *          *          *          *
* C & E Loss (m)       *          * Cum SA (1000 m2)     *          *          *          *
*******************************************************************************************

CROSS SECTION OUTPUT  Profile #PF 3
*******************************************************************************************
* E.G. Elev (m)        *  326.11  * Element              *  Left OB *  Channel * Right OB *
* Vel Head (m)         *    0.21  * Wt. n-Val.           *          *   0.035  *          *
* W.S. Elev (m)        *  325.90  * Reach Len. (m)       *          *          *          *
* Crit W.S. (m)        *  325.87  * Flow Area (m2)       *          *    4.94  *          *
* E.G. Slope (m/m)     *0.014297  * Area (m2)            *          *    4.94  *          *
* Q Total (m3/s)       *   10.00  * Flow (m3/s)          *          *   10.00  *          *
* Top Width (m)        *   10.34  * Top Width (m)        *          *   10.34  *          *
* Vel Total (m/s)      *    2.02  * Avg. Vel. (m/s)      *          *    2.02  *          *
* Max Chl Dpth (m)     *    0.50  * Hydr. Depth (m)      *          *    0.48  *          *
* Conv. Total (m3/s)   *    83.6  * Conv. (m3/s)         *          *    83.6  *          *
* Length Wtd. (m)      *          * Wetted Per. (m)      *          *   10.82  *          *
* Min Ch El (m)        *  325.40  * Shear (N/m2)         *          *   63.98  *          *
* Alpha                *    1.00  * Stream Power (N/m s) *          *  129.54  *          *
* Frctn Loss (m)       *          * Cum Volume (1000 m3) *          *          *          *
* C & E Loss (m)       *          * Cum SA (1000 m2)     *          *          *          *
*******************************************************************************************

CROSS SECTION OUTPUT  Profile #PF 4
*******************************************************************************************
* E.G. Elev (m)        *  326.87  * Element              *  Left OB *  Channel * Right OB *
* Vel Head (m)         *    0.48  * Wt. n-Val.           *          *   0.035  *          *
```

```
* W.S. Elev (m)        *  326.39  * Reach Len. (m)       *          *          *          *
* Crit W.S. (m)        *  326.39  * Flow Area (m2)       *          *   10.15  *          *
* E.G. Slope (m/m)     *0.014266  * Area (m2)            *          *   10.15  *          *
* Q Total (m3/s)       *   31.00  * Flow (m3/s)          *          *   31.00  *          *
* Top Width (m)        *   10.78  * Top Width (m)        *          *   10.78  *          *
* Vel Total (m/s)      *    3.06  * Avg. Vel. (m/s)      *          *    3.06  *          *
* Max Chl Dpth (m)     *    0.99  * Hydr. Depth (m)      *          *    0.94  *          *
* Conv. Total (m3/s)   *   259.5  * Conv. (m3/s)         *          *   259.5  *          *
* Length Wtd. (m)      *          * Wetted Per. (m)      *          *   11.98  *          *
* Min Ch El (m)        *  325.40  * Shear (N/m2)         *          *  118.52  *          *
* Alpha                *    1.00  * Stream Power (N/m s) *          *  362.11  *          *
* Frctn Loss (m)       *          * Cum Volume (1000 m3) *          *          *          *
* C & E Loss (m)       *          * Cum SA (1000 m2)     *          *          *          *
*******************************************************************************************

Warning: Slope too steep for slope area to converge during supercritical flow calculations (normal depth


CROSS SECTION OUTPUT  Profile #PF 5
*******************************************************************************************
* E.G. Elev (m)        *  327.39  * Element              *  Left OB *  Channel * Right OB *
is below critical depth). Water surface set to critical depth.
* Vel Head (m)         *    0.64  * Wt. n-Val.           *          *   0.035  *          *
* W.S. Elev (m)        *  326.75  * Reach Len. (m)       *          *          *          *
* Crit W.S. (m)        *  326.75  * Flow Area (m2)       *          *   14.10  *          *
* E.G. Slope (m/m)     *0.013575  * Area (m2)            *          *   14.10  *          *
* Q Total (m3/s)       *   50.00  * Flow (m3/s)          *          *   50.00  *          *
* Top Width (m)        *   11.11  * Top Width (m)        *          *   11.11  *          *
* Vel Total (m/s)      *    3.55  * Avg. Vel. (m/s)      *          *    3.55  *          *
* Max Chl Dpth (m)     *    1.35  * Hydr. Depth (m)      *          *    1.27  *          *
* Conv. Total (m3/s)   *   429.1  * Conv. (m3/s)         *          *   429.1  *          *
* Length Wtd. (m)      *          * Wetted Per. (m)      *          *   12.82  *          *
* Min Ch El (m)        *  325.40  * Shear (N/m2)         *          *  146.38  *          *
* Alpha                *    1.00  * Stream Power (N/m s) *          *  519.11  *          *
* Frctn Loss (m)       *          * Cum Volume (1000 m3) *          *          *          *
* C & E Loss (m)       *          * Cum SA (1000 m2)     *          *          *          *
*******************************************************************************************

Warning: Slope too steep for slope area to converge during supercritical flow calculations (normal depth


CROSS SECTION OUTPUT  Profile #PF 6
*******************************************************************************************
* E.G. Elev (m)        *  327.98  * Element              *  Left OB *  Channel * Right OB *
is below critical depth). Water surface set to critical depth.
* Vel Head (m)         *    0.82  * Wt. n-Val.           *          *   0.035  *          *
* W.S. Elev (m)        *  327.16  * Reach Len. (m)       *          *          *          *
* Crit W.S. (m)        *  327.16  * Flow Area (m2)       *          *   18.68  *          *
* E.G. Slope (m/m)     *0.013149  * Area (m2)            *          *   18.68  *          *
* Q Total (m3/s)       *   75.00  * Flow (m3/s)          *          *   75.00  *          *
* Top Width (m)        *   11.47  * Top Width (m)        *          *   11.47  *          *
* Vel Total (m/s)      *    4.01  * Avg. Vel. (m/s)      *          *    4.01  *          *
* Max Chl Dpth (m)     *    1.76  * Hydr. Depth (m)      *          *    1.63  *          *
```

```
* Conv. Total (m3/s)   *   654.0  * Conv. (m3/s)         *          *   654.0  *          *
* Length Wtd. (m)      *          * Wetted Per. (m)      *          *   13.77  *          *
* Min Ch El (m)        *  325.40  * Shear (N/m2)         *          *  174.91  *          *
* Alpha                *    1.00  * Stream Power (N/m s) *          *  702.20  *          *
* Frctn Loss (m)       *          * Cum Volume (1000 m3) *          *          *          *
* C & E Loss (m)       *          * Cum SA (1000 m2)     *          *          *          *
*******************************************************************************************

Warning: Slope too steep for slope area to converge during supercritical flow calculations (normal depth


********************************************************************************

SUMMARY OF REACH LENGTHS
is below critical depth). Water surface set to critical depth.
River: Harrington Creek
*****************************************************************
*     Reach      *   River Sta.   *  Left   * Channel *  Right  *
*****************************************************************
*1               *    10          *        2*        2*        2*
*1               *    9.5         *       18*       15*       12*
*1               *    9           *       30*       30*       30*
*1               *    8           *       21*       21*       21*
*1               *    7           *       22*       22*       22*
*1               *    6           *     16.8*     16.8*     16.8*
*1               *    4.5         *Culvert  *         *         *
*1               *    3           *        0*        0*        0*
*****************************************************************

********************************************************************************

SUMMARY OF CONTRACTION AND EXPANSION COEFFICIENTS
River: Harrington Creek

*******************************************************
*     Reach      *   River Sta.   * Contr.  * Expan.  *
*******************************************************
*1               *    10      *       .1*       .3*
*1               *    9.5     *       .1*       .3*
*1               *    9       *       .1*       .3*
*1               *    8       *       .1*       .3*
*1               *    7       *       .1*       .3*
*1               *    6       *       .1*       .3*
*1               *    4.5     *Culvert  *         *
*1               *    3       *       .1*       .3*
*******************************************************

Profile Output Table - Standard Table 1
***************************************************************************************************************************************************
**************
```

```
* Reach       * River Sta   * Profile * Q Total * Min Ch El * W.S. Elev * Crit W.S. * E.G. Elev * E.G. Slope * Vel Chnl * Flow Area * Top Width *
Froude # Chl *
*             *             *         *  (m3/s) *       (m) *       (m) *       (m) *       (m) *      (m/m) *    (m/s) *      (m2) *       (m) *
*
*****************************************************************************************************************************************************
**************
* 1                                 1          *    327.15 *    327.23 *    327.23 *    327.27 *   0.028849 *          *      0.57 *      7.28 *
                                                 0.50                                                          0.88
1.00 *      * 10                          *
* 1                         * PF    2          *    327.15 *    327.27 *    327.27 *    327.34 *   0.025143 *          *      0.91 *      7.28 *
                                                 1.00                                                          1.10
1.00 *      * 10                          *
* 1                         * PF    3           10.00 *    327.15 *    327.73 *    327.73 *    328.02 *   0.017730 *          *      4.19 *      7.28 *
                                                                                                               2.39
1.00 *      * 10                          *
* 1                         * PF    4           31.00 *    327.15 *    328.39 *    328.39 *    328.99 *   0.015539 *          *      9.12 *      8.17 *
                                                                                                               3.43
0.99 *      * 10                          *
* 1                         * PF  PF 5                *    327.15 *    328.92 *    328.92 *    329.62 *   0.012114 *          *     14.32 *     12.90 *
                                                50.00
0.91 *      * 10                          *                                                                   3.78
* 1                         *     PF 6                *    327.15 *    329.46 *    329.46 *    330.20 *   0.009451 *          *     23.04 *     19.17 *
                                                75.00
0.84 *      * 10                          *                                                                   3.99
*                           *                         *           *           *           *           *            *          *                   *
*            *                            *                                                                                            *
*                             *
* 1                               PF 1                *    326.75 *    326.81 *    326.81 *    326.84 *   0.030992 *          *      0.64 *     10.50 *
1.01 *      * 9.5                         *     0.50                                                              0.78
* 1                         *     PF 2                *    326.75 *    326.85 *    326.85 *    326.90 *   0.026516 *          *      1.03 *     10.79 *
1.00 *      * 9.5                         *     1.00                                                              0.97
* 1                         *     PF 3                *    326.75 *    327.18 *    327.18 *    327.39 *   0.016141 *          *      5.05 *     12.92 *
                                                10.00
1.00 *      * 9.5                         *                                                                       2.01
* 1                         *     PF 4                *    326.75 *    327.64 *    327.64 *    328.05 *   0.012112 *          *     11.49 *     15.10 *
                                                31.00
0.98 *      * 9.5                         *                                                                       2.86
* 1                         *     PF 5                *    326.75 *    327.96 *    327.96 *    328.49 *   0.010864 *          *     16.44 *     16.57 *
                                                50.00
0.97 *      * 9.5                         *                                                                       3.33
* 1                         *     PF 6                *    326.75 *    328.32 *    328.32 *    328.98 *   0.009603 *          *     22.85 *     19.20 *
                                                75.00
0.96 *      * 9.5                         *                                                                       3.73
*                           *                         *           *           *           *           *            *          *                   *
*            *                            *                                                                                            *
*                             *
* 1                                 1                 *    326.00 *    326.12 *    326.11 *    326.16 *   0.021869 *          *      0.55 *      5.40 *
                                                 0.50                                                          0.92
0.92 *      * 9                           *
* 1                         * PF                  1.00 *    326.00 *    326.20 *           *    326.25 *   0.012584 *     0.95 *      1.05 *      6.42 *
0.75 *      * 9                           *
* 1                         * PF 2               10.00 *    326.00 *    326.87 *           *    326.97 *   0.003651 *     1.50 *      8.34 *     15.40 *
0.53 *      * 9                           *
* 1                         * PF 3               31.00 *    326.00 *    327.31 *           *    327.59 *   0.006252 *     2.62 *     16.60 *     27.15 *
0.75 *      * 9                           *
* 1                         * PF 4               50.00 *    326.00 *    327.88 *           *    328.01 *   0.002219 *     2.01 *     46.69 *     68.25 *
0.47 *      * 9                           *
* 1                         * PF 5               75.00 *    326.00 *    328.22 *           *    328.33 *   0.001893 *     2.07 *     72.35 *     81.26 *
0.45 *      * 9                           *
*                           * PF 6                    *           *           *           *           *            *          *                   *
*            *                            *                                                                                            *
*                             *
* 1                                               0.50 *    325.75 *    326.01 *           *    326.02 *   0.001834 *     0.43 *      1.31 *      7.10 *
0.30 *      * 8                           *
                            * PF 1
```

```
* 1                                        1.00 *    325.75 *    326.10 *            *    326.11 *   0.002035 *     0.57 *      2.01 *      8.29 *
0.33 *      * 8                   *
* 1                   * PF 2              10.00 *    325.75 *    326.82 *            *    326.88 *   0.001944 *     1.26 *     11.31 *     16.36 *
0.40 *      * 8                   *
* 1                   * PF 3              31.00 *    325.75 *    327.36 *            *    327.43 *   0.001870 *     1.65 *     42.26 *    100.84 *
0.42 *      * 8                    *
* 1                   * PF 4              50.00 *    325.75 *    327.93 *            *    327.95 *   0.000490 *     1.04 *    113.27 *    140.72 *
0.23 *      * 8                    *
* 1                   * PF 5              75.00 *    325.75 *    328.26 *            *    328.28 *   0.000396 *     1.03 *    160.35 *    142.52 *
0.21 *      * 8                    *
*                     * PF 6                    *           *           *            *          *            *          *           *           *
*            *                     *                                                                                               *
* 1            *          1                     *    325.75 *    325.86 *    325.86 *    325.92 *   0.025815 *          *      0.49 *      4.68 *
                                          0.50                                                                   1.02
1.00 *      * 7                   *
* 1                   * PF        2             *    325.75 *    325.93 *    325.93 *    326.01 *   0.022803 *          *      0.80 *      5.06 *
                                          1.00                                                                   1.25
1.00 *      * 7                   *
* 1                   * PF        3       10.00 *    325.75 *    326.48 *    326.48 *    326.77 *   0.012024 *          *      4.62 *      9.02 *
                                                                                                                 2.44
0.93 *      * 7                   *
* 1                   * PF                31.00 *    325.75 *    327.36 *            *    327.39 *   0.001117 *     1.28 *     59.16 *    118.74 *
0.33 *      * 7                    *
* 1                   * PF 4              50.00 *    325.75 *    327.93 *            *    327.94 *   0.000309 *     0.83 *    132.30 *    134.89 *
0.18 *      * 7                    *
* 1                   * PF 5              75.00 *    325.75 *    328.26 *            *    328.27 *   0.000286 *     0.87 *    177.69 *    139.85 *
0.18 *      * 7                    *
*                     * PF 6                    *           *           *            *          *            *          *           *           *
*            *                     *                                                                                               *
* 1            *          1                     *    325.50 *    325.62 *    325.57 *    325.63 *   0.004490 *          *      1.11 *      9.74 *
                                          0.50                                                                   0.45
0.42 *      * 6                   *
* 1                   * PF        2             *    325.50 *    325.68 *    325.60 *    325.70 *   0.003935 *          *      1.77 *      9.94 *
                                          1.00                                                                   0.56
0.43 *      * 6                   *
* 1                   * PF        3       10.00 *    325.50 *    326.32 *    325.97 *    326.39 *   0.002699 *          *      8.39 *     10.67 *
                                                                                                                 1.19
0.43 *      * 6                   *
* 1                   * PF  PF 4                *    325.50 *    327.20 *    326.49 *    327.35 *   0.002493 *          *     18.08 *     11.48 *
                                         31.00
0.44 *      * 6                   *                                                                             1.71
* 1                   *     PF 5                *    325.50 *    327.67 *    326.85 *    327.90 *   0.002894 *          *     23.78 *     13.31 *
                                         50.00
0.48 *      * 6                   *                                                                             2.11
* 1                   *     PF 6                *    325.50 *    327.71 *    327.26 *    328.20 *   0.006111 *          *     24.33 *     13.68 *
                                         75.00
0.70 *      * 6                   *                                                                             3.10
*                     *                    *    *           *           *            *          *            *          *           *
*            *
* 1            *                                *           *           *            *          *            *          *           *
*           * 4.5                 * Culvert                                                                 *                      *         *
*                     *                         *           *           *            *          *            *          *           *
*            *                     *                                                                                               *
* 1            *          1                     *    325.40 *    325.48 *    325.47 *    325.50 *   0.014297 *          *      0.78 *      9.59 *
                                          0.50                                                                   0.64
0.71 *      * 3                   *
* 1                   * PF        2             *    325.40 *    325.52 *    325.50 *    325.56 *   0.014312 *          *      1.19 *      9.69 *
                                          1.00                                                                   0.84
0.76 *      * 3                   *
* 1                   * PF        3       10.00 *    325.40 *    325.90 *    325.87 *    326.11 *   0.014297 *          *      4.94 *     10.34 *
                                                                                                                 2.02
0.94 *      * 3                   *
                      * PF
```

```
* 1                          PF 4           *    325.40 *    326.39 *    326.39 *    326.87 *  0.014266 *           *     10.15 *     10.78 *
                                     31.00
1.01 *      * 3                   *                                                                      3.06
* 1                     *     PF 5           *    325.40 *    326.75 *    326.75 *    327.39 *  0.013575 *           *     14.10 *     11.11 *
                                     50.00
1.00 *      * 3                   *                                                                      3.55
* 1                     *     PF 6           *    325.40 *    327.16 *    327.16 *    327.98 *  0.013149 *           *     18.68 *     11.47 *
                                     75.00
1.00 *      * 3                   *                                                                      4.01
************************************************************************************************************************************************
**************
```

Appendix F

Appendix F

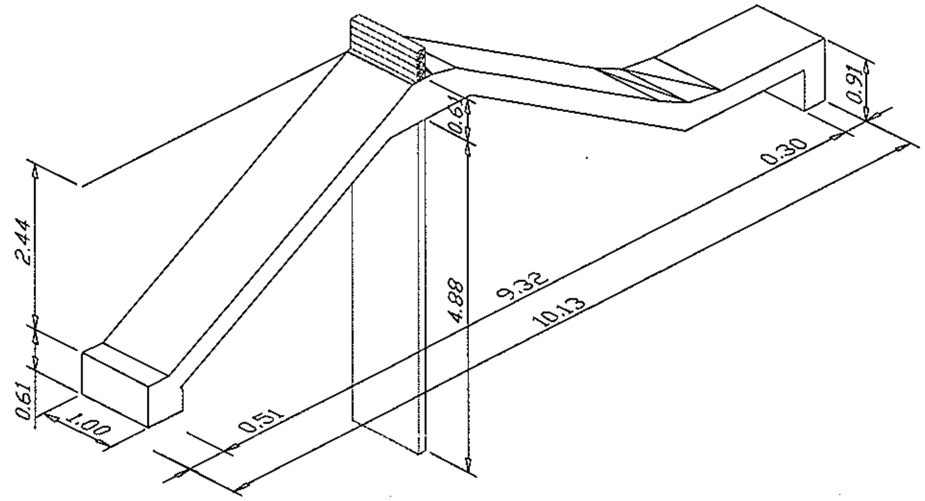
Detailed Results of Stability Analyses

Calculations By B.Craig Date March '04 Project No. P14504.00

Checked ______ Date ______ Calculation No. 1

Subject Harrington Dam - Overflow Section Page 1 of 5

Geometry and Materials



Geometrical Definitions

Base Elevation	326.506	m
Log Top Elevation (Summer)	329.990	m
H.W.L. (Summer)	330.010	m
T.W.L. (Summer)	326.810	m
Log Top Elevation (Winter)	329.990	m
H.W.L. (Winter)	330.010	m
T.W.L. (Winter)	326.810	m
Log Top Elevation (Flood I)	329.990	m
H.W.L. (Flood I)	331.130	m
T.W.L. (Flood I)	328.400	m
Log Top Elevation (Flood II)	329.990	m
H.W.L. (Flood II)	331.130	m
T.W.L. (Flood II)	328.400	m
Deck Top Elevation	330.525	m
Thickness of Deck	0.250	m
Ice Elevation	329.710	m
Volume of Section	14.12	m^3
Centre of Gravity X	5.535	m
Centre of Gravity Y	1.047	m
Length of Pier Section	10.130	m
Width of Pier Section	1.000	m
Length of Sluiceway #1 Section	0.000	m
Width of Sluiceway #1 Section	0.000	m
Distance to Edge of Sluiceway #1 Section	0.000	m
Length of Sluiceway #2 Section	0.000	m
Width of Sluiceway #2 Section	0.000	m
Distance to Edge of Sluiceway #2 Section	0.000	m

Material Properties

f_c'	20.00	MPa	Concrete Compressive Strength
f_{b1}	0.00	MPa	Rock Bearing Strength
f_{b2}	0.58	MPa	Till Bearing Strength
ϕ_1	24.0	°	Angle of Friction #1
ϕ_2	27.0	°	Angle of Friction #2
ϕ_3	30.0	°	Specified Angle of Sliding Friction
ϕ_4	33.0	°	Angle of Friction #4
ϕ_5	36.0	°	Angle of Friction #5
τ_n	0.00	MPa	Cohesion
τ_1	0.38	MPa	(0.17√fc')/2
τ_2	0.76	MPa	(0.17√fc')
τ_3	1.00	MPa	(0.05fc')
γ_{conc}	23.50	kN/m^3	Unit Weight of Concrete
γ_{water}	9.81	kN/m^3	Unit Weight of Water
ϕ_β	30.0	°	Basic Friction Angle

Loadings

0.93	%g	Vertical Ground Acceleration (Summer)
1.40	%g	Horizontal Ground Acceleration (Summer)
0.93	%g	Vertical Ground Acceleration (Winter, DEice)
1.40	%g	Horizontal Ground Acceleration (Winter, DEice)
29.2	kN/m	Ice Force on Concrete
29.2	kN/m	Ice Force on Logs/Gates

ACRES

Calculations

By B.Craig Date March '04 Project No. P14504.00

Checked ______ Date ______ Calculation No. 1

Subject Harrington Dam - Overflow Section Page 2 of 5

Stability Results (ODSG)

Input Summary

	Load Case									
	#1	#2	#3 (Sum)	#3 (Win)	#4	#5 (Sum)	#5 (Win)	#6		
M_1	331.79	331.79	331.79	331.79	331.79	331.79	331.79	331.79	kN	Weight of Section
V_{water}	7.04	7.04	7.04	7.04	18.54	7.04	7.04	18.54	m^3	Volume of Water Over Section
M_2	69.09	69.09	69.09	69.09	181.88	69.09	69.09	181.88	kN	Weight of Water Over Section
x	8.63	8.63	8.63	8.63	6.39	8.63	8.63	6.39	m	Location of Water Force Along X-Axis
ICE	-	29.20	-	29.20	-	-	29.20	-	kN	Total Ice Force
y	-	3.20	-	3.20	-	-	3.20	-	m	Location of Ice Force Along Y-Axis
W	-	-	-	-	-	0.90	0.90	-	kN	Westergaards Force
y	-	-	-	-	-	1.44	1.44	-	m	Location of Westergaards along Y-Axis
S_H	-	-	-	-	-	1.40	1.40	-	%g	Horizontal Seismic Coefficient
S_V	-	-	-	-	-	0.93	0.93	-	%g	Vertical Seismic Coefficient
w_1	60.22	60.22	60.22	60.22	103.08	60.22	60.22	103.08	kN	Hydrostatic Pressure From Headwater
y	1.17	1.17	1.17	1.17	1.49	1.17	1.17	1.49	m	Location of Headwater Force Along Y-Axis
w_2	0.45	0.45	0.45	0.45	17.60	0.45	0.45	17.60	kN	Hydrostatic Pressure From Tailwater
y	0.10	0.10	0.10	0.10	0.63	0.10	0.10	0.63	m	Location of Tailwater Force Along Y-Axis
H_1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	kN	Other Horizontal Force
y	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	m	Location of Other Horizontal Force Along Y-Axis
V_1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	kN	Other Vertical Force
x	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	m	Location of Other Vertical Force Along X-Axis

Results (ODSG)

		Load Case #1 - Usual (Summer)		Load Case #2 - Usual (Winter)	
Cohesion	MPa	0.00		0.00	
% Uplift at Upstream Face	%	100.0		100.0	
Total Uplift	kN	185.00		185.00	
Effective Base	%	100.0		100.0	
Length of Base in Compression	m	10.13		10.13	
Resultant	m	5.577		5.144	
Stress at Heel	kPa	-27.78		-22.30	
Cracked		NO		NO	
Stress at Toe	kPa	-14.85		-20.32	
Allowable Stress at Toe	kPa	-387		-387	
F.S. Overturning		1.98		1.84	
F.S. Sliding ϕ= 24		1.61		1.08	
F.S. Sliding ϕ= 27		1.84		1.24	
F.S. Sliding ϕ= 30		**2.09**		**1.40**	
F.S. Sliding ϕ= 33		2.35		1.58	
F.S. Sliding ϕ= 36		2.62		1.76	
Accepted F.S. Sliding		1.50		1.50	

		Load Case #4 - Flood I		Load Case #6 - Flood II	
Cohesion	MPa	0.00		0.00	
% Uplift at Upstream Face	%	100.0		100.0	
Total Uplift	kN	338.00		338.00	
Effective Base	%	100.0		100.0	
Length of Base in Compression	m	10.13		10.13	
Resultant	m	5.535		5.535	
Stress at Heel	kPa	-22.17		-22.17	
Cracked		NO		NO	
Stress at Toe	kPa	-12.51		-12.51	
Allowable Stress at Toe	kPa	-446		-446	
F.S. Overturning		1.48		1.48	
F.S. Sliding ϕ= 24		0.91		0.91	
F.S. Sliding ϕ= 27		1.05		1.05	
F.S. Sliding ϕ= 30		**1.19**		**1.19**	
F.S. Sliding ϕ= 33		1.33		1.33	
F.S. Sliding ϕ= 36		1.49		1.49	
Accepted F.S. Sliding		1.30		1.30	

ACRES

Calculations

By B.Craig
Date March '04
Project No. P14504.00
Checked
Date
Calculation No. 1
Subject Harrington Dam - Overflow Section
Page 3 of 5
Stability Results (ODSG) - Continued

Input Summary

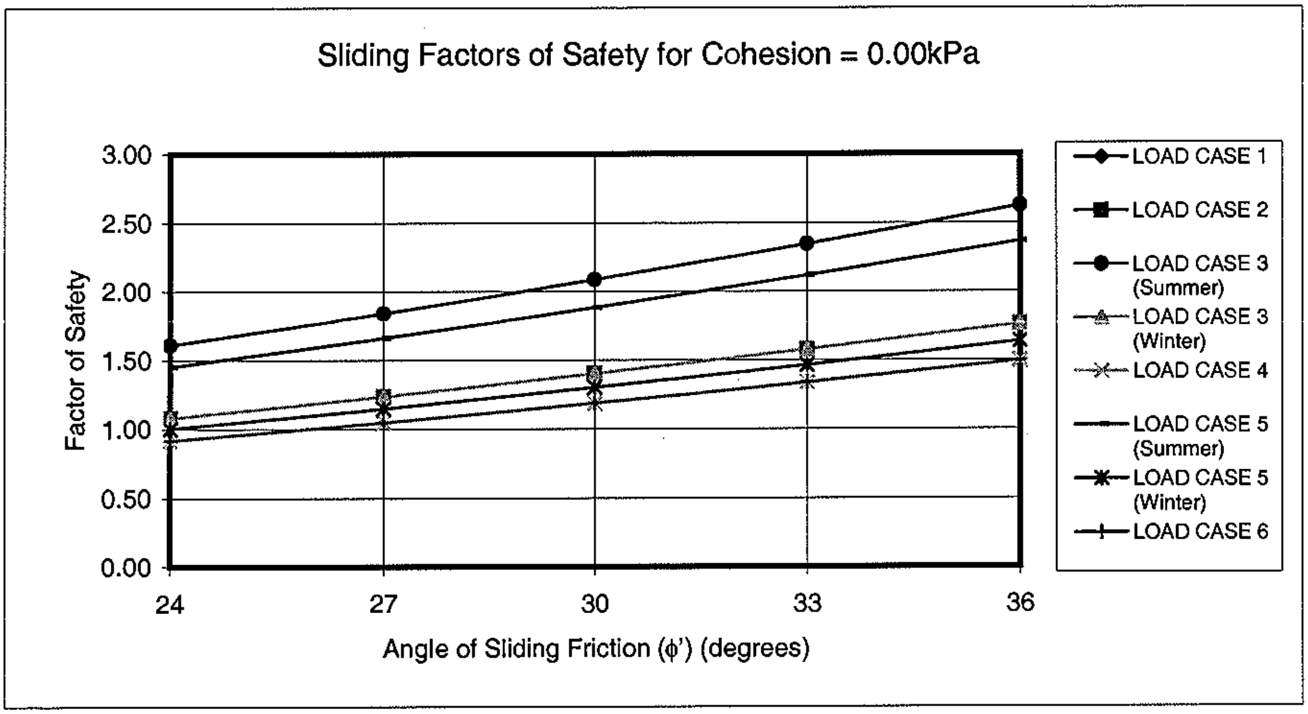
	Load Case									
	#1	#2	#3 (Sum)	#3 (Win)	#4	#5 (Sum)	#5 (Win)	#6		
M_1	331.79	331.79	331.79	331.79	331.79	331.79	331.79	331.79	kN	Weight of Section
V_{water}	7.04	7.04	7.04	7.04	18.54	7.04	7.04	18.54	m^3	Volume of Water Over Section
M_2	69.09	69.09	69.09	69.09	181.88	69.09	69.09	181.88	kN	Weight of Water Over Section
x	8.63	8.63	8.63	8.63	6.39	8.63	8.63	6.39	m	Location of Water Force Along X-Axis
ICE	-	29.20	-	29.20	-	-	29.20	-	kN	Total Ice Force
y	-	3.20	-	3.20	-	-	3.20	-	m	Location of Ice Force Along Y-Axis
W	-	-	-	-	-	0.90	0.90	-	kN	Westergaards Force
y	-	-	-	-	-	1.44	1.44	-	m	Location of Westergaards along Y-Axis
S_H	-	-	-	-	-	1.40	1.40	-	%g	Horizontal Seismic Coefficient
S_V	-	-	-	-	-	0.93	0.93	-	%g	Vertical Seismic Coefficient
w_1	60.22	60.22	60.22	60.22	103.08	60.22	60.22	103.08	kN	Hydrostatic Pressure From Headwater
y	1.17	1.17	1.17	1.17	1.49	1.17	1.17	1.49	m	Location of Headwater Force Along Y-Axis
w_2	0.45	0.45	0.45	0.45	17.60	0.45	0.45	17.60	kN	Hydrostatic Pressure From Tailwater
y	0.10	0.10	0.10	0.10	0.63	0.10	0.10	0.63	m	Location of Tailwater Force Along Y-Axis
H_1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	kN	Other Horizontal Force
y	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	m	Location of Other Horizontal Force Along Y-Axis
V_1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	kN	Other Vertical Force
x	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	m	Location of Other Vertical Force Along X-Axis

Results (ODSG)

		Load Case #3 - Post-Earthquake (Summer)		Load Case #3 - Post-Earthquake (Winter)	
Cohesion	MPa	0.00		0.00	
% Uplift at Upstream Face	%	100.0		100.0	
Total Uplift	kN	185.00		185.00	
Effective Base	%	100.0		100.0	
Length of Base in Compression	m	10.13		10.13	
Resultant	m	5.577		5.144	
Stress at Heel	kPa	-27.77		-22.30	
Cracked		NO		NO	
Crack Propagated		NO		NO	
Stress at Toe	kPa	-14.85		-20.32	
Allowable Stress at Toe	kPa	-527		-527	
F.S. Overturning		1.98		1.84	
F.S. Sliding ϕ= 24		1.61		1.08	
F.S. Sliding ϕ= 27		1.84		1.24	
F.S. Sliding ϕ= 30		**2.09**		**1.40**	
F.S. Sliding ϕ= 33		2.35		1.58	
F.S. Sliding ϕ= 36		2.62		1.76	
Accepted F.S. Sliding		1.10		1.10	

		Load Case #5 - Earthquake (Summer)		Load Case #5 - Earthquake (Winter)	
Cohesion	MPa	0.00		0.00	
% Uplift at Upstream Face	%	100.0		100.0	
Total Uplift	kN	185.00		185.00	
Effective Base	%	100.0		100.0	
Length of Base in Compression	m	10.13		10.13	
Resultant	m	5.548		5.109	
Stress at Heel	kPa	-27.02		-21.55	
Cracked		NO		NO	
Crack Propagated		NO		NO	
Stress at Toe	kPa	-14.99		-20.46	
Allowable Stress at Toe	kPa	-580		-580	
F.S. Overturning		1.93		1.80	
F.S. Sliding ϕ= 24		1.45		1.00	
F.S. Sliding ϕ= 27		1.66		1.15	
F.S. Sliding ϕ= 30		**1.88**		**1.30**	
F.S. Sliding ϕ= 33		2.12		1.46	
F.S. Sliding ϕ= 36		2.37		1.64	
Accepted F.S. Sliding		1.00		1.00	

Calculations	By	B.Craig	Date March '04	Project No.	P14504.00
	Checked		Date	Calculation No.	1
Subject Harrington Dam - Overflow Section				Page 4 of 5	
Sensitivity Plots (ODSG)					



ACRES

Calculations By B.Craig Date March '04 Project No. P14504.00

Checked ______ Date ______ Calculation No. 1

Subject Harrington Dam - Overflow Section Page 5 of 5

Minimum Angle of Sliding Friction and Bonding Results (ODSG)

Minimum Sliding Angle of Friction to Achieve Required Factor of Safety and % Bonding Results

		Case 1		Case 2		Case 3 (Summer)	
τ (MPa)		0.00		0.00		0.00	
Minimum angle of sliding friction to satisfy F.S. against sliding (deg.)		22.553		31.724		16.938	
Percentage of bonded area to satisfy peak sliding F.S.	ϕ_c= 24 °						
	ϕ_c= 27 °						
	ϕ_c= 30 °						
	ϕ_c= 33 °						
	ϕ_c= 36 °						
Desired F.S. for sliding		1.50		1.50		1.10	

		Case 3 (Winter)		Case 4		Case 5 (Summer)	
τ (MPa)		0.00		0.00		0.00	
Minimum angle of sliding friction to satisfy F.S. against sliding (deg.)		24.387		32.317		17.064	
Percentage of bonded area to satisfy peak sliding F.S.	ϕ_c= 24 °						
	ϕ_c= 27 °						
	ϕ_c= 30 °						
	ϕ_c= 33 °						
	ϕ_c= 36 °						
Desired F.S. for sliding		1.10		1.30		1.00	

		Case 5 (Winter)		Case 6	
τ (MPa)		0.00		0.00	
Minimum angle of sliding friction to satisfy F.S. against sliding (deg.)		23.950		32.317	
Percentage of bonded area to satisfy peak sliding F.S.	ϕ_c= 24 °				
	ϕ_c= 27 °				
	ϕ_c= 30 °				
	ϕ_c= 33 °				
	ϕ_c= 36 °				
Desired F.S. for sliding		1.00		1.30	

Appendix G

Appendix G

MNR Dam Safety Bulletins

Dam Safety Bulletin #1

Boom Logs

MNR Policy and Procedure Directive (1970)

Where there is a large collection of debris and floodwood, MNR installs suitable booms upstream to protect the dam.

MNR Legal Opinion (1999)

MNR installs boom logs upstream of a dam to catch debris to protect the dam. From a legal perspective, MNR's corporate position is that the boom logs must be capable of collecting debris.

The color, of the boom logs, does not change MNR's corporate position. The fact that the colored logs are also used as navigational aids and serve as warning devices is irrelevant since MNR does not use them for this purpose.

Design Considerations

A boom type that performs well in one location may not perform well in another location that may have entirely different conditions.

Debris load design calculations must take into consideration the debris that might be expected during a flood event. The worst possible time for a boom log to fail would be during a flood.

Boom log type, size and cost can vary significantly. Capital costs should take in to consideration the reduced maintenance or extended life of the boom.

DRAFT

Dam Safety Bulletin #2

Signage

MNR Policy and Procedure Directive (1970)

Where hazardous boating conditions exist near dams, the Ministry installs warning signs.

MNR Legal Opinion (1994 Inquest)

In its management of the Crown lands and waters of Ontario, MNR has a duty to be aware of public hazards and to both minimize those hazards wherever possible and warn those that may be affected by them.

The Ministry frequently uses warning signs on dams to alert boaters of danger ahead. Where there is no hazard to the boating public at a dam, a sign may not be placed.

Considerations for placing signs at dams

Signs should be used to warn the public of hazardous conditions that exist and to discourage the public from continuing unsafe activities that have taken place.

Signs are to be placed where they are highly visible for the purpose in which they are intended.

Signs are often subject to vandalism. They could disappear without your knowledge. Take pictures of signs when newly installed and make note of its condition each time the dam is visited.

Signs must be maintained.

Sample sign wording

DANGER   Fast Water Keep Clear

No Trespassing
No Camping
No swimming
(if these have been known to take place)

Note: some dam decks have been designed to also serve as a bridge so "No Trespassing " would not be applicable in these cases.

Portage (if on an identified canoe route)

Dam Ahead (where dam is around a corner or where only a weir that is not very noticeable)

Sign Design

Danger signs are to have 8" high red letters on a white background
Danger signs are to be 4' x 8' in size

All signs are to be bilingual

Restricting Access

In addition to the "No Trespassing" sign a locked chain should be placed across the access to the dam deck so that a conscious effort would have to be made to trespass.

Dam Safety Bulletin #3

Public Access to Dams

General

Public access to MNR dams poses a significant challenge with respect to public safety because of the potential for falling either into the water on the upstream side, or to the ground surface or water below the dam. There may also be safety issues with public access to hoisting equipment (overhead gantry, pedestal or rail hoists) and gains openings.

While handrails conforming to the requirements of the OHSA for industrial work environments should already be installed at all dams where there is a potential to fall into the water, or where there is a potential to fall 1.2m or more, these do not necessarily protect against fall hazards in all cases. For example, kick plates along the bottom of handrails are not usually installed at dams because of the problem that they create for snow removal and water flow impedance during dam overtopping. A member of the general public unaware of the hazard could still fall through the railing if attempting to cross the dam while there is ice, snow or other slippery condition on the deck.

All dams should be equipped with gains covers that cover the entire gains opening, and are equipped with locks so that the public does not have access to the gains opening.

Dams where the deck doubles as a vehicle bridge:

It is not feasible to block access to the dam deck where the deck also serves as a bridge. However, a combination of gates, chains, guiderails or handrails can be used to block access to the portion of the dam deck incorporating the gains opening and hoist mechanisms. Some type of barrier should always be used to inhibit public access to these areas. The bridge deck and barrier between the bridge and the rest of the dam should conform to the Ontario Highway Bridge Design Code (OHBDC). Section 5 of the OHBDC deals with barriers.

Appropriate signage should also be used advising the public of any hazards (i.e., Danger - No Trespassing or other appropriate signage). Consult Dam Safety Bulletin #2 for details on signage.
The type of barrier used to block access to all or part of the dam should reflect the degree of hazard associated with public access. For example, a locked chain requires little effort to pass, and may be used in cases where the hazard is low, whereas a fence requires some more effort to climb, and could be used where the hazard is high.

Dams where the deck doubles as a pedestrian bridge:

As in the case where the dam serves as a bridge deck for vehicles, pedestrian access to the portion of the dam occupied by the hoist mechanism and gains opening should be restricted by an appropriate barrier and signage. Where it is not possible to restrict access to this portion of the dam while still leaving an area for pedestrian passage, a barrier should inhibit access to the entire dam, and other means of pedestrian passage used.

The portion of the dam accessible for pedestrian passage should conform to the standards stipulated in Section 5-4.5 of the OHBDC. Structures supporting pedestrian traffic should be designed to the loading stipulated in Section 2-4.3.3 of the OHBDC as a minimum.

Alternate means of pedestrian passage should be explored when major dam upgrades or dam replacement are being considered, or when the public safety risks are high. These may consist of pedestrian walkways attached to the dam, or completely separate pedestrian bridges. Walkways or bridges should conform to the OHBDC requirements.

The Regional Engineering Unit can facilitate procurement of any consulting services required for design of facilities appropriate for vehicle or pedestrian passage over dams.

Appendix H

Appendix H

Dam Operator Questionnaire

HARRINGTON

P14504.09.04

Dam Safety – General Dam Operator Questionnaire

It is recommended that the dam operator complete this questionnaire for each site at the start of a Dam Safety Review.

This questionnaire will update information on discharge facilities and operating equipment. The information will be used to conduct the Dam Safety Review. The information is broken down into the following categories:

Part I - Site Description
Part II - General Operational Information
Part III - Hydraulic Discharge and Operating Facilities
  A. Discharge Facilities
  B. Operating Equipment
  C. Operating Problems
Part IV Past Dam Incidents
Part V Emergency Preparedness Plan (EPP) Information

Throughout the questionnaire, the following definitions of spillway and sluice apply:

Spillway	A structure over which flood flows are discharged. The discharge is uncontrolled, i.e., an overflow structure.
Sluice	A structure through which flood flows are discharged; the flow is controlled by gates, stop logs or valves.
An emergency	Severe flooding, possible dam failure conditions or a person(s) in danger from a boating accident or drowning.

Office: UTRCA Watershed: Trout C Site: HARRINGTON
Prepared by: Chris Tasker Date: Feb 14/2003
Person(s) to contact for additional information:
Name: Chris Tasker Telephone: (519) 451-2800 x 238

Questions	Answers/Observations/Comments
Part I –Site Description (To be completed prior to distributing questionnaire. Data to be reviewed and confirmed by Operating Staff)	
1. Facilities Summary **Type** Sluices –gate bays high length high Sluices –log 3 x 3 x 9' x 9'' Sluices –valve (Manufacturer, size, type, etc.) Debris boom NO Non-overflow walls wingwalls Spillways/overflow walls Upstream retaining walls Yes Downstream retaining walls Yes Other –	**Number** ~~Drop inlet~~ - actually overtop!
2. Elevation Datum (Canadian Geodetic Datum (CGD) or other - specify)	

Part II - General Operational Information

3. Please list any major repairs/maintenance since construction that you know of.	- over topped in 2000 - repaired erosion at downstream east side of dam - installed gabions on restored slope - repairs still required on west side
4. (a) Who operates this site?	☐ Contractor ☐ Other Contact person NA Legal Agreement in place?
(b) How many staff are normally available to operate the site?	NA
(c) Is this person/team responsible for operating other sites? (d) If yes, where?	☐Yes ☐No NA
(e) If answer to (c) is yes, is there sufficient staff to operate these sites simultaneously?	☐Yes ☐No NA
(f) If answer to (e) is no, is other assistance available? (g) If yes, who and from where?	☐Yes ☐No NA
5. (a) Is an operations log book kept at the dam? (b) Is an operations log book kept elsewhere? (c) If yes to either (a) or (b), where is it located and what information is logged?	☐Yes ☑No ☐Yes ☑No
(d) Do staff stay at this site during an emergency?	☐ Yes ☑No
(e) How are communications maintained with the area office? (i) at site (ii) traveling to/from site	MikeNet / Cell " "
6. Most likely means of access under emergency conditions during: (a) Spring (b) Summer/Fall (c) Winter	☑Road ☐Boat ☐Snowmobile ☐ATV ☐Helicopter ☑Walk ☑Road ☐Boat ☐Snowmobile ☐ATV ☐Helicopter ☐Walk ☑Road ☐Boat ☐Snowmobile ☐ATV ☐Helicopter ☑Walk

7. Are problems or restrictions for accessing the site in an emergency situation foreseen? (a) Spring (b) Summer/Fall (c) Winter If yes, please describe (e.g. will the access road or a bridge be accessible if there is a major flood?)	☐Yes ☑No ☐Yes ☑No ☐Yes ☑No
8. Length of time it will take staff to access the site under emergency conditions.	
(a) Spring	☑Less than 1/2 h ☐1/2 to 2 h ☐2 h to 1/2 d ☐1/2 to 1 d ☐More than 1 d
(b) Summer/Fall	☑Less than 1/2 h ☐1/2 to 2 h ☐2 h to 1/2 d ☐1/2 to 1 d ☐More than 1 d
(c) Winter	☑Less than 1/2 h ☐1/2 to 2 h ☐2 h to 1/2 d ☐1/2 d to 1 d ☐More than 1 d
9. Once at the site, how long will it take staff to achieve maximum spill capacity (assuming headwater level is at Maximum Operating Level)?	☐Less than 1/2 h ☑1/2 to 1 h ☐1 h to 2 h ☐2 h to 1/2 d ☐1/2 d to 1 d ☐2 d ☐3 d ☐More than 3 d
10. How many staff members are required to achieve maximum spill capacity for the above time estimate?	2
11. (a) Are there any emergency procedures in place to deal with a dam accident or extreme flood condition? (b) If yes, what is the name of the document?	☐Yes ☑No
12. How often is this dam operated?	0 month 0 year
13. (a) Is there a water level gauge at this site? (b) If no, is there a gauge at a dock nearby? (c) What is the location of the gauge (if applicable)? (d) To what is this gauge referenced? (e) Is the gauge metric or imperial?	☐Yes ☑No ☐Yes ☑No dock ☐CGD ☐Local structure datum ☐ Other datum ☐ Metric ☐ Imperial

14. (a) Are there any recreational activities (such as boating, fishing, canoe portages, hiking or snowmobiling) in close proximity to the dam in either upstream or downstream areas? (b) If yes, please describe.	☑ Yes ☐ No fishing on pond
15. (a) What other agencies are involved with flow regulation along the river? (b) Who are the contact persons?	NA
16. What else may be affected by changes in water levels?	☐ cottagers ☑ recreational boaters ? ☐ municipal water supply ☐ private water supply ☑ ~~sensitive~~ fisheries/habitat ☐ Float plane landing
17. (a) Are there any known operator safety issues or equipment deficiencies? (b) If yes, please explain. (c) Has the Ministry of Labor visited the site? (d) If yes, please list any comments they made.	☐ Yes ☑ No ☐ Yes ☑ No
18. Is the public allowed on the dam?	☑ Yes ☐ No
19. (a) Are there any public safety concerns? (b) If yes, please explain (c) Is vandalism a problem? Please elaborate.	☑ Yes ☐ No upstream embankment erosion ☐ Yes ☑ No
20. What signage is provided at this dam?	☐ Danger – Fast Water ☐ No Trespassing ☐ No Swimming ☑ Other unstable ice
21. (a) Is there a debris boom upstream of the dam? (b) If yes, is it chained (logs) or cable-strung (manufactured)? (c) Is it permanent or seasonal? (d) Is there a safety boom upstream? (e) Is it permanent or seasonal?	☐ Yes ☑ No ☐ Chained ☐ Cable strung ☐ Permanent ☐ Seasonal ☐ Yes ☐ No ☐ Permanent ☐ Seasonal
22. What structural aspects of the dam do you inspect during operational visits?	no operational visits monthly inspections

23. Log Settings (a) What is the normal regulated water level (b) How many logs are usually in for the normal summer setting? (c) How many logs are normally removed for the winter drawdown condition? (d) How many logs can actually be removed in an emergency? (e) Is the bottom log fixed in place and not removed?	Gauge CGD local 3x3 high now 3x2 high none none – once w/ near deck log removal not possible ☐Yes ☑No

Part III - Hydraulic Discharge and Operating Facilities	
A Discharge Facilities	
24. (a) Is a rating curve/table available for this site?	☐Yes ☑No
(b) Have any structural or channel modifications been made since the date on the rating table? (e.g., different size stoplogs, additional stoplogs, shaved stoplogs, dredging, etc.) (c) If yes, please describe these modifications and how they will affect the rating table?	☐Yes ☑No
25. (a) Does fully open represent lifting the gates clear of the deck?	☐Yes ☐No ☑Not applicable
(b) If no, can they be easily lifted clear of the deck during an emergency?	☐Yes ☐No ☑Not applicable
26. (a) Have all log sluices and/or all gate sluices ever been fully opened? (b) If yes, under what headwater elevation and when? (c) If no, what is the constraint?	☑Yes ☐No ☐Not applicable ~~[illegible]~~ normal headpond on the receding end of hydrog
B Operating Equipment	
27. Type of equipment used to operate the discharge facilities:	None
(a) Sluice Operation	☐crab winch ☐spud winch ☐other - specify with: ☐diesel ☐electric ☑hand – valve – not certain it would open, concern over sediment release if operated. ☐other - specify

(b) Log Chutes and other outlet works.	☐crab winch ☐spud winch ☑other - specify none with: ☐diesel ☐electric ☑hand ☐other - specify
28. (a) Is primary (pole) power available at the site? (b) Is auxiliary power available? (c) If yes, specify source.	☐Yes ☑No ☐Not applicable ☐Yes ☑No ☐Not applicable
29. (a) Is the discharge facility operating equipment located at the site (keys, winch handles, chain falls, etc.)? (b) If no, where are they located? (c) Is there more than one set?	☐Yes ☐No ☑Not applicable ☐Yes ☐No
30. (a) If the gates are automated, is the operation remotely controlled? (b) If yes, from where?	☐Yes ☐No ☑Not applicable
31. (a) Have any backup provisions been made should the equipment fail? (b) If yes, what are the provisions? (c) If yes, is the backup located on site? (d) If no, where is backup located?	☐Yes ☐No ☑Not applicable ☐Yes ☐No
32. If the backup is located off-site, how much more time is required to achieve maximum discharge?	hrs
33. (a) Has the mechanical equipment ever failed? (b) If yes, when did the failure occur? (c) What was the nature and extent of the failure? (d) Has it been satisfactorily repaired?	☐Yes ☐No ☐Not applicable not sure whether valve is operable. ☐Yes ☐No
C Operating Problems	
34. (a) Are there problems that may reduce the number of stop logs which can be removed or the number of gates that can be opened during normal or flood conditions? (b) If yes, please describe.	☑Yes ☐No ☐Not applicable – once w/l near or over deck log removal is difficult – water level rise is faster than response would allow opera – overtopping of spillway wall

35. (a) Has debris blockage ever occurred at this site? (b) If yes, at what time of the year does blockage occur? (c) What was the nature & extent of the blockage?	☐Yes ☑No ☐Not applicable ☐ All the time only ☐ During spring only ☐ During floods
36. Is there potential for debris from upstream to interfere with operations at the site under: (a) Normal Operation (b) Flood/Emergency Operation (c) If the answer to (a) or (b) is yes, please describe the situation.	 ☐Yes ☑No ☐Not applicable ☐Yes ☑No ☐Not applicable
37. (a) Is there a debris management program in place (e.g. debris boom, regular removal of debris, etc.)? (b) If yes, briefly describe program.	☐Yes ☑No
38. (a) Do ice jams affect this site? (b)Are there special operations to accommodate ice jam inflows? (c) Do ice jams block/hinder discharge facilities? (d) Do ice jams break booms? (e) If answer to any of the above is yes, please describe the situation.	☐Yes ☑No ☐Yes ☑No ☐Yes ☑No ☐Yes ☑No
39. Has an ice sheet formation been observed: (a) in the headpond or reservoir area? (b) against the intake headworks? (c) against the gate sluices? (d) against the log sluices? (e) against gravity walls/bulkheads?	 ☑Yes ☐No ☐Yes ☐No ☐Not applicable ☐Yes ☐No ☑Not applicable ☐Yes ☐No ☐Not applicable ☐Yes ☐No ☐Not applicable
40. (a) Are there any measurements or other estimates of the ice thickness? (b) If yes, please indicate these.	☐Yes ☑No
41. What is the duration of the headpond/reservoir ice cover (months)?	Jan to Mar
42. Is the frozen headpond generally covered with snow?	☐Yes ☐No
43. (a) Are any photographs of the headpond ice conditions available? (b) If yes, where are they located and when were they taken?	☐Yes ☑No

44. (a) Are there any other observations regarding ice cover? (b) If yes, please describe.	☐Yes ☑No
45. (a) What is the deck surface? (b) Describe snow/ice removal concerns.	☐ Concrete ☐ Wood ☑ Metal grating
Part IV – Past Dam Incidents	
46. Describe any past dam incidents (such as seepage, overflow during flooding, sinkholes in the headpond, washout of an abutment, etc.)	- over topping - ~~[illegible]~~ erosion of embankment behind east wall - scour behind west wall
Part V –EPP Information	
47. Please provide the following emergency contact phone numbers. (a) Dam Operator (b) Alternate Dam Operator (c) District Emergency Response Coordinator (d) Regional Engineer (e) Provincial Response Center (f) OPP (g) Medical Emergencies	Name Office # Home # Cell #
48. (a) Are there permanent residents living within 0.5 km downstream of the dam? (b) If yes, please indicate their names and phone numbers.	☑Yes ☐No Name Phone #
49. (a) Is there an access road to this site? (b) Who maintains the access road to the site? (c) Is this access road plowed in the winter and spring?	☑Yes ☐No ☑Yes ☐No ☐Not applicable

50. (a) Is there emergency equipment available at the site such as life preservers and a first-aid kit? (b) If not available at the site, where are the nearest available ones?	☐Yes ☑No
51. Note and describe any physical features that use you use to cue yourself that water levels are abnormal (both during flood and drought).	deck

Discharge Facilities

(one line for each discharge structure - sluices, spillways, turbines, etc.)

Facility	Structure					Rating Table		Operation			
								Log Sluices			Gate Sluices[1] Yes/No/ Unknown
	Number/ ID	Width ~~(m)~~ ft	Crest/ Sill Elev. (m)	Log Height ~~(m)~~ inches	Capacity (m^3/s)	Table No.	Date	Logs Per Sluice	Logs that can be Removed		
									Normal Condition	Emergency Condition	
log sluices	18	3x9'		9				3	9	0	
Valve	1	?		?	?						

1- Can gates be fully opened under emergency conditions? If no, to what percentage can they be opened?

Drawings

0 40 80 120 160 200 Metres

SCALE 1:2000 (plotted as A1 size sheet)

DATE	NO.	ISSUE / REVISION	CH.	APP.	APP.
JUL. 27, 2007	B	ISSUED WITH FINAL DAM SAFETY ASSESSMENT REPORT	B.C.	P.L.	M.M.
APR. 01, 2004	A	ISSUED WITH DRAFT DAM SAFETY REPORT	B.C.	P.L.	M.M.

ACRES
ACRES INTERNATIONAL

UPPER THAMES RIVER
CONSERVATION AUTHORITY

DAM SAFETY PROGRAM – REVIEW OF DAMS OWNED/OPERATED BY UTRCA AND ABCA

HARRINGTON DAM
KEY PLAN

DESIGN
PREPARED ______
CHECKED ______

DRAWING
PREPARED X. ZHAO
CHECKED P. LAST

PROJECT DISCIPLINE LEAD

PROJECT ENGINEER
P. LAST

PROJECT MANAGER
M. McFARLANE

SCALE

ACRES PROJECT NO.
P14504

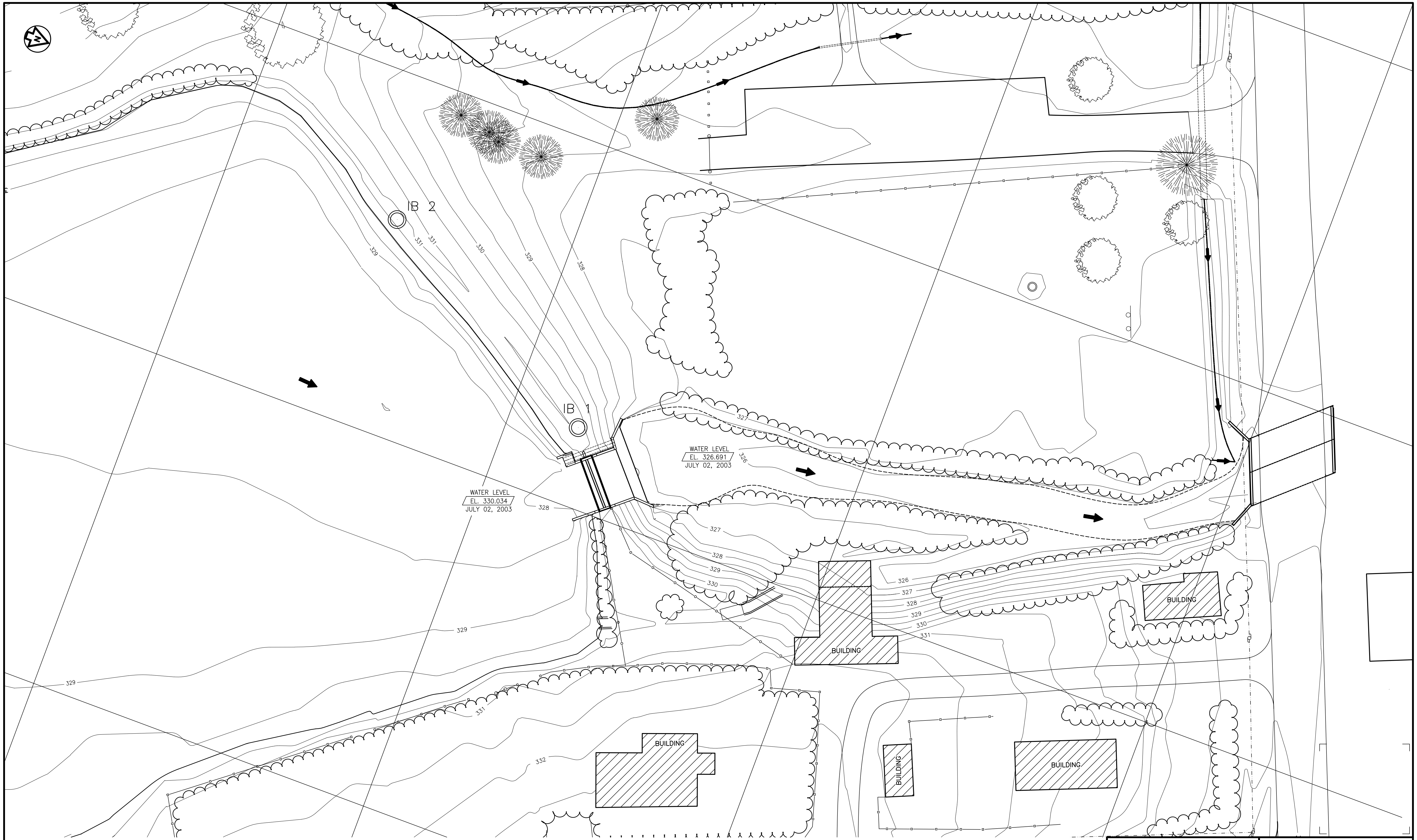
DRAWING NO.
14504–HD–001

REVISION
B

Plot Scale PLOTSCALE
Jul 26 , 2007 , 2:44pm Login name: Zhao114056
Drawing Name: R:\P14504\Civil\Aerial Dwgs\Harrington\14504-HT-001 Harrington.dwg

B

DRAWING No. 14504–HD–001



LEGEND:

☁	VEGETATION
✹	TREE
◎	IRON BAR

REFERENCE GLOBAL SURVEYING SERVICES JULY 02, 2003

0 5 10 15 20 25 Metres

Scale 1:250

DATE	NO.	ISSUE / REVISION	CH.	APP.	APP.
JUL. 27, 2007	B	ISSUED WITH FINAL DAM SAFETY ASSESSMENT REPORT	B.C.	P.L.	M.M.
APR. 01, 2004	A	ISSUED WITH DRAFT DAM SAFETY REPORT	B.C.	P.L.	M.M.

ACRES INTERNATIONAL

UPPER THAMES RIVER
CONSERVATION AUTHORITY

DAM SAFETY PROGRAM – REVIEW OF DAMS OWNED/OPERATED BY UTRCA AND ABCA

DESIGN
PREPARED ____
CHECKED ____

DRAWING
PREPARED L.MONTEAN
CHECKED P.LAST

PROJECT DISCIPLINE LEAD

PROJECT ENGINEER
P.LAST

PROJECT MANAGER
M.McFARLANE

HARRINGTON DAM
GENERAL ARRANGEMENT
SURVEY PLAN

SCALE
1:250

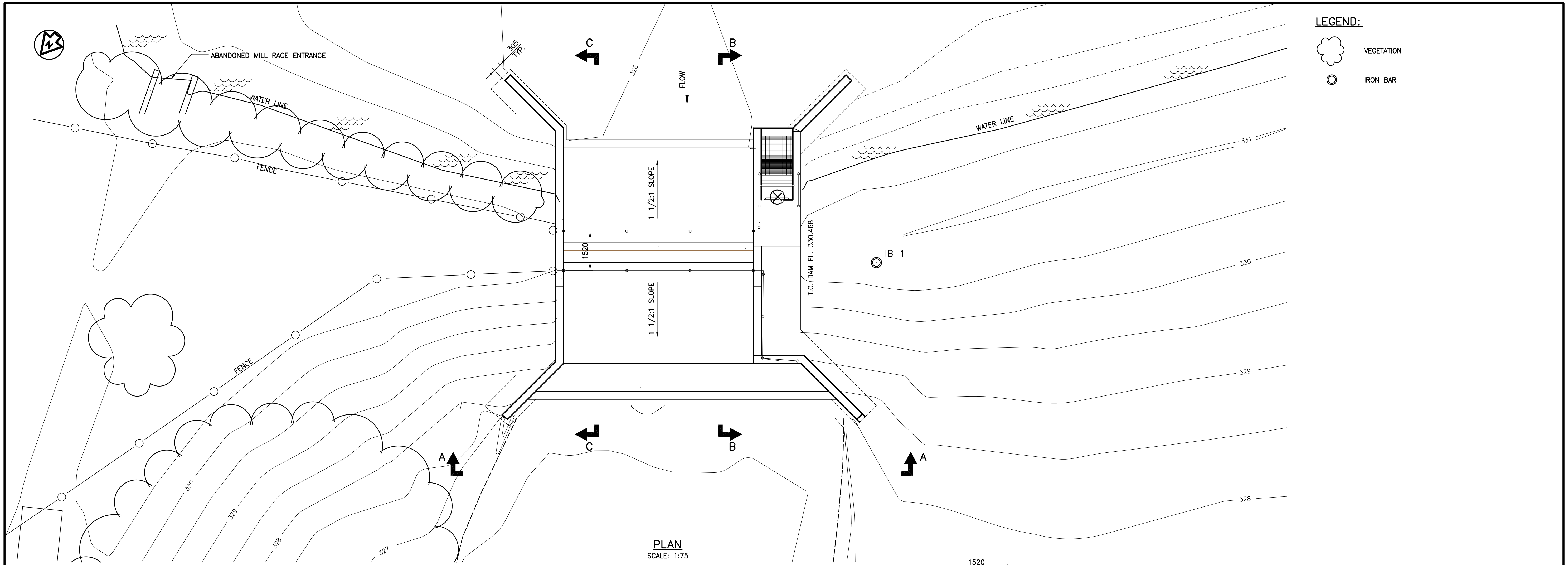
ACRES PROJECT NO.
P14504.02

DRAWING NO.
14504–HD–002

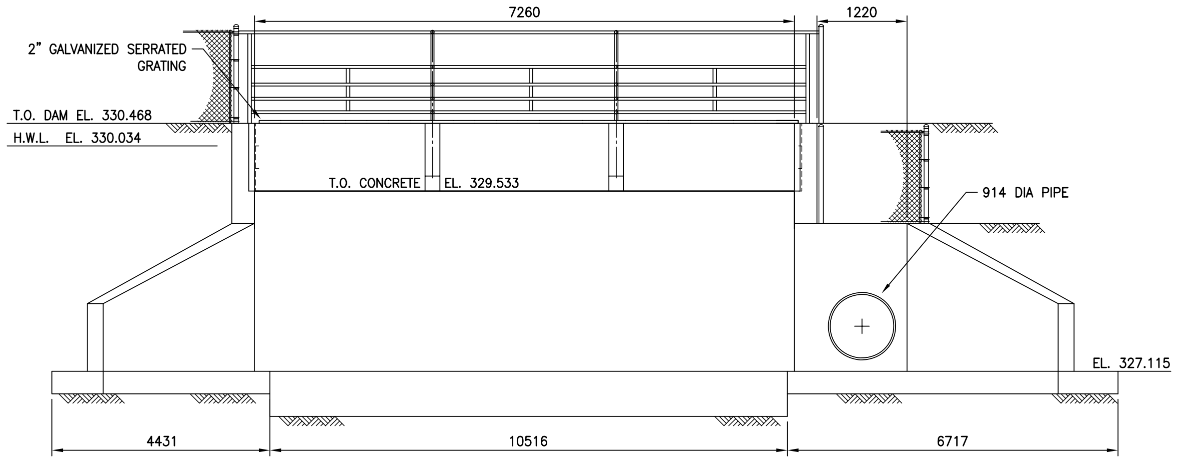
REVISION
B

Plot Scale PLOTSCALE
Jul 26 , 2007 , 2:48pm Login name: Zhao114056
Drawing Name: R:\P14504\Civil\Harrington\14504–HD–002.dwg

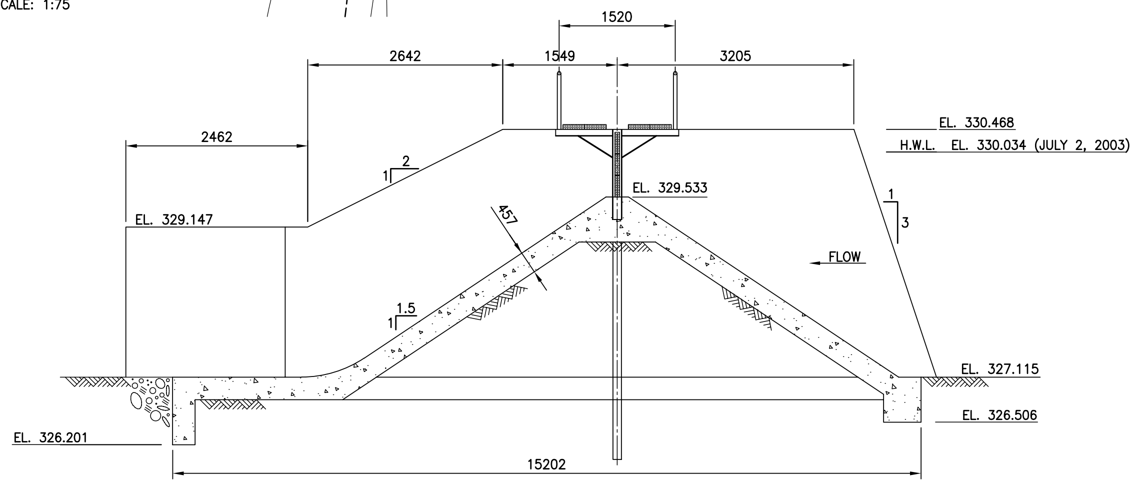
DRAWING No. 14504–HD–002 B



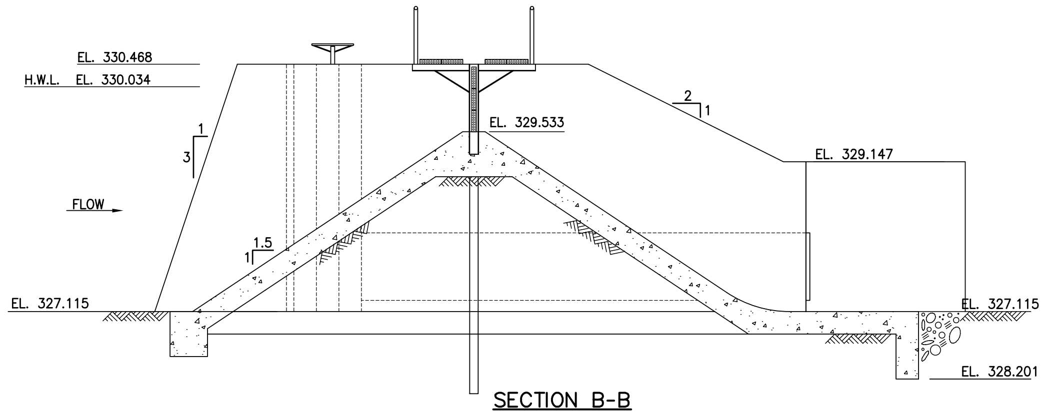
PLAN
SCALE: 1:75



ELEVATION A-A
SCALE: 1:50



SECTION C-C
SCALE: 1:50



SECTION B-B
SCALE: 1:50

1:75 0 1.5 3 4.5 6 7.5 METRES
1:50 0 1 2 3 4 5 METRES

DATE	NO.	ISSUE / REVISION	CH.	APP.	APP.
JUL. 27, 2007	B	ISSUED WITH FINAL DAM SAFETY ASSESSMENT REPORT	B.C.	P.L.	M.M.
APR. 01, 2004	A	ISSUED WITH DRAFT DAM SAFETY REPORT	B.C.	P.L.	M.M.

ACRES INTERNATIONAL

UPPER THAMES RIVER
CONSERVATION AUTHORITY

DAM SAFETY PROGRAM – REVIEW OF DAMS OWNED/OPERATED BY UTRCA AND ABCA

DESIGN
PREPARED
CHECKED
DRAWING
PREPARED L.MONTEAN
CHECKED P.LAST
PROJECT DISCIPLINE LEAD
PROJECT ENGINEER P.LAST
PROJECT MANAGER M.McFARLANE

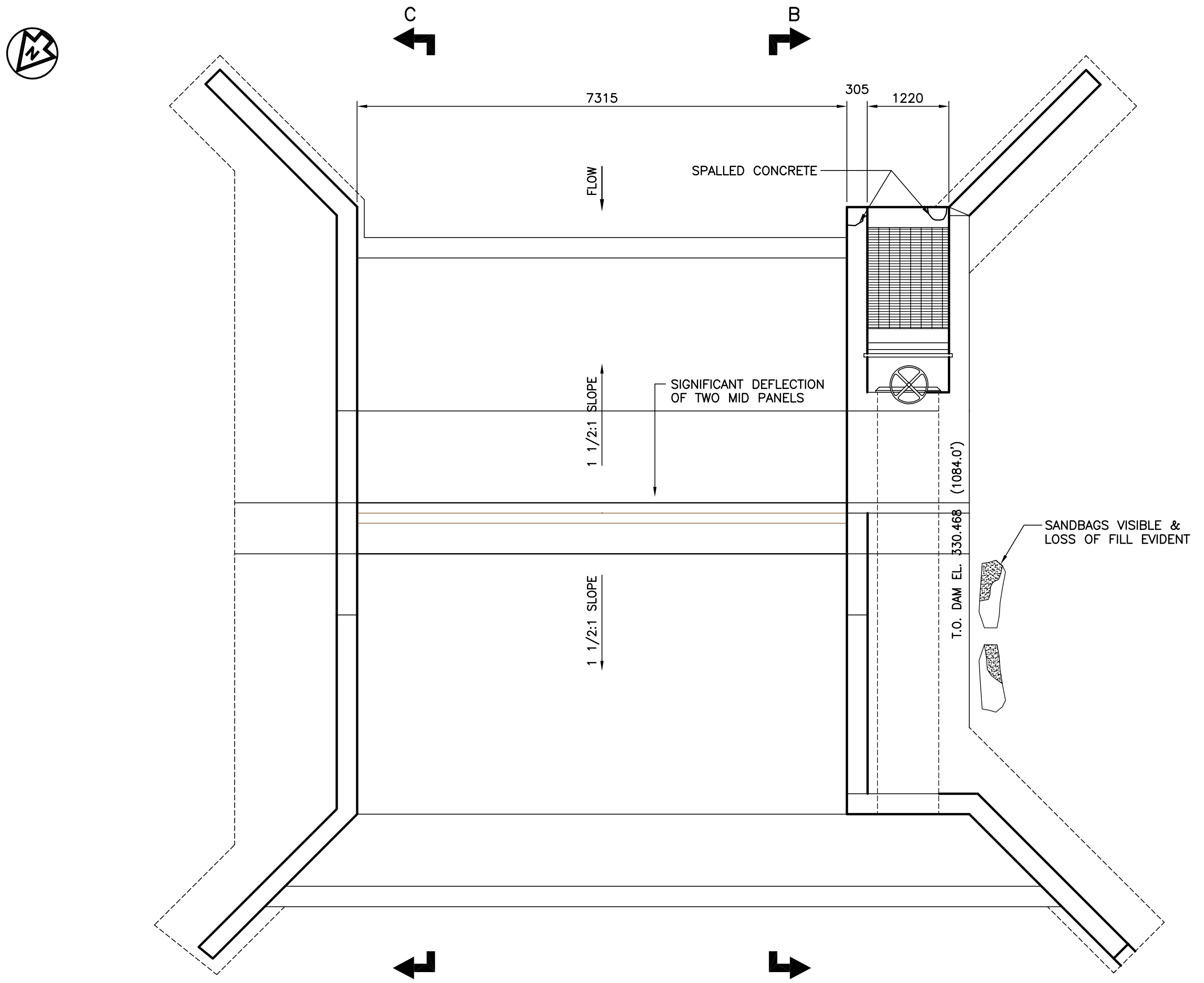
HARRINGTON DAM
GENERAL ARRANGEMENT
PLAN, ELEVATION AND SECTIONS

SCALE AS NOTED
ACRES PROJECT NO. P14504.02
DRAWING NO. 14504–HD–003
REVISION B

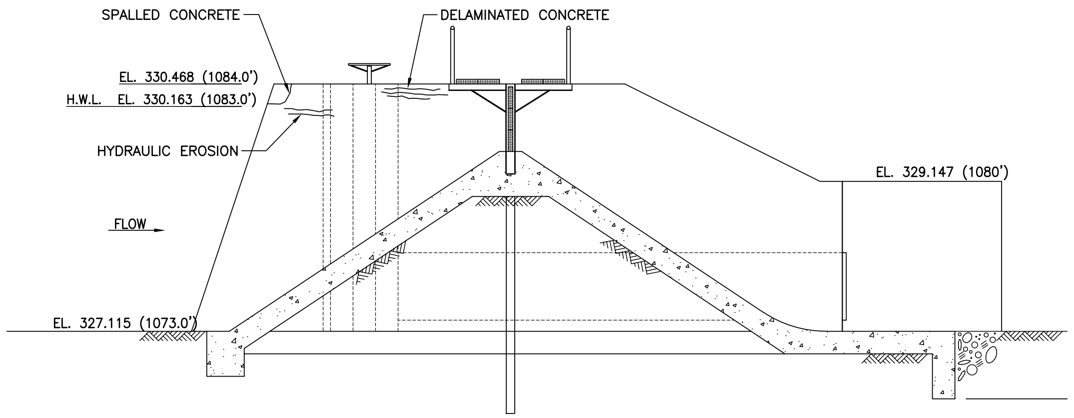
Plot Scale PLOTSCALE Login name: Zhao114056
Jul 26 , 2007 , 2:47pm
Drawing Name: R:\P14504\Civil\Harrington\14504–HD–003.dwg

B

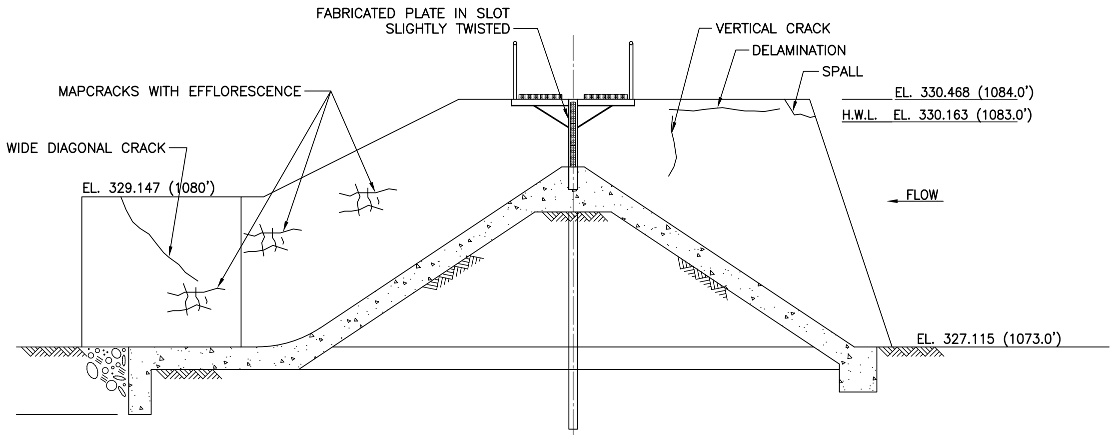
DRAWING No. 14504–HD–003



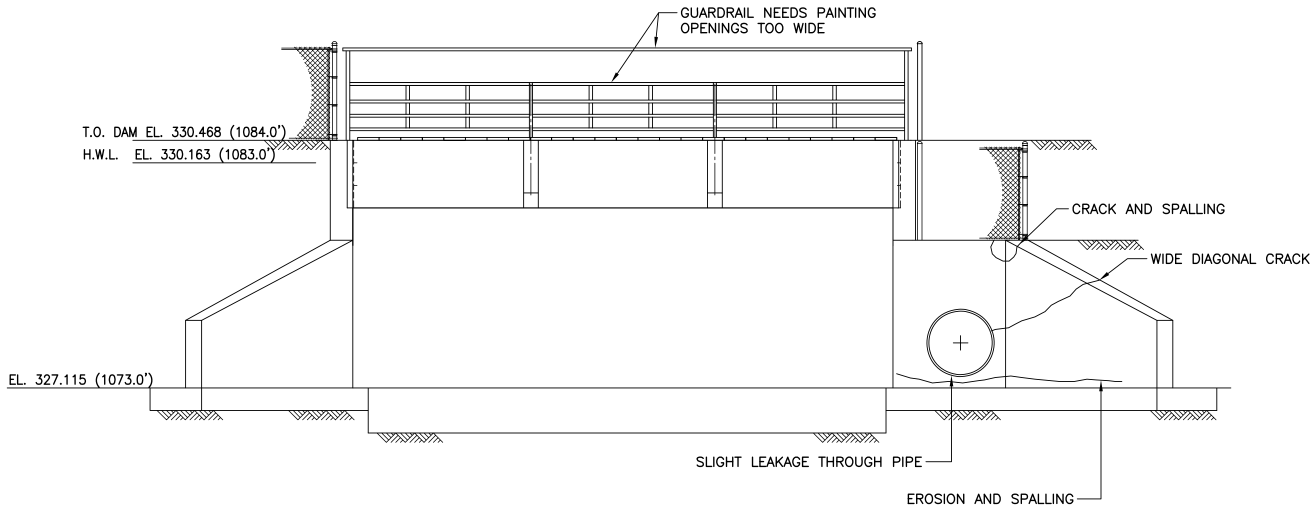
PLAN
SCALE: 1:50



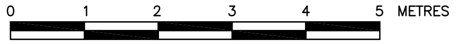
SECTION B-B
SCALE: 1:50



SECTION C-C
SCALE: 1:50



SECTION A-A
SCALE: 1:50



SCALE: 1:50

JUL. 27, 2007	B	ISSUED WITH FINAL DAM SAFETY ASSESSMENT REPORT	B.C.	P.L.	M.M.
APR. 01 2004	A	ISSUED WITH DRAFT DAM SAFETY REPORT	B.C.	P.L.	M.M.
DATE	NO.	ISSUE / REVISION	CH.	APP.	APP.

ACRES
ACRES INTERNATIONAL

UPPER THAMES RIVER
CONSERVATION AUTHORITY

DAM SAFETY PROGRAM – REVIEW OF DAMS OWNED/OPERATED BY UTRCA AND ABCA

DESIGN
PREPARED
CHECKED

DRAWING
PREPARED L.MONTEAN
CHECKED P.LAST

PROJECT DISCIPLINE LEAD

PROJECT ENGINEER P.LAST

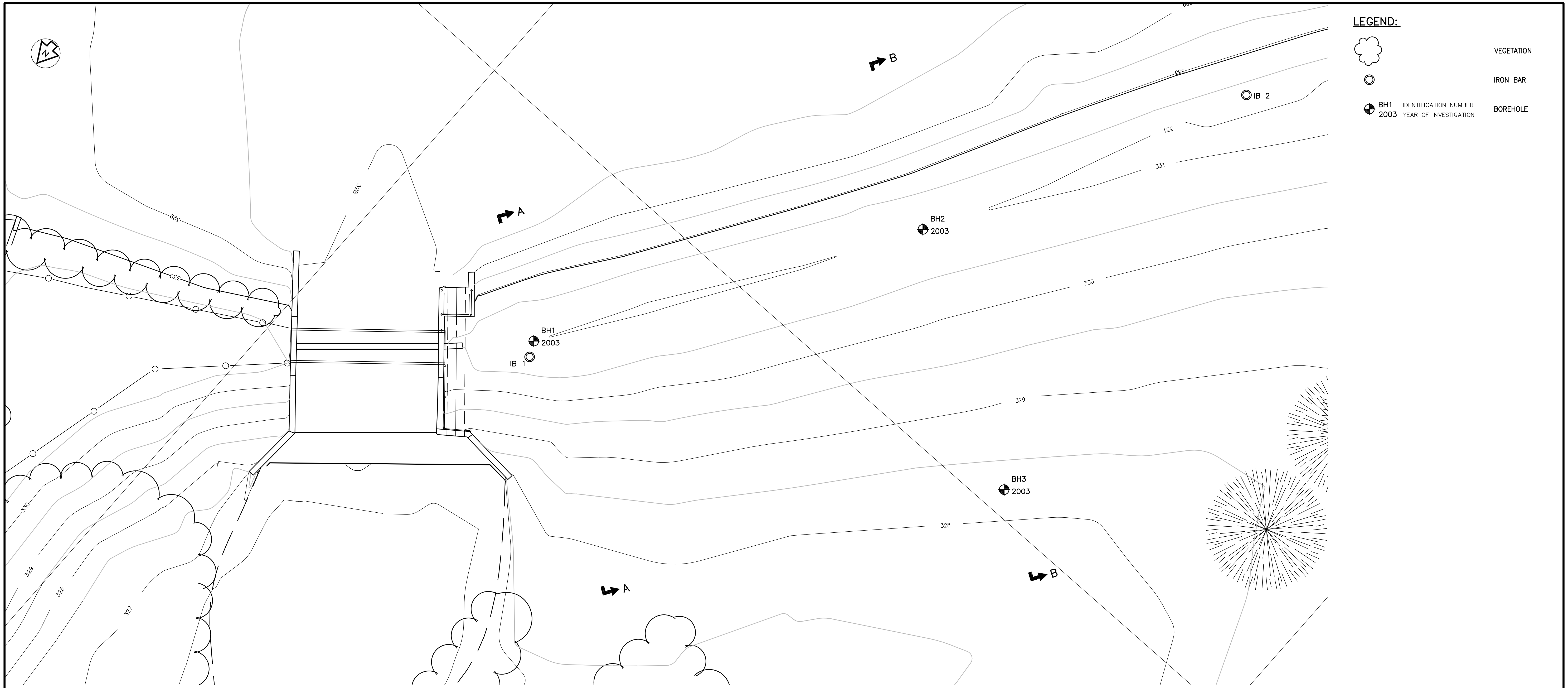
PROJECT MANAGER M.McFARLANE

HARRINGTON DAM
EXISTING CONDITIONS
PLAN, ELEVATION AND SECTIONS

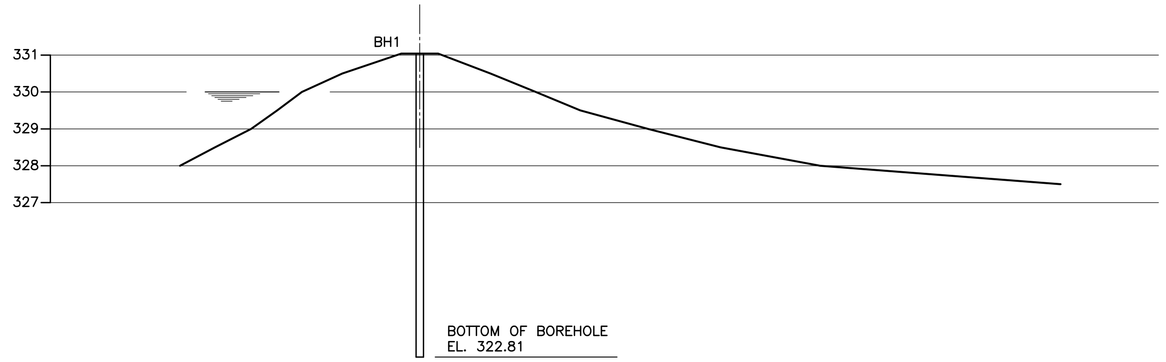
SCALE 1:50
ACRES PROJECT NO. P14504.02
DRAWING NO. 14504–HD–004
REVISION B

Plot Scale PLOTSCALE
Jul 26 , 2007 , 2:47pm Login name: Zhao114056
Drawing Name: R:\P14504\Civil\Harrington\14504–HD–004.dwg

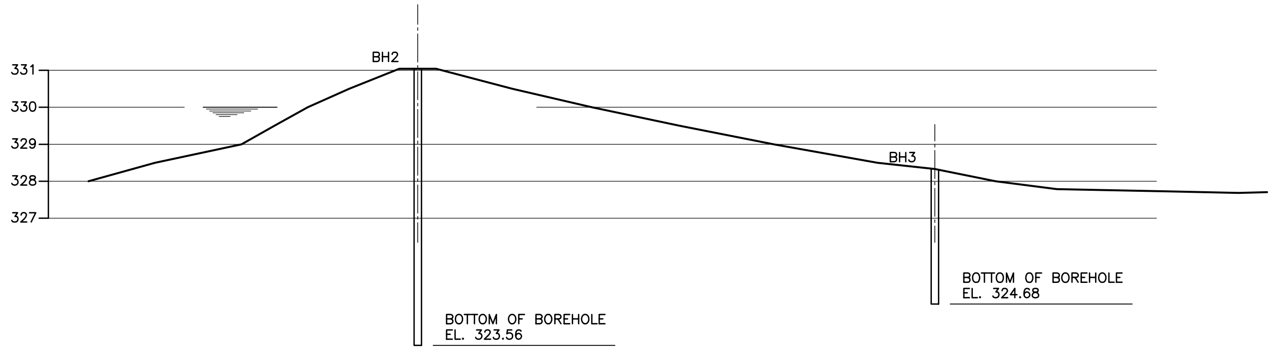
DRAWING No. 14504–HD–004 B



PLAN
SCALE: 1:100



SECTION A-A
SCALE: 1:100



SECTION B-B
SCALE: 1:100

Plot Scale PLOTSCALE
Jul 26 , 2007 , 2:46pm Login name: Zhao114056
Drawing Name: R:\P14504\Civil\Harrington\14504-HD-005.dwg

DRAWING No. 14504-HD-005 A

DATE	NO.	ISSUE / REVISION	CH.	APP.	APP.
JUL. 27, 2007	A	ISSUED WITH FINAL DAM SAFETY ASSESSMENT REPORT	B.C.	P.L.	M.M.

ACRES
ACRES INTERNATIONAL

UPPER THAMES RIVER
CONSERVATION AUTHORITY

DAM SAFETY PROGRAM – REVIEW OF DAMS OWNED/OPERATED BY UTRCA AND ABCA

DESIGN
PREPARED ____
CHECKED ____

DRAWING
PREPARED X. ZHAO
CHECKED P.LAST

PROJECT DISCIPLINE LEAD

PROJECT ENGINEER P.LAST

PROJECT MANAGER M.McFARLANE

HARRINGTON DAM
LOCATION OF BOREHOLES

SCALE AS NOTED

ACRES PROJECT NO. P14504.02

DRAWING NO. 14504-HD-005

REVISION A