REPORT ON

THE STATUS OF IMPLEMENTATION OF OBSERVATIONS AND ADVICE OF THE DAM SAFETY EXPERTS

By:

The Manitoba Floodway Authority
January 6, 2006

Introduction

As part of the Floodway Expansion project, and as identified in the Project Definition and Environmental Assessment (pre-design) process, the Inlet Control Structure, the West Dyke and the West Floodway Embankment will undergo improvements generally in accordance with Canadian Dam Association Dam Safety Guidelines.

This report has been prepared by the Manitoba Floodway Authority in accordance with a requirement of Environment Act Licence No. 2691.

Background

In July 2004 at the completion of the Project Definition and Environmental Assessment (PDEA) studies for Floodway Expansion pre-design, there remained a few unresolved issues with respect to dam safety. These were essentially issues on which there were differing views by the project consultants.

The Manitoba Floodway Authority (MFA) believed it would be beneficial to obtain perspectives from independent experts before proceeding to final design on these issues. Accordingly, MFA retained the services of a panel of five very experienced external advisors, who are experts in various aspects of the types of works and issues at hand. They were tasked to review the relevant work to date and participate in a workshop to consider the issues in some depth and provide their comments and advice to the MFA. Staff of MFA, the project consultants, the panel of experts and others participated in the workshop held on October 13 and 14, 2004.

Prior to the workshop, each of the panel experts was provided with a copy of the relevant documents from the PDEA (pre-design) studies. Panel members were asked to focus on three principal aspects of concern to MFA:

- The possible need for back-up gates versus improved reliability (supplementary redundancy) of the existing gates, or some other approach yet to be identified, for the existing Inlet Control Structure;

- The design criteria for wind related to the freeboard on the West Dyke, and;

- The flood stages at or near the design stage at the Inlet Control Structure and the proposed invoking of "emergency overflow" operations that may include procedures or permanent facilities.

Participants toured the Inlet Control Structure and West Dyke on the morning of October 13, 2004. At the workshop, consideration of each of the three principal areas of interest was generally initiated with a presentation by the relevant project consultants, followed by discussion involving all of the participants who wished to

contribute. While the discussions were structured to cover these three subjects in particular, they were also expanded to deal somewhat more generally with related aspects of the project, including broader considerations of public safety and project effectiveness. The project configuration as set out in the PDEA studies was the basis for the discussions.

A summary of observations and advice by the panel of external experts was prepared as a draft on April 12, 2005. The report has been accepted by the Manitoba Floodway Authority and is appended as Attachment "A".

On July 8, 2005, the Minister for Manitoba Conservation (the Minister) issued Environment Act Licence No. 2691 pursuant to *The Environment Act* and Canada's Responsible Authorities made a decision pursuant to the *Canadian Environmental Assessment Act* to permit the Red River Floodway Expansion Project to proceed. Both the provincial license and federal screening report included conditions related to dam safety. The MFA and Manitoba Water Stewardship are committed to complying with all of the federal and provincial environmental conditions as they proceed with construction and operating phases of the project.

Environment Act Licence No. 2691 – Clause 37

"The Authority shall, within six months of the date of this Licence, provide to the Director a report on its response to the report "Summary of Observations and Advice by a Panel of External Experts" concerning a workshop on issues involving the Inlet Control Structure and West Dyke convened on October 13 – 14, 2004. The report shall describe the status of implementation of the observations and advice of the experts' report, and shall be placed and maintained on the Authority's website."

Federal Screening Report – Chapter 15 Effects of Accidents and Malfunctions

"The MFA will report to the RAs on the outcomes of the Dam Safety Review including the measures taken in response to any and all deficiencies identified in the Review, and the preparation and implementation of manuals and Emergency Preparedness Plans, as recommended in the Review."

Reponses to the Key Observations and Advice by the Panel of External Experts

The report "Summary of Observations and Advice by a Panel of External Experts" is appended as Attachment "A". Included in Chapter 7.0 is the summary of the key observations and advice by the Panel in point form. The Panel's report generally followed the discussions at the workshop around the MFA's three principal aspects of concern (see bullets under Background above), and additionally the Panel presented general considerations relating to project effectiveness and public safety. These four topic areas are presented below in accordance with the numbering system in the

Panel's report together with the point form key observations and advice (in italics) along with MFA responses to each.

7.1 General:

- *"The capability and integrity of the West Dyke, the gated Inlet Control Structure, and the West Floodway Embankment are all fundamental to preventing massive flooding in Winnipeg, and should be given very high priority in this project."*

  The reader is referred to Section 2.1 and 2.2 of the Expert Panel Report for background information on this advice.

  The Floodway Expansion project is a flood protection project for Winnipeg, West St. Paul and East St. Paul. The corresponding flood protection components such as the West Dyke, the Inlet Control Structure, the Floodway Channel, the West Floodway Embankment (East Dyke), and the Outlet Structure are being designed and constructed in accordance with the selected design flood, the 1 in 700 year flood. Further, all the bridges crossing the Floodway will be above the design flow level in the Floodway.

  The West Dyke, the Inlet Structure and the West Floodway Embankment are of particular concern as they are the main elements protecting Winnipeg from the water in storage in the Red River Valley south of Winnipeg during a flood event. Accordingly they were the main elements considered under the Dam Safety investigations that were undertaken as part of the pre-design process. These same elements have been given a high priority in the final design process which is underway and will be given a high priority when under construction. The following responses provide more detail as to the planning activities, investigations, analyses, design and construction that are or will be undertaken related to these facilities.

  The Panel of Experts had suggested during the Workshop that should a situation arise where there are budget restrictions, that these main elements be given a priority for budget funding. The MFA maintains that these main elements are adequately covered within the existing budget.

- *"Considering the large potential for loss of life, these components must be designed with sufficient safety margins to provide an extremely low risk of failure during passage of the (1:700) Design Flood, including allowances for contingencies such as unexpectedly high winds, or partial channel blockage."*

  Safety margins are an integral part of the design and operation of the main components of the Floodway Expansion project. These safety margins are provided in the form of freeboard on the dykes and embankments, increased

reliability of operating systems such as the gates and their component operating systems, and in the form of evacuation plans and eventual evacuations in advance of the critical point during a major flood. All these forms of safety margins have been incorporated or will be considered for incorporation as the final design of each of the project components proceeds and as the evacuation and emergency preparedness plans are updated or prepared. The safety margins are being selected based on a target of achieving an extremely low risk of failure so that the potential for loss of life is reduced. Contingency plans will also be developed/ revised during the preparation of the emergency preparedness plan and the Operational Phase Environmental Protection Plan.

- *"Opportunities should be taken to provide levels of safety or protection beyond minimum project requirements where this can be done at modest cost. One example is in the raising and extension of the West Floodway Embankment, where waste materials from the Floodway channel excavation can be used."*

  The reader is referred to Section 2.4 of the Expert Panel Report for background information on this advice.

  The final design of the project components takes into consideration opportunities to increase or refine the factors of safety or levels of protection beyond that proposed in the pre-design process. The specific examples are:

  - The West Floodway Embankment – Two-dimensional computer analysis of wind and wave action during the final design stage refined the embankment (dyke) height. The revised embankment elevation has been incorporated into the first channel widening excavation contract awarded in the fall 2005. Excess (or waste) material from adjacent Floodway widening work is being placed and compacted on the West Floodway Embankment to the required elevations as determined in the final design analysis.

  - West Dyke – Discussed in detail in Item 7.3 later in this report.

  The Expert Panel suggested that the highway bridges could be cambered to maximize extra clearance (distance between 1 in 700 year design water surface elevation and bottom of bridge girders) over as great a Floodway channel width as practicable. The final design of the bridges includes a 0.3 metre clearance at the abutments and approximately 0.6 metre clearance at the centre of the channel. It was determined through the design process that raising the bridges further could not be achieved at a modest cost but rather a significant additional cost, and therefore was not pursued.

  The Expert Panel also suggested that the Inlet Control Structure upgrading work should provide sufficiently higher gates either by retrofitting the existing gates or

providing back-up gates. This subject is discussed in more detail in Item 7.2 later in this report.

- *"For a range of floods larger than the Design Flood, very strong consideration should be given to an alternative to operating Rule 3, which currently calls for planned flooding of Winnipeg when upstream water levels reach 778 ft. With vulnerable areas evacuated, considerably larger floods could be forced through the Floodway channel by allowing upstream levels to rise somewhat further, encroaching on freeboard but not risking loss of life. This alternative could avoid massive property damage during such floods, and should be factored into the project planning, at least as an available option."*

  The reader is referred to Section 2.3 of the Expert Panel Report for background information on this advice.

  Clause 12 of Environment Act Licence No. 2691 states that *"the Department (Manitoba Water Stewardship) shall operate the Development in accordance with the rules of operation in Attachment 1 of this Licence."*

  The Clean Environment Commission recognized that it is *"not prudent to restrict the Manitoba Government's ability to modify the rules in emergency situations….governments need flexibility when responding to natural disasters."* [P.55, CEC Report, June 2005]. Accordingly, Clauses 13 and 14 of Environment Act Licence No. 2691 identify the conditions under which Manitoba Water Stewardship shall vary the rules of operation, either by filing a notice of alteration pursuant to Section 14 of *The Environment Act*, or under emergency conditions in accordance with the provisions of *The Water Resources Administration Act*.

  The present Inlet Control Structure gates are generally only sufficient to reliably control flows through the City and upstream of the Inlet to the design water levels up to the 1 in 700 design flood condition. If faced with a situation with a flood of a magnitude greater than the 1 in 700 year event, governing officials would very likely give serious consideration to operating the Inlet Control Structure gates to their ultimate limit, whether reliable or not, in an attempt to avoid or minimize flooding in Winnipeg. This would be an emergency action.

  An altogether different situation would be the planning for a reliable alternative to Rule 3, as suggested by the Panel of Experts. In order to achieve protection for floods up to 30% or greater than the 1 in 700 design flood, there is a requirement for sufficiently higher level control on the river at the Inlet Control Structure either by retrofitting the existing gates or providing back-up gates. This subject is covered in greater detail in Item 7.2 later in this report and it is acknowledged that such a proposal would require filing of a notice of alteration pursuant to Section 14 of *The Environment Act*.

- *"It is important that project-specific evacuation plans and assessment of their timing be pursued and completed as soon as possible for various vulnerable areas, so that the relevant information can be accounted for in the planning and design of this project."*

  The reader is referred to Section 6.1 of the Expert Panel Report for background information on this advice.

  The MFA as well as emergency operation officials at the Provincial and City levels recognize the value in evacuation plans specific to this project. Generally evacuation plans are prepared for all types of emergency situations. However, following the 1997 flood these plans were revised to reflect flood specific evacuations.

  In order to plan for evacuation on a scale for floods between a 1997 flood and the 1 in 700 year design flood, further detailed analyses are required over and above those undertaken in the pre-design process. Dam break analyses are currently being undertaken in the final design stage that will identify development of flooding in Winnipeg and downstream. The information provided by these analyses is proposed to be used in refining the evacuation plans. While it is recognized that the City would be evacuated for some event smaller than the design event, the dam break analyses will assist in determining timing and locations of evacuations for various flood magnitudes. The evacuation planning process is expected to be undertaken over a two year period following completion of the dam break analyses.

7.2 Gates:

- *"Reliability of the existing operating gates should be improved by implementing measures proposed in the PDEA studies and by the Panel. These include aspects such as security; fire protection; some mechanical upgrades; and mandated high levels of regular maintenance and testing, with assured funding. Further fault tree analysis should be used to quantitatively assess present reliability and various improvement measures."*

  The reader is referred to Section 3.1 and 3.3 of the Expert Panel Report for background information on this advice.

  The final design stage of this project includes designing and constructing the Inlet Control Structure upgrading works as proposed in the pre-design process. A number of the upgrading works (improvements) are listed in Section 3.1 of the Expert Panel Report. MFA is reviewing the additional suggestions by the Panel of Experts, such as further fault tree analyses, and ceramic coatings for the piston

rods. Further, as required under Section 5.1 (d) of *The Manitoba Floodway Authority Act*, MFA is responsible for and is currently developing a program and annual budget to comprehensively address maintenance of the Floodway and the related structures.

- *"Options for a cost-effective system of back-up to the operating gates should be studied in detail, with a view to implementing the most favourable option if possible. Assessments of evacuation timing will affect the importance of this. The back-up system must be adequately reliable, but not nearly to the extent required of the operating gates."*

- *"The operating gates should be retro-fitted, or back-up gates designed, with sufficient height to protect the City in the event of contingencies such as high winds, channel blockage or large local inflows; and to permit the alternative operating mode for flows larger than the Design Flood."*

  The reader is referred to Section 3.2 and 3.3 of the Expert Panel Report for background information on this advice.

  As stated in the third and last bullets of Section 3.3 in the Expert Panel Report, results of the evacuation plans and their timing need to be defined before loss of life risks can be adequately assessed for various gate failure scenarios. Once these steps are complete, further analyses to determine whether there is justification for back-up gates or if the existing gates should be retro-fitted can be undertaken. The analyses would also take into consideration economics of the alternatives, as well as provision of added flexibility to handle contingency situations and extreme flood events (alternative to existing Rule 3). It is important to note that the potential future upgrading of the Inlet Control Centre gates is not precluded by proceeding with the current improvements. As previously discussed, such a proposed change to the flood protection system and its planned operation would require filing of a notice of alteration pursuant to Section 14 of *The Environment Act*.

7.3 West Dyke Freeboard:

- *"West Dyke freeboard proposed in the PDEA studies is believed to be of the right order, but dyke erodibility should be further assessed and freeboard checked for other severe wind and overtopping conditions. Dyke height should also be adjusted to avoid local low spots when passing extreme floods."*

  The reader is referred to Section 4.0 of the Expert Panel Report for background information on this advice.

In general, the final design of the West Dyke has incorporated the advice of the Expert Panel, as follows:

- Due to the extreme potential consequences of an overtopping failure, conservative criteria for wind and wave action have been adopted in determining the freeboard on the West Dyke. This refers to the frequency (probability of the events) for wind and wave action. For all intents and purposes, the probability of the wind and wave action events, together with the 1 in 700 year design flood, and the probability of failure of the dyke due to overtopping is essentially equivalent to that recommended by the Expert Panel.

- The freeboard requirement was determined utilizing a comprehensive two-dimensional computer model as part of the final design process. Various wind directions were assessed to determine the most severe wind and wave condition.

- Conservative criteria for erosion protection have also been adopted in determining the design of the West Dyke. This is based on an evaluation of the erodibility (erosiveness) of the clay soils used in the dyke construction, in combination with a vegetation (grass) cover. Riprap is proposed along the "wet" side slopes of the West Dyke where erosion of the grass-covered clay soils has been predicted to be possible.

- Less stringent freeboard criteria (than above) have been applied to the very low sections of the West Dyke near the west end where an overtopping failure would have much less serious consequences.

Based on the above, the capacity and the reliability of the West Dyke have not been compromised.

The Expert Panel also suggested that the crest elevation of the West Dyke be calculated and raised where necessary to protect against an extreme flood (beyond the design 1 in 700 year event). Since this recommendation is related to the future potential consideration of an alternative to Rule 3, this is not being undertaken at this time. It is important to note, however, that potential additional raising of the West Dyke in the future is not precluded by proceeding with the current design.

7.4 Emergency Overflow Operations:

- *"Facilities and/or operational plans should be in place to deal with extreme floods, as is proposed in the PDEA studies, and should be such as to permit the option of protecting property in Winnipeg for a range of flows larger than the Design Flood."*

- *"The scheme should include breaching of a section of the West Dyke that is well to the south of the most populated areas, and where the dyke height is not too great, as suggested in the PDEA studies."*

- *"An operational plan to actively breach such a section to the required extent is strongly favoured, rather than provision of a fuse-plug type of washout section. If the designated section is made lower than the adjacent dyke, the amount should be small, and the dyke material relatively inerodible."*

  The reader is referred to Section 5.0 of the Expert Panel Report for background information on this advice.

  In general, the final design of the West Dyke has incorporated the advice of the Expert Panel regarding the requirement for an emergency overflow to deal with floods considerably larger than the 1 in 700 year design flood, as follows:

  - An operational plan is proposed whereby a section of the West Dyke would be actively breached by emergency excavation to the extent required during an extreme flood event.

  - The breach section of the West Dyke is to be located just north of the Avonlea Corner, as proposed during the pre-design (PDEA) process, and confirmed in recent analyses during final design. This area is considered to be reliably accessible during an extreme flood event.

  - The limits of the emergency section are currently being determined. A "fuse-plug type" of washout section is not proposed and the breach section will be constructed of the same clay material as the remainder of the West Dyke. However, at the limits of the breach section, more robust construction materials are being considered (such as riprap erosion protection or sheet piles) to prevent "unraveling" of the dyke beyond the limits of the emergency excavation. This will prevent or reduce the likelihood of unintended erosion and washout of the West Dyke and therefore maintain control of the overflow.

  - The breach section will not have a crest elevation any lower than that meeting the criteria for the 1 in 700 year design flood water level, and wind and wave action as determined by the two-dimensional computer analyses.

Attachment “A”

MANITOBA FLOODWAY EXPANSION PROJECT

DISCUSSION PAPER

EXPERT WORKSHOP - WINNIPEG - OCT. 13-14, 2004

SUMMARY OF OBSERVATIONS AND ADVICE
BY
PANEL OF EXTERNAL EXPERTS

EXECUTIVE SUMARY

A panel of independent experts was retained by the Manitoba Floodway Authority (MFA) to review and provide advice on three specific issues not fully resolved in the Project Definition and Environmental Assessment (PDEA) studies (July/04) and to offer any related perspectives and advice. The particular aspects of concern were:

- The possible need for a back-up to the Inlet Control Structure operating gates, versus supplementary redundancy of the existing gates;
- Design criteria for wind-related freeboard on the West Dyke; and
- The need for emergency overflow facilities or procedures to deal with extreme floods.

Following the review of relevant documents, a workshop was held on Oct. 13-14, 2004, to discuss these and related issues with MFA staff and PDEA consultants. Concerning the three specific questions, the Panel's advice arising out of its reviews and discussions is briefly that:

- Reliability of the existing operating gates should be enhanced by a number of improvements recommended by the PDEA consultants and Panel members. In addition, options for a back-up system should be studied in detail, with a view to defining and implementing a cost-effective option. Evacuation and other analyses are needed to provide further bases for these actions;

- Freeboard for the West Dyke proposed in the PDEA studies is of the right general magnitude, but additional conditions should be checked and considered in the final planning and design; and,

- Extreme floods must be considered in the project development. An operational plan to actively breach a designated section of the West Dyke well south of the City should be defined, and implemented to the extent necessary when Winnipeg can no longer be protected by the works included in this project.

Related observations and points of advice that are considered important by the Panel include the following:

- The capacity and integrity of the West Dyke, the gated Inlet Control Structure, and the West Floodway Embankment are all fundamental to preventing disastrous flooding in Winnipeg and should be given very high priority in this project;

- Opportunities should be taken to provide for contingencies and to enhance safety or protection beyond minimum project requirements where this can be done at little cost. One example is in the raising and extension of the West Floodway Embankment using waste materials from the channel excavation;

- As an alternative to Operating Rule 3, an option should be considered which would call for protection of most property in the City for a range of floods larger than the (1:700) Design Flood. With vulnerable areas evacuated, larger flows could be forced through the Floodway by encroaching on normal freeboard, rather than opening the gates to massively flood Winnipeg (Rule 3); and,

- Project-specific evacuation plans for various vulnerable areas should be advanced as quickly as possible, to allow aspects such as practical timelines to be factored into the planning and design of the project.

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1.0 INTRODUCTION

At the completion of the Manitoba Floodway Expansion Project Definition and Environmental Assessment (PDEA) studies in July, 2004, there remained a few unresolved issues. These were essentially issues on which there were differing views by project consultants, or on which the Manitoba Floodway Authority (MFA) otherwise believed it would be beneficial to obtain perspectives from independent experts before proceeding to final design.

Accordingly, the MFA retained the services of a panel of five very experienced external advisors, who are experts in various aspects of the types of works and issues at hand. They were tasked to review the relevant work to date and participate in a workshop to consider the issues in some depth and provide their comments and advice to the Authority. Staff of the MFA, the project consultants and others also participated in the workshop. A list of the external Panel and other participants is given in Annex A.

Prior to the workshop, each of the Panel members was provided with copies of the following documents from the PDEA (pre-design) studies:
- Preliminary Engineering Report - July, 2004;
- Appendix F - West Dyke Surveys, Field Investigations and Pre-design - July, 2004;
- Appendix C - Inlet Control Structure Pre-design - July, 2004.

In addition, they were given relevant excerpts from "Appendix B - Floodway Expansion" of the Flood Protection ("SAFE") Studies for Winnipeg completed in November, 2001.

Panel members were asked to focus on three principal aspects of concern to the MFA:
1. The possible need for back-up gates versus improved reliability (supplementary redundancy) of the existing gates, or some other approach yet to be identified, for the existing Inlet Control Structure.
2. The design criteria for wind related to the freeboard on the West Dyke, and
3. The flood stages at or near the design stage at the Inlet Control Structure and the proposed invoking of "emergency overflow" operations that may include procedures or permanent facilities.

Participants toured the Inlet Control Structure and West Dyke on the morning of Oct.13. At the workshop, consideration of each of the three principal areas of interest was generally initiated with a presentation by the relevant project consultants, followed by discussion involving all of the participants who wished to contribute. Material presented by the consultants is attached in Annex B. While the discussions were structured to cover these three subjects in particular, they were also expanded to deal somewhat more generally with related aspects of the project, including broader considerations of public safety and project effectiveness. The project configuration as set out in the PDEA studies was the basis for the discussions.

The summary contained in the following sections is intended to reflect primarily the observations, views and advice of the five external Panel members, arrived at with the benefit of input from and discussions with other workshop participants.

2.0 GENERAL CONSIDERATIONS

The Panel is of the view that it is important to examine the three specific issues of concern in the context of certain broad issues relating to project effectiveness and public safety. Following is a particularly relevant considerations.

2.1 Application of Dam Safety Principles

Standards and guidelines have been adopted in many jurisdictions around the world for application to the safety of dams. Examples are the Dam Safety Guidelines of the Canadian Dam Association, and a number of provincial standards in Canada. These generally contain a combination of standards-based and risk-based provisions.

The proposed floodway works have some similarities to dams in terms of their relationships to public safety, and it is therefore appropriate to apply many of the underlying principles and some approaches used in dam safety work to certain aspects of this project. The approaches are not always applicable directly, however, and care needs to be taken to ensure that it is really the appropriate underlying principles - essentially relating to acceptable levels of incremental risk to public safety - that are being followed.

Examples of this are aspects such as freeboard on the West Dyke and along the left bank of the Floodway channel (i.e. the East Dyke and the West Embankment of the Floodway); and safety and redundancy at the Inlet Control Structure. Reference will be made to these in later sections.

2.2 Acceptable Levels of Risk

The acceptable level of risk to property due to a given hazard (such as flooding) can sometimes be appropriately established on the basis of an economic evaluation (e.g. present worth of benefits vs. costs of avoidance). This was a substantial part of the basis for selecting the 1:700 Design Flood for this project.

Where there is a risk to many human lives, society demands fairly stringent requirements, and a failure probability approach is often applied to aspects for which it is possible to reasonably estimate such probabilities. (Some dam safety evaluation applies this to property loss, as well). An examination of some published tolerance criteria and guidelines from around the world, including Canadian dam safety guidelines, suggests that a tolerable annual probability of loss of life associated with

man-made facilities, involving 100 fatalities or so from a single event, falls in the range of about 10^{-5} to $10^{-7.}$

For the Floodway project, fatalities of this order or greater could occur if one of the major components were to fail during passage of a large flood (ranging from somewhat smaller to larger than the Design Flood) unless vulnerable areas of the City had been previously evacuated or had sufficient warning time to evacuate. Those major, critical components are:

- West Dyke (at least the higher portions);
- Water retaining barriers along the left side of the Floodway channel (i.e. the East Dyke and the West Embankment of the Floodway); and
- Inlet Control Structure and gates - failure of which could lead to overtopping of Primary Dykes in the City.

The populations at risk during a major flood in Winnipeg can be extremely large. The Panel recognizes that much of this population are the beneficiaries of flood protection afforded by this project and, as such, it could be argued that they may be prepared to accept a somewhat higher level of risk than if they were not. However, sudden failure of critical components of the project during a large flood would clearly risk much higher loss of life than would likely occur with no flood control works.

On balance, it is the view of Panel members that an annual failure probability not exceeding about 10^{-6} is a reasonable target in designing major parts of these critical components under conditions described above (i.e. vulnerable areas not evacuated, nor afforded sufficient warning time to fully evacuate).

Because the City would not normally be evacuated in advance for any flood events up to the magnitude of the Design Flood, this probability criterion would apply to some failure modes of the critical components for all such flood conditions. For larger floods, the City must be evacuated in advance, and the criterion with respect to loss of life would, of course, not apply.

2.3 Emergency Operation Beyond Rule 3

2.3.1 Consideration of Floods Larger than the Design Event

The project is being designed for safe passage of the Design Flood (estimated to be a 1:700 event) having a peak total natural flow of 272,000 cfs at James Avenue. Greater floods can obviously occur, however, and the public interest requires that a range of such floods be considered, preferably up to the largest reasonably conceivable flood (the Probable Maximum Flood). Purposes of this are seen by the Panel to include the following:

- To determine the impacts of such floods on the infrastructure and residents of the City and elsewhere;

- To permit various operating modes in the event of such floods to be considered, and the most advantageous mode(s) to be identified;
- To allow the possible adoption of these modes to be factored into the planning for the project, and to permit incorporation of physical features into the project which will facilitate adoption of the most advantageous mode(s); and
- To provide future operators of the project with information necessary to make appropriate decisions during passage of such floods.

2.3.2 Basis of Project Studies and Assumptions to Date:

Larger floods, and facilities / operating modes to accommodate them, have indeed been included by the project consultants in the PDEA studies. Fundamental assumptions in these studies to this point have been that:

a) So long as upstream water levels (at the Inlet Control Structure) are below elev. 778 ft., the control gates will be operated to restrict inflow into Winnipeg such that freeboard on the (enhanced) Primary Dykes will not be compromised (Rule 2); and
b) When the level reaches 778, the gates will be opened (and flow also permitted over or through the West Dyke, if necessary) to prevent any further rise, with the excess flows passed through Winnipeg (Rule 3).

This latter operation would occur for any flood larger than the Design Flood. It would be preceded by evacuation of the populations from vulnerable areas, but would result in massive flooding of large portions of Winnipeg with estimated damages of many billions of dollars. The decision to implement such an operation would thus be a very difficult one to make, especially so because in most cases such extreme damage could be avoided, as discussed below.

While the PDEA studies dealt with this subject to a limited extent, the Panel is of the view that the potential benefits of an alternative emergency operational approach are so great that it should be much more strongly considered, and adopted if possible. The approach, and further reasons for it, are described briefly in the following sub-section.

2.3.3 Alternative Operational Approach - Pushing the Limits:

It is intended that evacuation of vulnerable areas would be completed when flood levels threaten to reach and exceed Design Flood levels (i.e. 778 ft. at the Inlet Control Structure) but not necessarily before that. Thus, in order to provide adequate public safety for the occurrence of wind events and other contingencies / uncertainties, the West Dyke and other critical components of the system will require significant freeboard above the Design Flood levels.

The proposed approach, then, if inflows should continue to increase, would be to hold flows through the City to levels still containable by the (enhanced) Primary Dykes. Upstream levels would be allowed to rise above 778 if necessary, forcing more flow through the Floodway channel and, incidentally, storing a further increment upstream.

This operating mode would continue until virtually all available freeboard had been utilized. At that time, if inflows still continued to increase, further rise of upstream levels would be prevented by opening of the gates and/or overtopping or controlled breach of the West Dyke, thereby flooding large parts of the City. The flow split could be managed to minimize damages to some extent.

Providing that any potentially affected residents immediately upstream of the City were also evacuated in advance of the rising levels, this approach would pose no added risk to life. It could, however, prevent the flooding of major portions of Winnipeg for a range of floods considerably greater than the Design Flood. While it is recognized that this mode of operation could raise legitimate issues about additional potential damage to facilities immediately upstream, which need to be addressed, the net benefits could be so enormous that the possibility can not be ignored.

2.3.4 Considerations Related to Alternative Operational Approach:

The risk of upstream components such as the West Dyke failing due to a strong south wind or other event would, of course, be greater while upstream levels were surcharged above the design condition. However, the extent of flooding due to such a failure may not differ greatly from that which would occur with an earlier deliberate flooding of the City under Rule 3. Thus, there would appear to be no substantial downside to this alternative mode of operation, except for impacts of the additional ponding in the much less populated areas immediately upstream.

Passage of more than the planned design flow through the Floodway (with through-City Red River flows at design levels) could result in overtopping of some segments of Primary Dykes in the northern part of the City due to backwater effects in the Red River. The areas so flooded, however, would most likely be flooded in any case by implementation of Rule 3 (at 778 ft. upstream); and much larger areas in the southern part of the City - including the downtown area - could potentially be saved from flooding for this range of flows. It is possible that backwater flooding in north Winnipeg under these conditions could be limited further by selective improvement of the most susceptible Primary Dyke areas and/or by reducing Red River flows through the City.

It must also be noted that the present Inlet Control Structure gates are only sufficient to reliably control flows through the City to acceptable values for still water head pond levels of about 778 ft. - or perhaps a bit less, depending on wind conditions and local inflows. Thus, viability of the proposed alternative mode of operation may require some modifications to the existing gates (or the provision of adequate back-up gates) - as will be discussed later. It may also require added freeboard on the West Floodway Embankment, as discussed in a later section.

2.3.5 Conclusions / Advice:

With various emergency actions and favourable wind conditions, it appears possible that the City could be substantially protected by operating in the above manner for floods up to 30% or so greater than the Design Flood. This could represent perhaps a 1:2,000 to 1:3,000 event - though all of these figures have yet to be specifically determined. In any case, the potential benefits of such operation could be enormous.

It is the view of the Panel that the specifics and implications of a mode of operation along the lines of the foregoing should be analyzed in some detail, and clearly documented. These should be made a part of the operational plan for the project, and implemented if possible. At minimum, they should be provided as an alternative to the implementation of Rule 3 for consideration by decision-makers at the time of a flood event.

In assessing these specifics and implications, it will be necessary to carry out further analyses relating to aspects such as the following:

- Flooding in the City due to backwater from the north - including the possibility of local Primary Dyke improvements to limit such flooding;
- Water levels through the Floodway and along its West Embankment for a range of floods larger than the Design Flood, including effects of bridge submergence where applicable;
- Water levels along the West Dyke and at the Inlet Control Structure for this range of larger floods.

2.4 Opportunities for Enhanced Protection at Little Cost

Where features of a project such as this one can be adjusted at little or modest cost to provide levels of safety or effectiveness significantly greater than those set out in minimum project requirements, the Panel believes such adjustments should be considered, and implemented where it is reasonable to do so. *There are aspects of this project where this approach could and should be taken.*

In particular, these would be aimed at serving the following purposes:

a) Insurance against contingencies / unknowns such as:
- partial blockage of the Floodway channel or structures - or the river channel;
- larger than expected local inflows from the Assiniboine or other streams, perhaps even including malfunction of the Portage Diversion; and
- sudden and/or extreme winds.

b) Improved operational flexibility in dealing with floods larger than the Design Flood.

Examples of low-cost opportunities for enhancement to serve these purposes could include the following, some of which are discussed in subsequent sections:

- Provision of generous freeboard allowances along the left side of the Floodway channel (i.e. on the East Dyke and West Floodway Embankment) by judicious use of waste materials from the Floodway channel excavation;

- Adjustments to the top elevation of the West Dyke to ensure that, in addition to meeting requirements for freeboard during the Design Flood, it does not have local low areas that would prematurely overtop when potentially "pushing the limits" with larger floods;
- Provision of sufficient additional gate height at the Inlet Control Structure to allow for contingencies (e.g. channel blockage; larger local inflows; extreme winds) and to permit the alternative mode of operation beyond Rule 2, described above. This could be done either by retrofitting the existing gates or by making back-up gates, if provided, sufficiently high;
- Consideration of various other possibilities such as cambering highway bridges in ways that will maximize extra clearance above the Design Flood surface over as great a Floodway channel width as practicable.

3.0 NEED FOR BACK-UP GATES

3.1 Improved Reliability

Panel members were of the view that measures to improve the reliability of the existing gates should be pursued and implemented, whether back-up gates are provided or not.

The extent of such improvements, however, would be influenced by the decision on back-up gates. Suggested improvements, a number of which were recommended in the PDEA studies, include the following:

- Improved security, including alarms, closed circuit cameras, etc., and restricted site access at least at critical times;
- Improved fire protection and power supply to the main control room;
- Formalized, mandated and fully documented (annually reported) maintenance program with assured future funding - preferably enshrined in legislation.
- Thorough, formalized and documented regular testing program, including aspects such as:
  a) Gate operation under dry; flowing water; partial and complete opening conditions, with full documentation including recording of hydraulic pressures, etc., and
  b) Lift-off testing of pre-stressed trunnion anchors.
- Preparation of an Operation, Maintenance and Surveillance Manual for the project - including the Inlet Control Structure and gates - along the lines suggested in the CDA Dam Safety Guidelines.
- Provision of an inventory of key spare parts such as supplemental pressure supply systems;
- Provision of stainless steel and bronze sliding surfaces, regular grease lubrication at the gate side seals, and possibly fluorocarbon coated rubber seals;
- Lubrication of trunnions and other pinned connections with both a centralized system and separate local grease nipples at each end of each pin;

- Consider provision of air bladders for supplementary lift to gates if necessary (some mixed views on the desirability of this);
- Assess the feasibility, including possible benefits and risks, of providing emergency supplementary gate lifting force from mobile cranes, using pre-installed lifting collars at the tops of hoist cylinders.

It was proposed that further fault tree analyses be considered as a means to quantify existing overall reliability, as well as the increase in reliability due to various improvement measures.

Subsequent to the meeting a suggestion was made that, if repair of hoist piston rods becomes an ongoing problem, ceramic coating be considered.

3.2 Considerations and Observations Regarding Back-up Gates

There are a number of considerations the Panel believes are important in relation to the decision on a back-up gate system. These, and related observations, can be summarized broadly under the following categories:

3.2.1 Implications of Potential Gate Failure:

- The PDEA studies indicate that the costs of back-up gates are not justifiable on grounds of economic losses due to gate failure, based on the assumed failure probabilities. The Panel members generally accept this conclusion, particularly if improved reliability measures are implemented - though some reservations were expressed around the possibility that all possible failure modes may not have been identified despite the good quality of analyses performed.
- The PDEA studies indicate that the risk of major loss of life (due to rapid overtopping of
  Primary Dykes) would most likely be associated only with a sudden structural failure of one of the gates due to a trunnion or trunnion anchorage failure. The Panel tentatively agreed with this conclusion, with the qualification that more specific assessment of the feasibility and likelihood of sufficiently rapid evacuation following other kinds of failure, such as a jammed gate, will be required to confirm this.
- The PDEA studies estimate a Population at Risk of around 13,000 people in the event of Primary Dyke overtopping due to a sudden gate failure, and an associated loss of life of about 25, with the methodology employed. The Panel notes that other methodologies may give significantly higher loss of life estimates, and that more detailed evaluation of evacuation issues is required to better assess this.
- The PDEA studies show that a failure of one of the two gates during a 1:75 or greater flood could cause the Primary Dykes to overtop. In light of this, it appears that a relatively high risk to life may be associated with a gate failure during passage of floods significantly smaller than the design event (say, in the 1:75 to 1:300 range) because the alert levels at such times could be relatively low.

3.2.2 Gate Capabilities:

- The PDEA studies estimate that the gates must be capable of limiting flows into the City to about 64,000 cfs to assure the (enhanced) Primary Dykes will not be overtopped during the Design Flood (based on estimated Assiniboine River and other local inflows totalling about 16,000 cfs). The studies indicate that the existing gates can achieve this for a still-water forebay water level of up to 778 ft. with no wind, but would be borderline with set-up due to a 1:100 south wind (i.e. some encroachment on the intended 2 ft. of freeboard on the Primary Dykes). The Panel makes a couple of related observations:
  a) Based on acceptable risk levels suggested in Section 2.2 above, a larger wind (say, about the 1:1000) should be considered in combination with the 1:700 flood. This could translate to a somewhat higher gate requirement, although it may be appropriate to counter this by allowing for some reduction of freeboard on the Primary Dykes for the short duration of this extreme event.
  b) Back-up gates, if provided, should be made capable of handling contingencies such as higher winds, partial channel blockage and greater than expected local inflows, as well as providing additional flexibility to deal with larger floods, as discussed in Section 2.3 above. It may also be possible to accomplish this by retrofitting the existing gates.
- It appears the existing gates have sufficient structural capacity to permit them to retain water to higher levels if they are appropriately modified. Two options suggested for modifications at the top are addition of Obermeyer gate components (comprising bottom-hinged steel segments supported by inflatable bladders), or simply extension of the top plates. Both would have to be assessed in more detail structurally, mechanically and hydraulically.
- The requirement to minimize the effects of potential sabotage or severe vandalism, not explicitly discussed in the PDEA studies, is an important matter. It must be seriously accounted for, both with regard to the decision on back-up gates and concerning the need to enhance reliability of the existing works.
- Functional and reliability requirements for back-up gates (or an alternative arrangement) are seen to include the following:
  a) Capability to achieve closure quickly enough to prevent overtopping of the Primary Dykes in the event of a sudden service gate failure;
  b) Provision of a reasonable degree of reliability, but not necessarily of the same order as the service gates under natural operating conditions, (since the overall failure probability would become unnecessarily low);
  c) As a minimum, only the capability to close either bay (not both at once) is needed;
  d) The possibility of interference by a failed service gate should be limited to an acceptable level;
  e) Vulnerability to sabotage of both the existing and back-up systems at once should be limited to the extent feasible.

3.2.3 Types of Back-up System:

- The back-up gate concept outlined in the SAFE studies would appear to provide a very high level of supplementary protection (at least without considering potential sabotage), though at significant cost. There may be substantially less costly alternatives, not yet studied, which would still provide an appropriate level of back-up protection.
- An upstream back-up system would generally be preferable to a downstream one in terms of possible interference by a failed gate, but it was felt that a downstream system should not be ruled out at this stage.
- There is the perception, at least, that the existing bay width (112 ft.) can not be reduced at any location due to navigation and/or ice considerations. This should be confirmed, inasmuch as it could greatly affect the viability/choice of back-up systems.

3.2.4 General Views of Experts:

- One of the gate experts on the Panel felt that, with an aggressive series of measures to enhance the reliability of the existing system, there would not be a compelling need for a total back-up gate system. The other gate expert cited experience with a number of trunnion anchor failures due to corrosion associated with concrete deterioration, and expressed some concern about other hazards / unknowns including human error, and the small number of gates. Although he agreed the multiple trunnions and double set of anchors make the likelihood of a sudden catastrophic structural failure low, he still felt that a back-up system is warranted, if practical at reasonable cost, on this project.

3.3 Conclusions / Advice

- ♦ Improved reliability of the existing system is considered to be required whether or not back-up gates are provided. Key aspects are in the areas of security; fire protection; assured high level of regular maintenance and testing; and some mechanical / structural upgrades.
- ♦ Further fault tree analyses of the gate system should be carried out to assess its present reliability, and to quantify the effects of proposed maintenance and other improvement measures on future reliability.
- ♦ More work needs to be done on the subject of evacuation of relevant areas of the City under various circumstances, as discussed in Section 6. Results of this work will be needed to confirm the estimated potential for loss of life associated with various gate failure scenarios. As part of this, the risks due to gate failure during floods smaller than the Design Flood should be assessed.
- ♦ There would be considerable benefit in providing back-up gates of sufficient water-retaining capability to prevent excessive flows through Winnipeg:
  a) during contingency events such as partial channel blockage, larger than expected local inflows and higher winds during the Design Flood; and

b) to permit floods greater than the design event to be potentially handled with limited flooding in the City.

It is possible these benefits could also be achieved by retrofitting of existing gates.

- The potential for sabotage or extreme vandalism needs to be considered, both in improved reliability measures for the service gate system and in assessing the need for and nature of a back-up system.
- The functional and reliability parameters for a back-up gate system need not be nearly as stringent as for the service gate system. The Panel concurs with PDEA consultants that significant effort should be applied to identifying and analysing various options for emergency closure which could be achieved at more modest cost than the option presented in the SAFE studies. Significant innovation may be required in this effort.
- Based on the information at hand, there was some variation of opinion among Panel members as to whether, or the degree to which, back-up gates are necessary for this project. As noted, project-specific evacuation plans and their timing need to be defined before loss-of-life risks due to various kinds of gate failure or malfunction, including jamming, can be adequately assessed. Subject to results of those studies, the majority of the Panel was of the view that some kind of back-up system should be provided, at least if a relatively economical system can be defined which will also provide added flexibility to handle contingency situations and extreme flood events. This is seen to be of more value in flood-protection terms than some other project expenditures currently proposed.

4.0 WEST DYKE FREEBOARD CRITERIA

4.1 Wind at Design Flood

4.1.1 Discussion and Observations:

A large south wind, with Red Sea water levels at their maximum design values (corresponding to 778 ft. at the Inlet Control Structure) could occur without sufficient warning to permit evacuation of areas that could be rapidly flooded by a major West Dyke failure. The PDEA studies have determined that loss of life could be extremely high if such a failure should occur under those circumstances (though specific evacuation plans / timing are needed to better quantify the probable degree). There is also some possibility of other contingencies, such as a partial channel blockage, that would cause a sudden rise in upstream water levels. The public interest therefore requires that conservative criteria be applied to determining freeboard for the West Dyke during passage of the Design Flood, when prior evacuation of the vulnerable population may not have occurred.

The acceptable levels of risk during such an event were discussed in Section 2.2, in which it was suggested that an annual probability of failure not exceeding about 10^{-6} would be a reasonable target in selecting the design level of protection for major

portions of the West Dyke. It appears such a target could be met at a cost that is reasonable for a project of this magnitude and importance. Adoption of the criterion would translate to a tolerable failure probability of slightly less than 1/1000 due to concurrent winds and other causes during passage of the Design Flood.

Because the dykes will be generally comprised of highly plastic clays and will have fairly flat downstream slopes, they are expected to have substantial resistance to erosion due to wave overtopping. Allowing for this, it is assumed that the PDEA criterion of 5% of waves overtopping during a 1:100 wind (with associated set-up) might be expected to produce no more than about a 10% chance of a major dyke failure during the limited duration of such a wind event.

The Panel therefore believes the dyke crest profile so derived is probably of about the right order. It suggests, however, that dyke erodibility should be more specifically assessed. With that information, the probability of failure with both the 1:100 and larger winds (up to, say, the 1/1000) should then be appraised to check the overall probability of a dyke failure during the Design Flood. If these analyses indicate a controlling condition, some adjustment of dyke elevations should be considered, though it is anticipated such adjustments would not be large.

The foregoing discussion applies to segments of the dyke at which overtopping failure could result in major loss of life (or excessive incremental property damage). There may be portions of the West Dyke (e.g. low portions nearer the west end) where failure would have much less serious consequences, and where lesser freeboard criteria would therefore be appropriate.

By way of clarification, the 1:100 (or 1:1000) wind in this case is understood to be a wind having an estimated 1/100 (or 1/1000) annual probability of exceedance during the limited time period in which flood levels are near their peak. It is not a 1/100 or 1/1000 AEP for the entire year, as is commonly used in much dam safety work.

4.1.2 Erosion Studies:

There has been significant research into embankment erosion due to overtopping, including recent development of field assessment techniques. Since erodibility is an important consideration in assessing the safety level of the West Dyke, it is suggested that an investigation be carried out to better evaluate this factor before finalizing the design. The involvement of someone like Mr. Greg Hanson of the U. S. Agricultural Research Service, who has done extensive past and recent testing in this field, would be valuable in such an investigation.

4.2 Dyke to Accommodate Alternate Emergency Operation ('Pushing the Limits')

For a range of floods greater than the Design Flood, there could be major benefits to Winnipeg if the available freeboard were to be fully utilized by allowing upstream levels to rise above 778 ft. at the Inlet Control Structure in order to push more water through the Floodway. This is discussed further in Section 2.3. Populations at risk, both above and below the West Dyke, would have to be evacuated in advance to assure their safety during such surcharging.

Further analysis is required to determine water surface profiles along the West Dyke that would be associated with the passage of various magnitudes of flood under this alternative emergency operating mode. The Panel suggests that the final crest profile of the West Dyke - while established basically by safety / freeboard requirements for the Design Flood - should also be adjusted modestly where practicable to reflect such extreme flood profiles.

4.3 Emergency Raising of West Dyke

The concept of providing less freeboard on the West Dyke, with the intention of raising it if required in advance of a forecasted (1:700) design flood, was discussed but clearly opposed by Panel members. It was noted that emergency raising introduces a number of weaknesses. These include uncertainties about the ability to construct the 40 miles or so of dyke in that period (which could be short) due to weather, equipment availability or other factors, and the reduced reliability and vulnerability to wave erosion of a top section so constructed.

4.4 Conclusions / Advice

- Due to the extreme potential consequences of an overtopping failure, conservative criteria should be adopted in determining the freeboard on major portions of the West Dyke for the Design Flood condition. A design annual failure probability (considering joint probabilities of flood, wind, erosion and contingencies) in the general order of 10^{-6} is suggested as an appropriate target for those portions where failure could be expected to result in a large loss of life.
- Considering the expected resistance to erosion of the dykes, the PDEA criteria of 5% wave overtopping with a 1:100 wind will likely result in a dyke crest profile of about the right order to meet this criterion. Further analysis should be carried out using this and other wind events, in combination with more reliable erodibility assessments for those events, to confirm or adjust the freeboard profile prior to final design.
- In support of this, it is suggested that an evaluation of dyke erodibility, including field investigations, be undertaken to assess the probabilities of dyke failure associated with various amounts of overtopping. Both periodic wave overtopping and continuous overtopping should be considered.
- Less stringent freeboard criteria than discussed above can be applied to areas of the dyke (such as lower portions near the west end) where an overtopping failure would have much less serious downstream consequences.

- While adequate freeboard during passage of the Design Flood would be the main criterion in determining the West Dyke crest profile, it is suggested that another scenario also be given some consideration. Water surface profiles associated with the alternative of pushing larger flood flows through the Floodway on an emergency basis (assuming no wind) should be computed. Modest local modifications to the crest elevation should then made where they would significantly improve the effectiveness in protecting against catastrophic damage in Winnipeg during such an extreme flood event.
- The Panel considers the West Dyke to be a critical element in protecting Winnipeg from calamitous flooding, and feels that it would be unwise to compromise its capacity or reliability. To count on emergency raising of the dyke in order to handle the Design Flood, for example, would be a mistake, in their view.
  In the event that costs must be cut to meet project budget limitations, it is the belief of the Panel that other components less important to flood protection should be given less priority for implementation at this time.

5.0 EMERGENCY FLOW RELEASE PROVISIONS

5.1 Discussion

The PDEA studies conclude there is a need for facilities and / or operating procedures to deal with floods larger than the Design Flood - up to something in the order of a PMF. The alternative means examined to achieve this were briefly as follows:

a) A lowered reach on the West Dyke designed as a fuse plug, which would activate automatically when the water levels reached its crest; or
b) Excavation of a reach of the West Dyke at the time a flood begins to exceed design levels.

These would be activated in order to prevent upstream water levels from exceeding 778 ft. at the Inlet Control Structure for inflows so large that increased releases through the fully opened gates could no longer prevent such a rise in levels. The flows so released would pass into the City, which would already be flooded to some extent by overtopping of the Primary Dykes due to excessive releases through the gates.

The Panel strongly agrees that provisions must be made to deal with extreme floods, whether as part of the physical works or as an operational activity during such an event.

As suggested in Section 2.3, it also believes these provisions should be such that they would permit the option of an operational approach involving some increase in upstream water levels (above 778) for a range of floods greater than the Design Flood. Under that approach, emergency flow releases would only be initiated when this surcharge reached a point where there was no longer judged to be any reasonable hope of preventing massive inundation of Winnipeg.

The Panel agrees with the PDEA consultants that any emergency release section should be located:

a) In a portion of the West Dyke that is of only modest height, to avoid the possibility that releases could become unnecessarily sudden or excessive, and where regaining control as the flood recedes would be easier;
b) Some distance removed from most populated areas, to provide as much additional time as possible for downstream evacuation in the event of activation.; and
c) So as to avoid, as much as practicable, transfer of risk whereby facilities / residences are flooded that would not otherwise be flooded under natural conditions.

The Panel agrees that there are some serious potential problems associated with provision of an automatic washout (i.e. fuse plug) section. These include:

- Possible premature washout due to wind or other events;
- Uncertainties regarding future dependability associated with frost, vegetation, etc.; and
- The possibility of more rapid release than desired.

For these reasons, particularly the potential for and unpredictability of premature failure, this option is not considered desirable.

It is not practicable, with the great length of the West Dyke and upstream considerations, to provide for enough head to pass major flows through a fixed-crest overflow section of reasonable length. The Panel therefore feels that, for this project, control of emergency flow releases by actively breaching an appropriate section of the dyke is the preferred option.

One possible configuration is to provide a somewhat lowered section of dyke where overflow would automatically begin, and which could be mechanically excavated, as needed, to increase its capacity. (The crest would be 'lowered' from the elevation computed to be required to contain a flood of a certain magnitude, whose surface elevation would vary.) This configuration has significant pros and cons. On the positive side, it would:

a) Visually delineate the reach where extreme flow releases would begin;
b) Provide a limited amount of "automatic" overflow capacity; and
c) Serve as an obvious warning to any downstream residents who may have resisted prior evacuation.

On the negative side:

a) It could overtop prematurely due to adverse wind conditions or other contingencies such as limited channel blockage;
b) There are variables associated with water surface profiles for different flood conditions, so that the crest profile chosen may not be well suited to all circumstances; and

c) It could restrict the ability to protect Winnipeg by 'pushing the limit' during passage of a range of floods larger than the Design Flood, unless raised on a emergency basis at that time.

Panel members were of mixed views on the overall merits of such an arrangement.

5.2 Conclusions / Advice

- The Panel strongly agrees that facilities and/or operational plans are required to deal with floods considerably larger than the Design Flood.
- It believes these provisions should be such that they will facilitate the option of protecting Winnipeg during floods greater than the Design Flood by raising upstream water levels to push more flow through the Floodway.
- Any emergency release section should be located at a section of the West Dyke:
  a) That is of only modest height,
  b) That is some distance from most inhabited areas, to maximize warning time, and
  c) That avoids, to the extent feasible, flooding of areas that would not be flooded naturally.

  The location just north of Avonlea Corner, suggested by PDEA consultants, appears to meet these criteria.
- The Panel does not favour provision of a fuse-plug type of washout section due to risks and uncertainties inherent with this type of structure, particularly on this project where wind set-up and wave action can be large and variable.
- The Panel favours an operational plan whereby a section of the West Dyke would be actively breached by excavation to the extent required during an extreme flood event.
- Panel members had mixed views on whether a lower dyke crest should be constructed in the reach designated for emergency breaching. There was consensus that, if a lowered section is provided, it should be constructed of the relatively inerodible materials used in other dyke sections, and that the amount of lowering should be small: 0.5 metre at most.

6.0 OTHER CONSIDERATIONS, COMMENTS AND ADVICE

6.1 Evacuation Plans

The development and execution of evacuation plans relating to various situations, areas and populations are an essential aspect of flood protection for southern Manitoba. It is understood that the Province has an Emergency Response Plan which includes guidelines for evacuation, and that substantial work has been done regarding evacuation considerations for Winnipeg, though such work is by no means complete.

The Panel notes that evacuation on the scale that could be required for a major flood at Winnipeg is unprecedented in Canada, and may be significantly complicated by the

remoteness from other major population centres. To provide adequate protection against multiple loss of life (Section 2.2), evacuation of the population in designated vulnerable areas should be completed by the arrival of the Design Flood. Thus, in addition to the requirement for advance and ongoing public education / awareness, a well-planned staged evacuation would be required. Execution of the final stage (i.e. staged mandatory evacuation) could take considerable time (perhaps a number of days) for such a massive and complex effort.

The timing and viability of well thought out evacuation plans are vital considerations in developing the final design of some key aspects of the floodway expansion project. For example, judgements about probable loss of life due to various types of gate or dyke failure, and other flow release scenarios, are heavily dependent on assumptions regarding these plans and their effective implementation. And the appropriate levels of safety / redundancy for these components are in turn dependent on those judgements.

The Panel suggests that the analysis and development of viable project-specific evacuation plans be completed as soon as possible so that relevant information concerning timing, in particular, can be factored into the final design of this project.

6.2 Risk Analyses

One of the PDEA project consultants has recommended that comprehensive risk analyses be conducted to assess areas of priority for expenditures on the project. The Panel would be supportive of such analyses, with the caveat that their value can be limited in many cases by inability to adequately assess relevant failure/event probabilities or to identify all potential failure modes.

6.3 Priorities

It is the advice of the Panel that the highest priority for this project should be given, in general, to the safety and reliability of components whose failure would result in massive flooding of the City. Principal among these are the West Dyke; barriers along the left side of the Floodway (i.e. the East Dyke and West Floodway Embankment); and the Inlet Control Structure and gates. Components that are not essential for flood protection, such as some bridge upgrading, must be seen as a lower priority at this time if choices have to be made.

7.0 SUMMARY OF KEY OBSERVATIONS AND ADVICE BY THE PANEL

7.1 General:

- The capability and integrity of the West Dyke, the gated Inlet Control Structure, and the West Floodway Embankment are all fundamental to preventing massive flooding in Winnipeg, and should be given very high priority in this project.
- Considering the large potential for loss of life, these components must be designed with sufficient safety margins to provide an extremely low risk of failure during passage of the (1:700) Design Flood, including allowances for contingencies such as unexpectedly high winds, or partial channel blockage.
- Opportunities should be taken to provide levels of safety or protection beyond minimum project requirements where this can be done at modest cost. One example is in the raising and extension of the West Floodway Embankment, where waste materials from the Floodway channel excavation can be used.
- For a range of floods larger than the Design Flood, very strong consideration should be given to an alternative to operating Rule 3, which currently calls for planned flooding of Winnipeg when upstream water levels reach 778 ft. With vulnerable areas evacuated, considerably larger floods could be forced through the Floodway channel by allowing upstream levels to rise somewhat further, encroaching on freeboard but not risking loss of life. This alternative could avoid massive property damage during such floods, and should be factored into the project planning, at least as an available option.
- It is important that project-specific evacuation plans and assessment of their timing be pursued and completed as soon as possible for various vulnerable areas, so that the relevant information can be accounted for in the planning and design of this project.

7.2 Gates:

- Reliability of the existing operating gates should be improved by implementing measures proposed in the PDEA studies and by the Panel. These include aspects such as security; fire protection; some mechanical upgrades; and mandated high levels of regular maintenance and testing, with assured funding. Further fault tree analysis should be used to quantitatively assess present reliability and various improvement measures.
- Options for a cost-effective system of back-up to the operating gates should be studied in detail, with a view to implementing the most favourable option if possible. Assessments of evacuation timing will affect the importance of this. The back-up system must be adequately reliable, but not nearly to the extent required of the operating gates.
- The operating gates should be retrofitted, or back-up gates designed, with sufficient height to protect the City in the event of contingencies such as high winds, channel blockage or large local inflows; and to permit the alternative operating mode for flows larger than the Design Flood.

7.3 West Dyke Freeboard:

- West Dyke freeboard proposed in the PDEA studies is believed to be of the right order, but dyke erodibility should be further assessed and freeboard checked for other severe wind and overtopping conditions. Dyke height should also be adjusted to avoid local low spots when passing extreme floods.

7.4 Emergency Overflow Operations:

- Facilities and/or operational plans should be in place to deal with extreme floods, as is proposed in the PDEA studies, and should be such as to permit the option of protecting property in Winnipeg for a range of flows larger than the Design Flood.
- The scheme should include breaching of a section of the West Dyke that is well to the south of the most populated areas, and where the dyke height is not too great, as suggested in the PDEA studies.
- An operational plan to actively breach such a section to the required extent is strongly favoured, rather than provision of a fuse-plug type of washout section. If the designated section is made lower than the adjacent dyke, the amount should be small, and the dyke material relatively inerodible.

ANNEX “A”

List of Workshop Participants

EXPERT WORKSHOP PARTICIPANTS

Expert Panel	Position	Firm
Bert Lukey	Professional Engineer (former Director of Prairie Farm Rehabilitation Adminsitration)	Independent Consultant - advisor on design, construction and safety of dams and member of review boards
Gary Salmon	Professional Engineer (former Director of Dam Safety, B.C. Hydro)	Independent Consultant working internationally on dam safety and Technical Coordinator of CEATI Dam Safety Interest Group
Graham Morgan	Professional Engineer (former Principal of Thurber engineering in geotechnical and earthworks fields)	Independent Consultant - advisor on design, construction and safety of dams and member of review boards
Michael Watson	Professional Engineer (former Specialist Mechanical Engineer (gates), B.C.Hydro's Dam Safety Program)	Independent Consultant on design and operation of mechanical equipment for hydroelectric plants with emphasis on all types of hydraulic gates and hoists
Michel Limoges	Vice President - Engineering (Hydroelectrical) - design, fabrication and erection of gates	HMI Construction
Primary Participants		
Alex Gerrard	Project Manager: pre-design of the inlet control structure & dam safety analysis	SNC-Lavalin
Rick Carson	Project Manager: lead consultant for pre-design	KGS Group
Dave MacMillan	Principal; liaison engineer of the lead consultant for pre-design	KGS Group
Warren Gendzelevich	Head, Geotechnical Department	Acres Manitoba
Doug McNeil	Vice President - Hydraulics	MFA
Rick Hay	Manager of Floodway Channel	MFA
Brian Peter	Manager of Design and Contracts, Floodway and Structures	MFA
Other Attendees		
Jim Thomson	Vice President - Transportation	MFA
Doug Peterson	Manager of Environmental Services	MFA
Ruth Eden	Manager of Design and Contracts, Bridges and Transportation	MFA
Gene Piasta	Senior Construction and Contracts Engineer	MFA
Norm Meier	Senior Technologist	MFA
Dr. Jay Doering	Head, Civil Engineering and member of the Floodway Expansion Technical Advisory Committee	University of Manitoba
Demetrios Kontzamanis	Principal	KGS Group
Steve Topping	Executive Director	Manitoba Water Stewardship
Shaun Moffatt (note taker)	Environmental Scientist	KGS Group

ANNEX “B”

Materials Presented at Expert Workshop

Floodway Expansion Project

Workshop
Inlet Control Gates and West Dyke
October 13 – 14 th, 2004

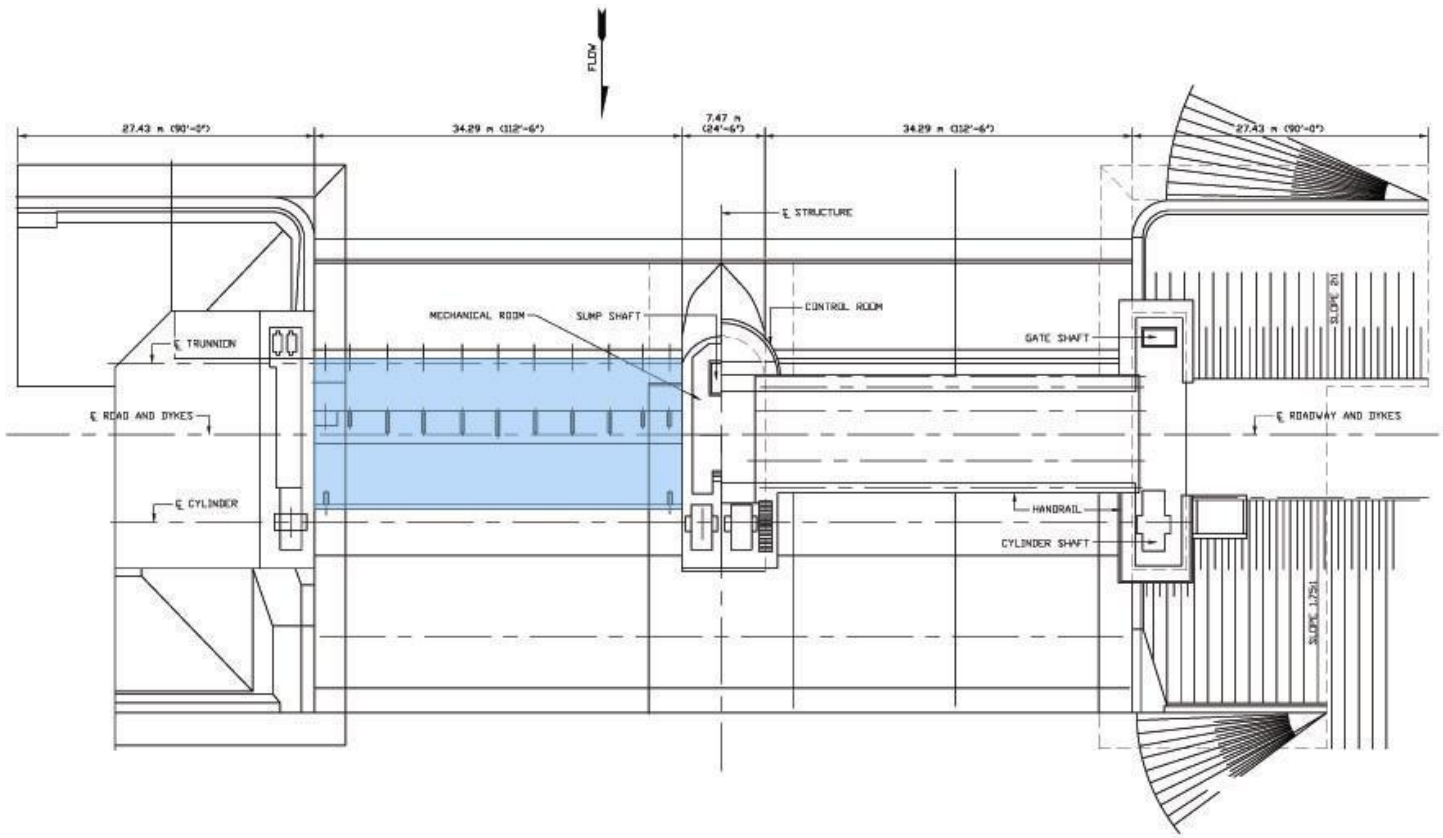
SNC - LAVALIN

Inlet Control Gates – Reliability

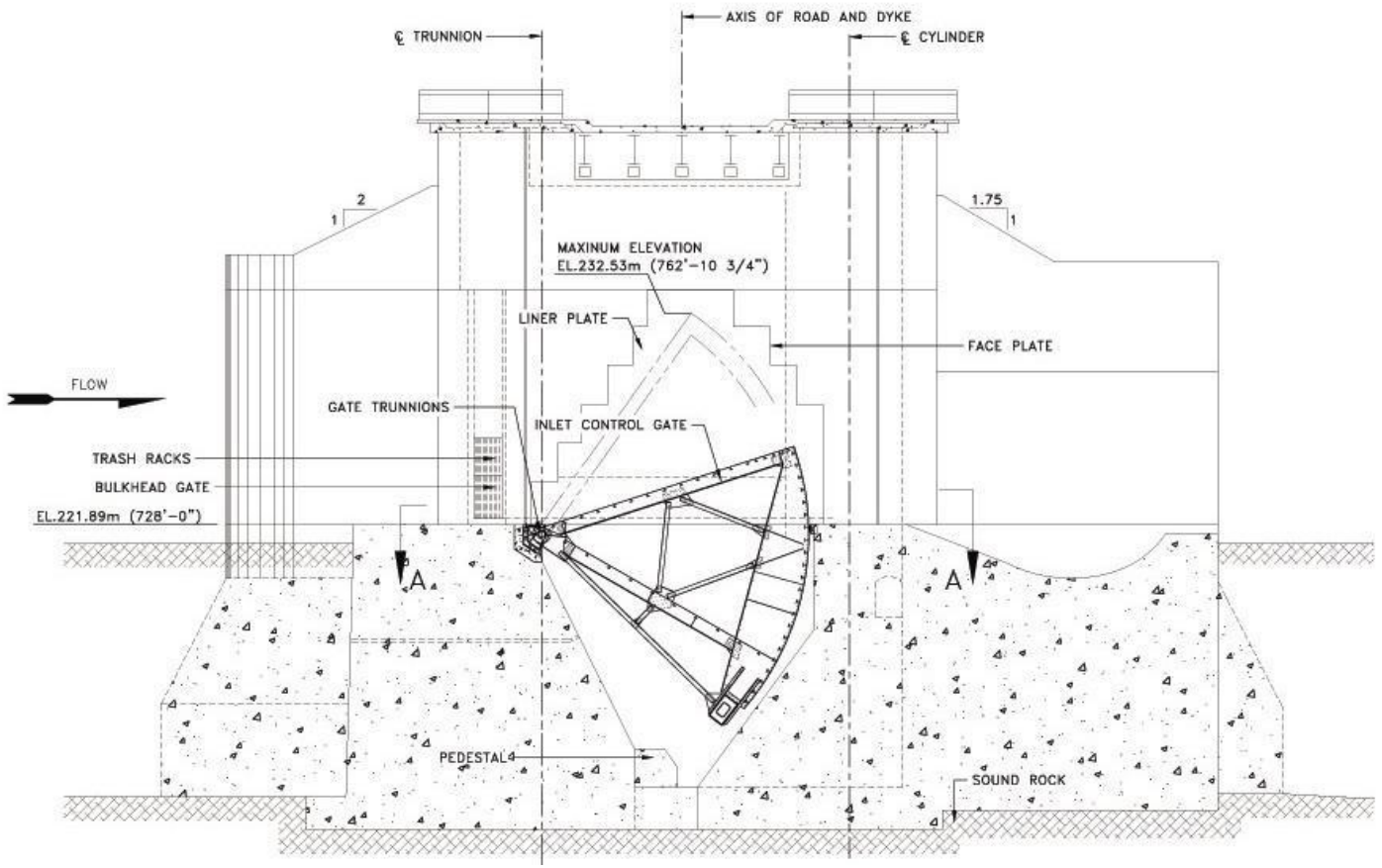
Objectives of Original Assignment

- Dam Safety Review
- Investigate reliability of gates
- Make recommendations for improving reliability/redundancy

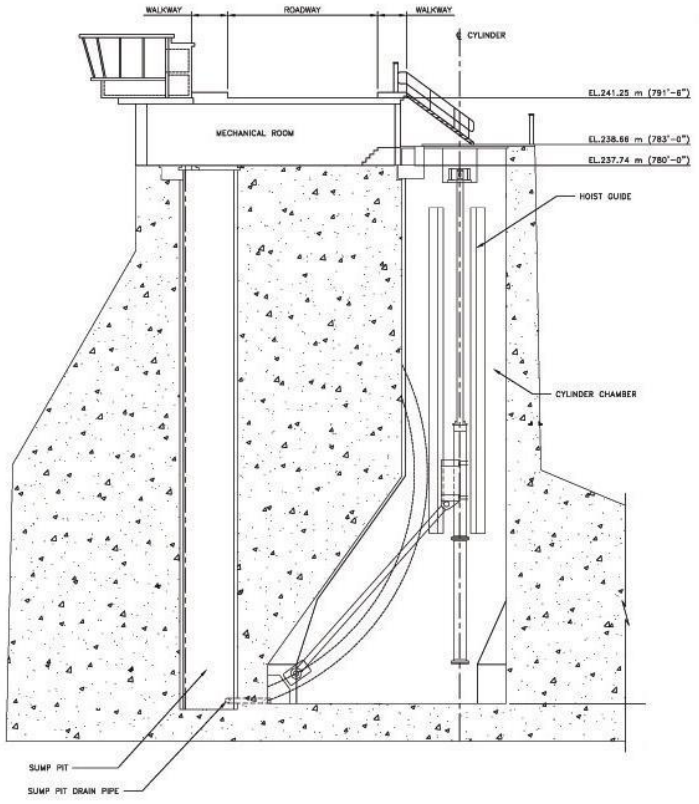
Plan of Inlet Control Structure



Section - Gate



Centre Pier – Hoist Cylinder



SECTION – CENTRE PIER
(GATE FULLY DOWN)

Methodology

1. Review Precedent Practice
2. Review Inherent Redundancies in structure
3. Model testing of gate operating characteristics
4. Failure modes analysis
5. Identify low cost measures to improve reliability
6. Risk Analysis for remaining items (property damage) to assist in decision making
7. Evaluation of risk of loss of life

Overall Criteria For Recommendations

Justification for Major Investments

1. **Dam Safety Deficiency**
2. **Economic considerations**

   a) **Should compete with other alternatives**
      - **For example, increasing channel capacity**

   b) **Additional investment should be < avoided property damage**

3. **Risk of loss of life must be acceptable**
4. **Risk of failure should not be higher than other elements of project with similar consequences**

Precedent practice

- Size of gates well within precedent
- Number of gates
  - < many installations
  - > some major flood protection projects
    - Netherlands, St Petersburg,
- Redundancies in hoist equipment
- No examples of back-up gates although many projects less vulnerable to loss of one gate
- Compliance with design standards typically accepted as criteria for integrity of gates as for dykes, dams, etc
- No “smoking gun” based on overall arrangement

Maelsant Storm Surge Barrier

Previous Experience - Failures

Review of previous failures history- Mostly North America

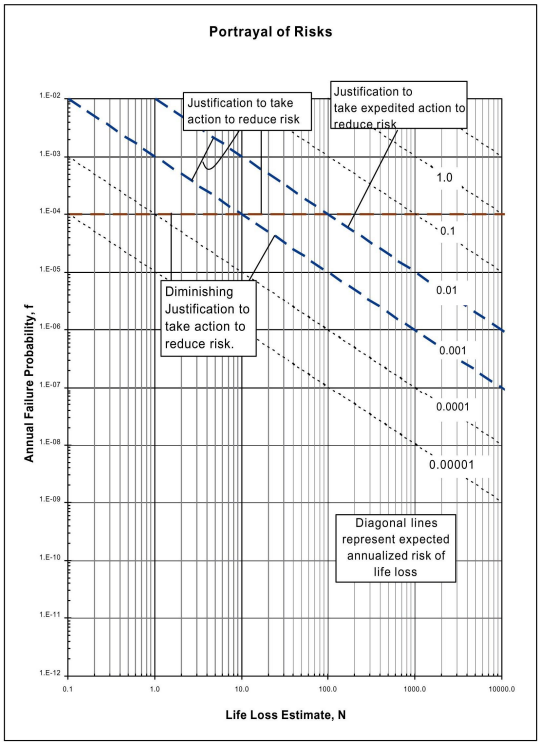
1. **Limited number of hoist failures**
2. **Blockage by debris, ice**
3. **Jamming**
4. **One example of loss of gate Folsom Dam**
   - **Due to failure of trunnion bearing**
   - **Hoist chain**
   - **Trunnion arm**
5. **Only example of major structural failure initiating loss of gate – India deficient weld design**

Inherent Redundancy in Arrangement

1. **Each gate is (or can be made to be) essentially independent**
   - Worst case- total loss of one gate
   - Remaining gate can compensate for floods up to 1:50 years
   - Additional capacity in dykes within Winnipeg will extend actual limits
2. **If failure equivalent to gate at 50% of max lip elevation, protection approx 1:370 year**

U.S.B.R f-N Chart

Figure 1. - The f-N Chart for Displaying Probability of Failure, Life Loss, and Risk Estimates



Source: "Guidelines for Achieving Public Protection in Dam Safety Decisionmaking" June 15, 2003
United States Department of the Interior
Bureau of Reclamation

Failure Modes Analysis

- **Hoists – improvements to reliability recommended**
  - **Power supplies**
  - **Pressure supply systems**
  - **Low cost improvements to reliability**
- **Gate opening versus closing tendency**
  - **Model tests confirm desirable tendencies**
  - **Modify to ensure positive closing (raising) forces**
- **Jamming – could cause property damage – not loss of life**
  - **Additional measures to reduce risk**
- **Limited number of failure modes with no redundancy**
  - **Total loss of gate due to structural failure / anchorage failure**
    - → Back-up gates only potential back-up
    - → If deficiencies identified, modify design

Risk Analysis – Property Damage

1. Focused on areas with limited redundancy
2. Probability of failure subjective/conservative – no data for many failure modes
   - Assumed probability +/- .0001 to .0002 per flood event
   - Lack of previous failures implies much lower probabilities of failure for modes such as structural failure
3. Calculated risk << cost of back-up gates < 10 %
4. Consistent with Safe Study findings

Risk Analysis – Property Damage

1. Risk related to property damage order of magnitude below cost of back-up gates
2. Risk can/should be further reduced - low cost
3. Ongoing maintenance and testing important – practical
4. OMS manual
5. Subsequent observation – further reduce risk due to jamming - outcome from meeting re Thames Barrier

Risk of Loss of Life

- Most failure modes provide time to avoid loss of life
- Only sudden loss of a gate creates risk of life loss
    - Lower limit of risk – approx. 1: 75 year flood with total loss of one gate
    - Potential loss of life increases with flood magnitude - approx. +/- 25 deaths for 1:700 years flood
- Potential failure modes with risk of loss of life
    - Catastrophic failure of gate structure and loss of gate
    - Cascade failure of all trunnion anchorages and loss of gate

Loss of Gate – Failure Modes

- **Design Considerations**
- **Gate has substantial inherent redundancy – 11 radial ribs carry load**
  - **Stresses in gate quite low – independent check**
  - **Stresses during operation < typical design practice**
  - **Thrust shared between 11 trunnions with high factor of safety > 5 on most highly loaded anchors**

  Most susceptible areas
  - **Future corrosion – can be controlled and steps taken**
  - **Trunnion bearings – replace now as preventive maintenance**
  - **Fatigue failure of downstream skinplate**
    - Will not result in loss of gate
    - Impact can be further reduced with bouyancy
  - **Trunnion anchorages – duplicate anchors already installed- monitor / replace/upgrade if necessary**

Failure Modes for Loss of Life

- Design meets or exceeds typical design standards
  - Typically gates would be judged to meet Dam Safety requirements
- More in depth analysis indicates that
  - Failure modes very limited
  - Failure modes are very improbable
- Potential risk reduction measures - much lower cost than back-up gates
- No identified deficiencies that indicate suspect deficiencies / failure mechanisms

Risk of Gate Failure versus Other Failures

- Very low probability of loss of a gate
- No known catastrophic gate failures initiated by structural failure in spite of serious lack of maintenance on many gates
- Prob > 0 but very low for credible mechanisms
- Many known failures of earth dykes and dams
- Historical data suggests risk > failure of gate

Other Considerations for Back-up Gates

- Tolerate wider range of conditions near El 778 upstream
  - High winds, high downstream inflows
  - Potential reduction in risk low relative to cost of back-up gates
- Dam safety investigations
  - Not judged to require back-up gates to comply
- Other lower cost alternatives have limitations
- Unidentified/unquantified risks
  - Social/business interuption costs- should be judged on same basis as other elements of project

Summary

- Some measures to improve reliability of gates are justified
- Back-up gates not justified by;
  - Risk of property damage – order of magnitude low
  - Dam Safety considerations
  - Other considerations
- Limited failure modes that could cause loss of life are
  - Very improbable
  - Risk could be reduced by other lower cost means- still >0
- Ongoing maintenance and testing - important with or without back-up gates
- Back-up gates can be added in future

Alternatives

- **Lower cost alternatives to back-up gates have limitations**
- **Alternatives for investment**
  - **Increase channel capacity**
    - → Reduce risk of property damage
    - → Lower upstream levels and risk
    - →
  - **West Dyke**
  - **Other?**
-

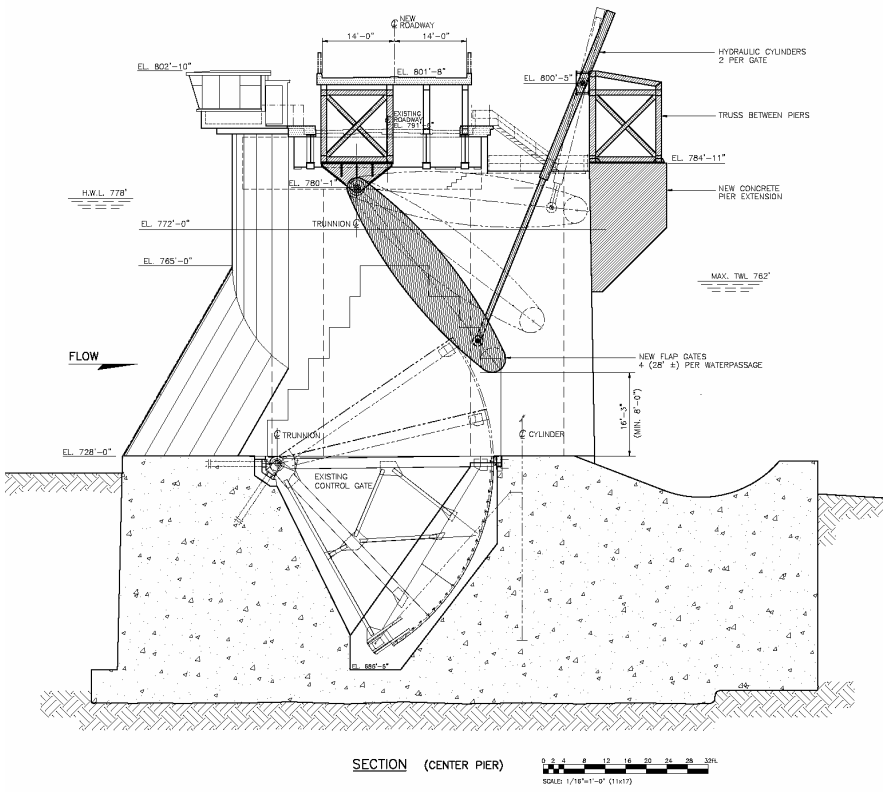
Floodway Expansion
Dam Safety Workshop

October 14/15, 2004

KGS-Acres-UMA

Redundant (Backup) Gates ?

- Gate Concept - 2000 SAFE study
- Background - SNC Risk Analysis
- Need for Redundant Gates
- Vulnerabilities
- Rationale for Gates



Redundant Gates - Risk Analyses (SNC)

- Concluded can’t be justified on economic losses
- Sudden loss of gate (structural / cascade failure of trunnions) leads to loss of life & billions $ damages
- sufficiently remote chance of failure

Recommended Improvements

- Reliability / redundancy improvements
- Reduce risk to very low level
- Further risk reduction via redundant gates not justified (SNC)

Rationale for SNC Recommendation

- Improvements to reliability
- Lack of precedent
- Not justified by property damage
- Ongoing Maintenance - essential
- Very low risk to loss of life – limited Failure Modes
- Relatively high costs $35 Million

Need for Redundant Gate

- Loss of Life failure modes identified
- Loss of Life for trunnion failure mode
  - 2 hr Inundation ~25 (~12,700 PAR)
- Reliability of future maintenance
  - budgets, commitment,retirements etc
- Some failure modes may not be understood at this time (Murphy's Law)

1997 Flood

Loss of Life

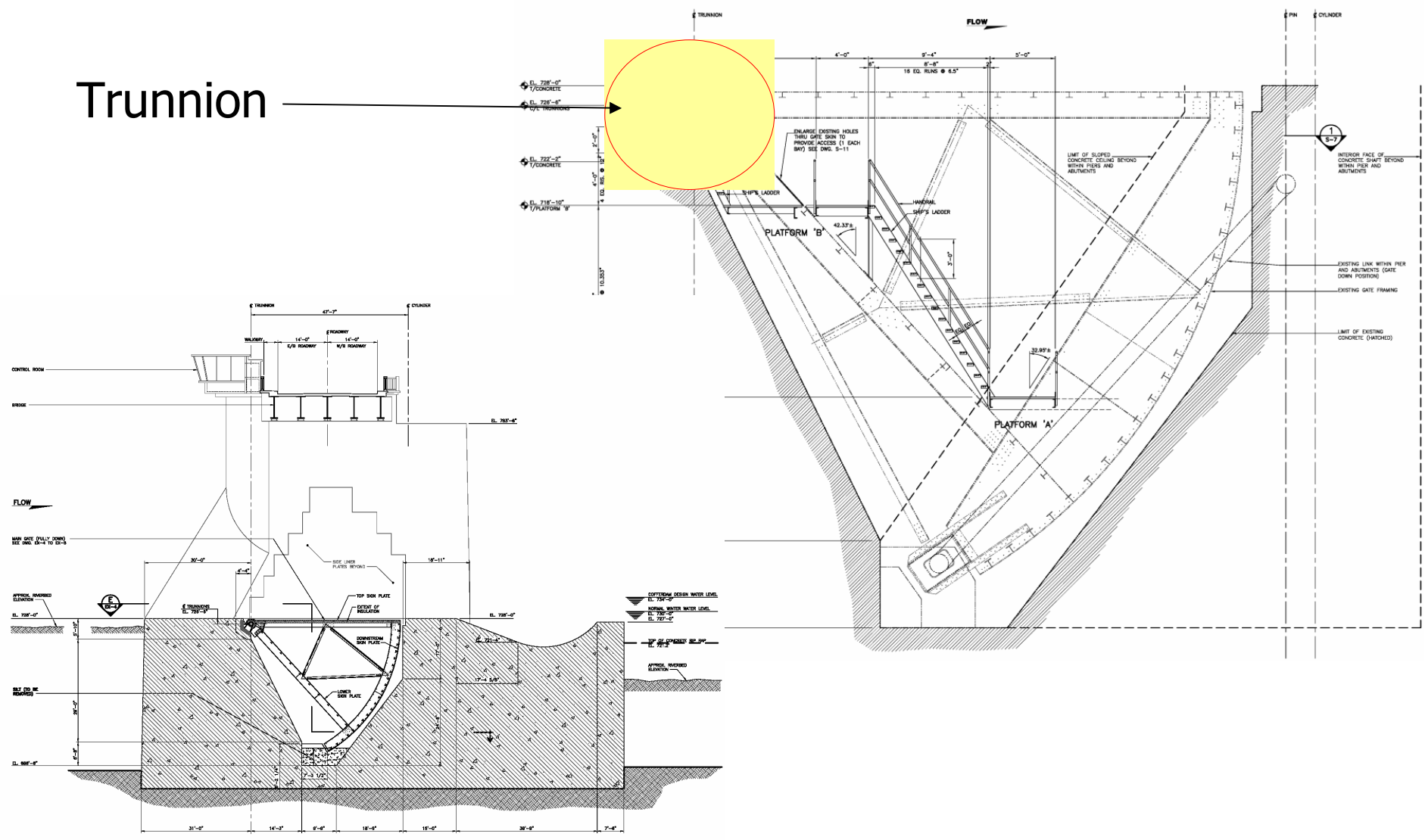
- Provincial Dam Safety standards across Canada have low tolerance to incremental loss of life.
- Loss of life - large expenditures generally accepted (i.e. Probable Maximum Flood spill capacity)

Design Practice

- Current design practice- structure would have 3 or 4 gates (redundant capability)
- Original design related to ice passage concerns and debris
- One time opportunity to address this shortcoming

Inlet Control Structure - Arrangement

Trunnion



Vulnerabilities - trunnions

- trunnions - difficult to inspect and maintain
- Potential for cascade failure
- Folsom Dam precedent
- Costly to replace
- Post tensioning anchors difficult to monitor and rehab

Vulnerabilities - Maintenance

- Access to underside of gate needs dewatering
- difficult to rely on in the future
- maintenance funding next 50 years
- opportunity for today with Floodway funding

Vulnerabilities - Maximum Surcharge

- Flow restriction at El. 778’ is limited
- vulnerable to high winds and high Assiniboine River flows
- redundant gates will provide back-up for this condition

Rationale for Redundant Gates

- Failure Consequences
  - Loss of life potential - 25 +
  - Billion dollars damage potential - $ 2 B +
- One time opportunity to address this shortcoming
- Public perception - sometimes drives expenditures

Rationale for Redundant Gates

- Comparison to other protection elements
- Adjacent earth structures
  - dam safety assessment complete
  - exposed to many floods
  - very low risk for non overtopping failure
  - if concerns - increased surveillance etc to increase reliability
- Gates are a relative measure ~ 5% of project cost

Redundant Gate Concept

- Preliminary concept from SAFE Study
- Are other lower cost concepts viable ?
- Single use lower cost alternative?
- Further assessment is warranted
  - alternatives
  - maintenance practices / commitments
  - review of precedents (this type of structure)

Floodway Expansion
Dam Safety Workshop

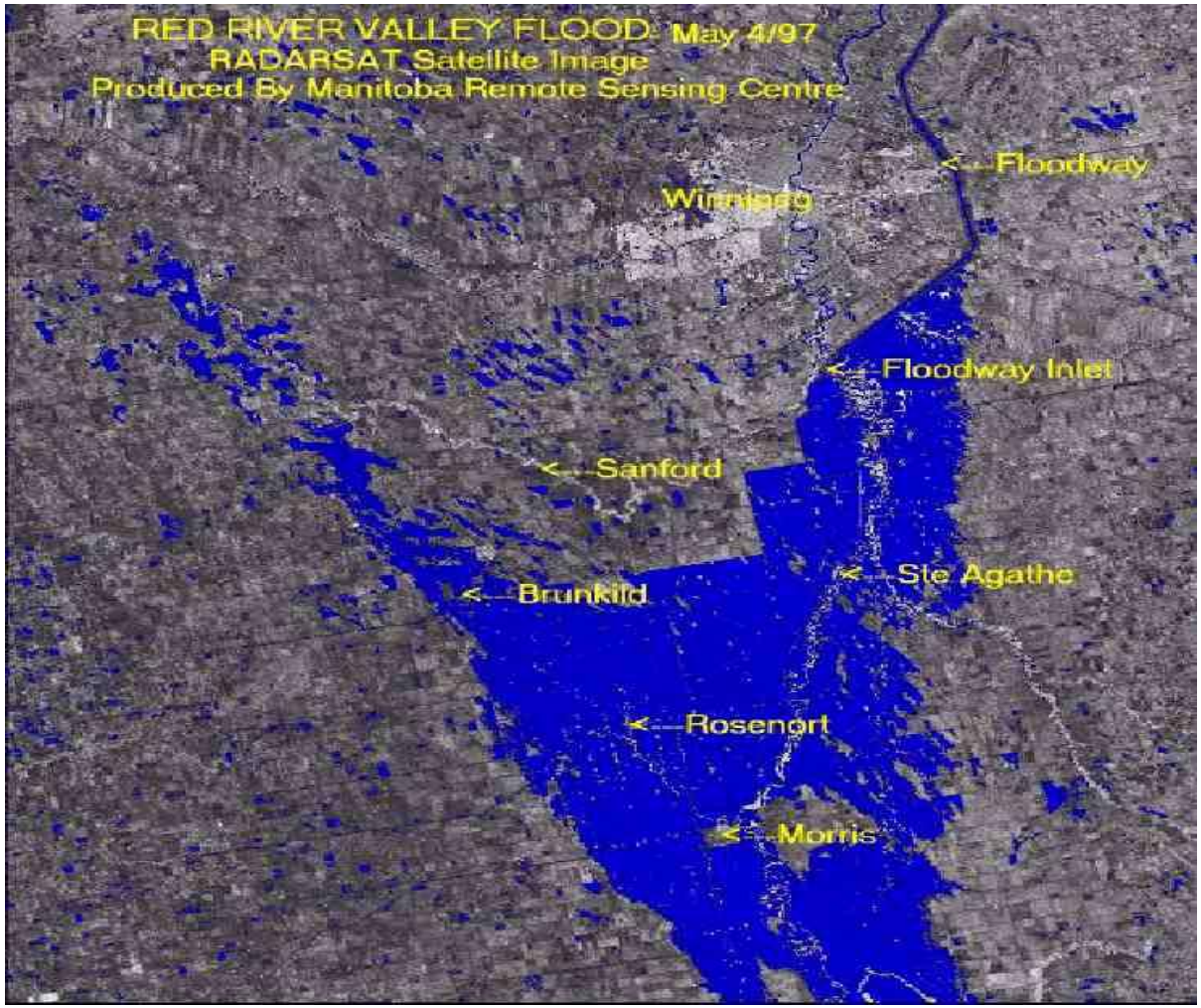
West Dyke Issues

October 14/15, 2004

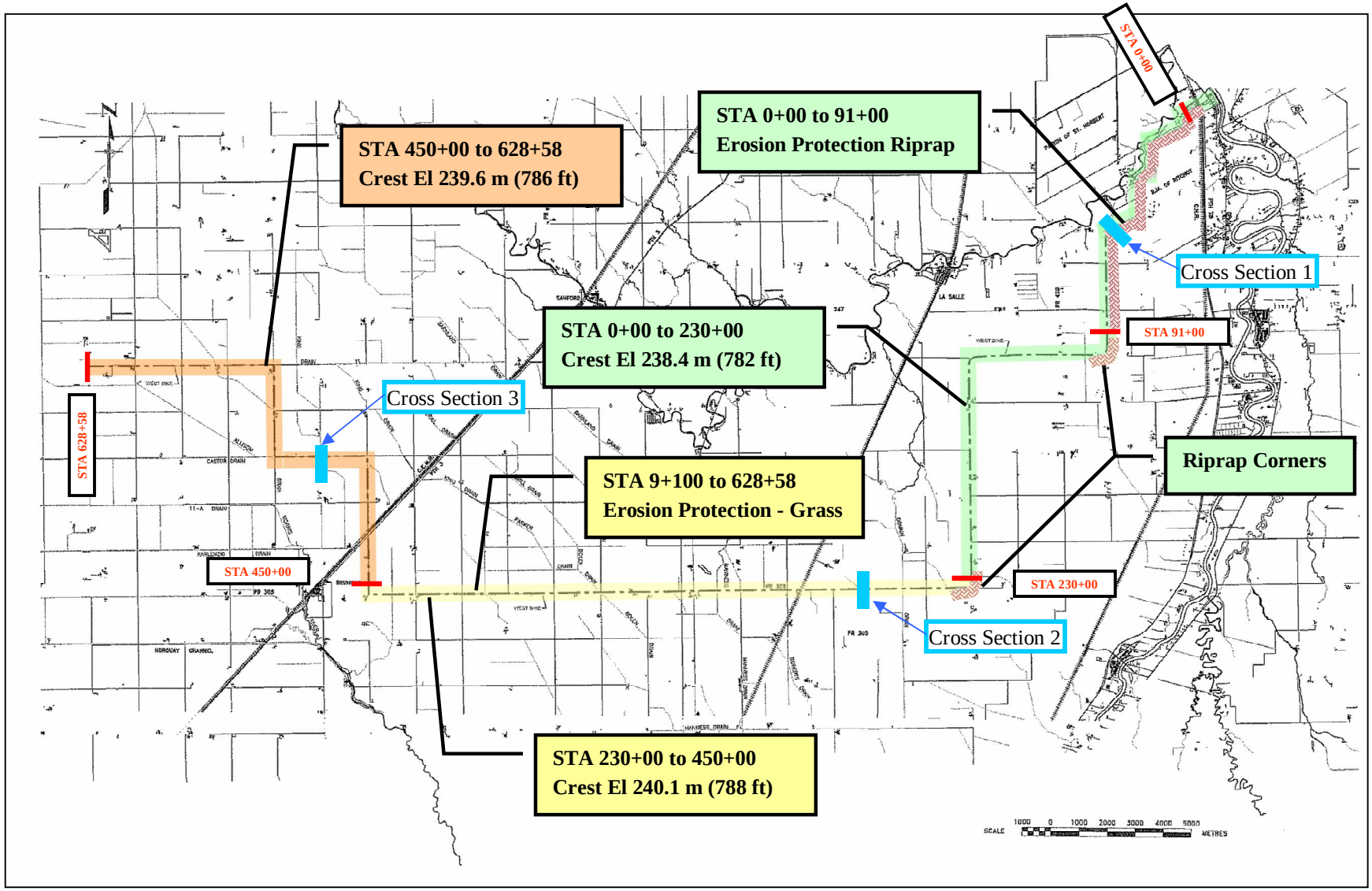
Pre-Cursor Information

- ***Findings of incremental cost studies:***
- $1,000,000 buys approximately 4 m^3/s (140 cfs)
- 100 m^3/s (3,500 cfs) buys 35 years on flood frequency curve
- $35,000,000 buys 140 m^3/s (~5,000 cfs)
- $35,000,000 increases flood protection to 1 in 750 chance of exceedance

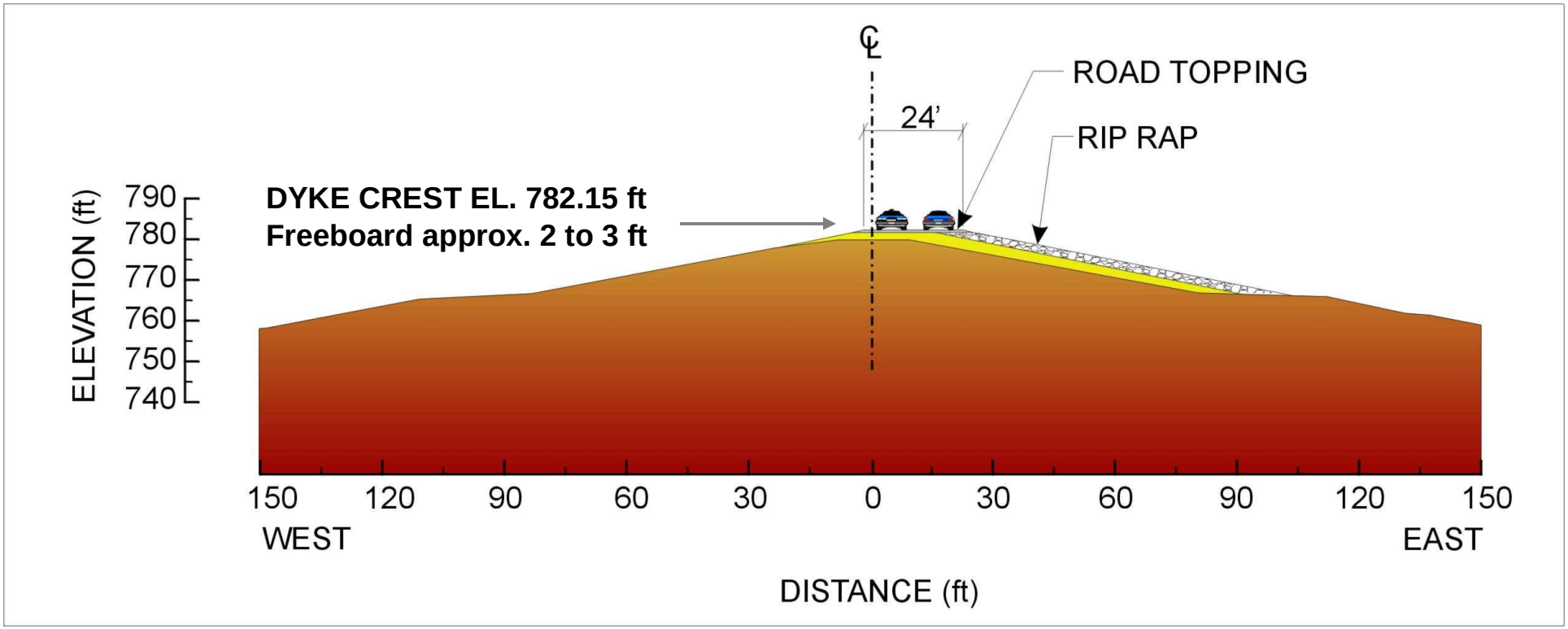
Dam Safety Issues at West Dyke



West Dyke


STA 450+00 to 628+58
Crest El 239.6 m (786 ft)
STA 0+00 to 91+00
Erosion Protection Riprap
STA 0+00
Cross Section 1
STA 91+00
STA 0+00 to 230+00
Crest El 238.4 m (782 ft)
Cross Section 3
STA 628+58
Riprap Corners
STA 9+100 to 628+58
Erosion Protection - Grass
STA 450+00
STA 230+00
Cross Section 2
STA 230+00 to 450+00
Crest El 240.1 m (788 ft)

West Dyke – Section 1



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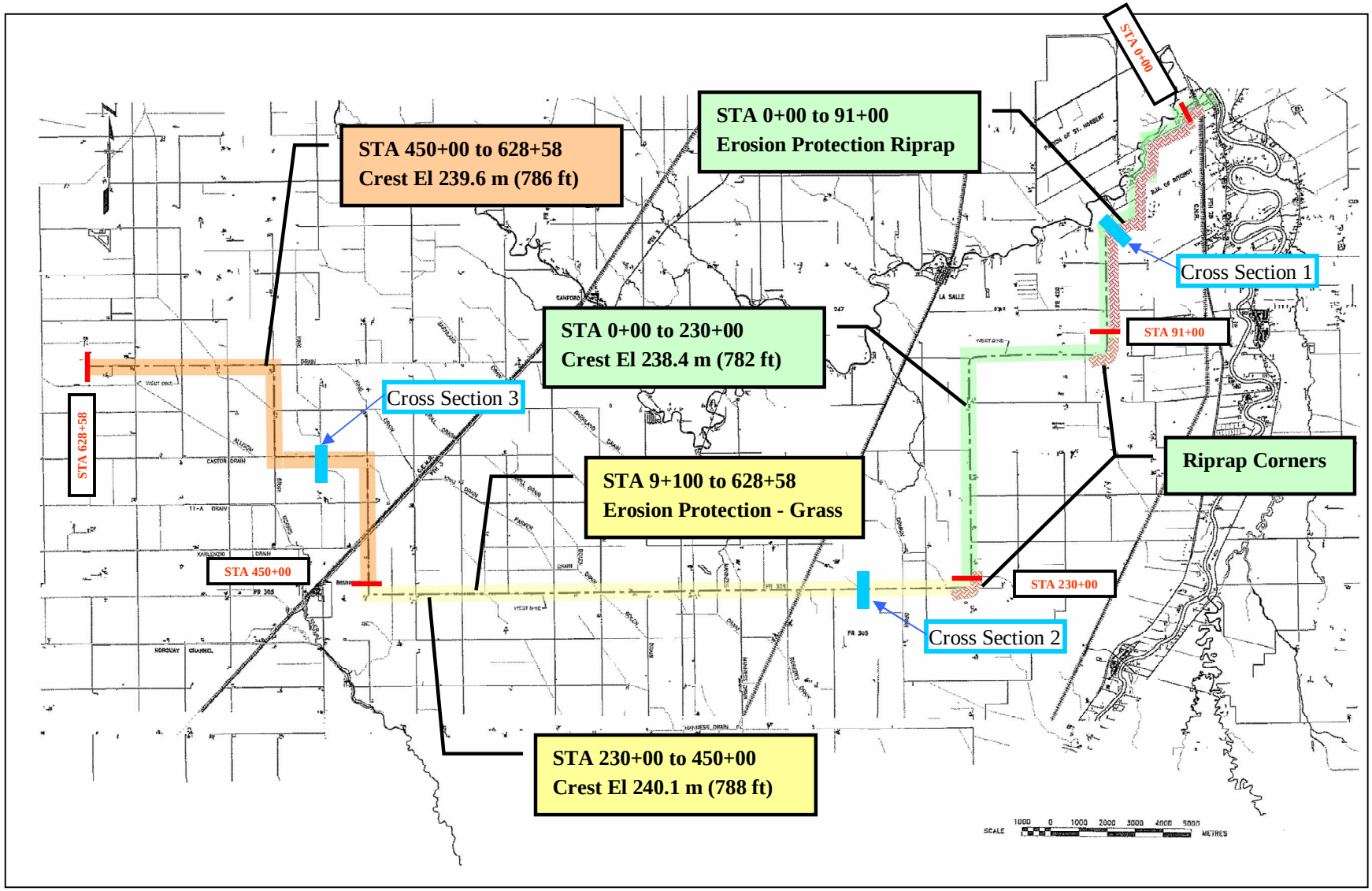
West Dyke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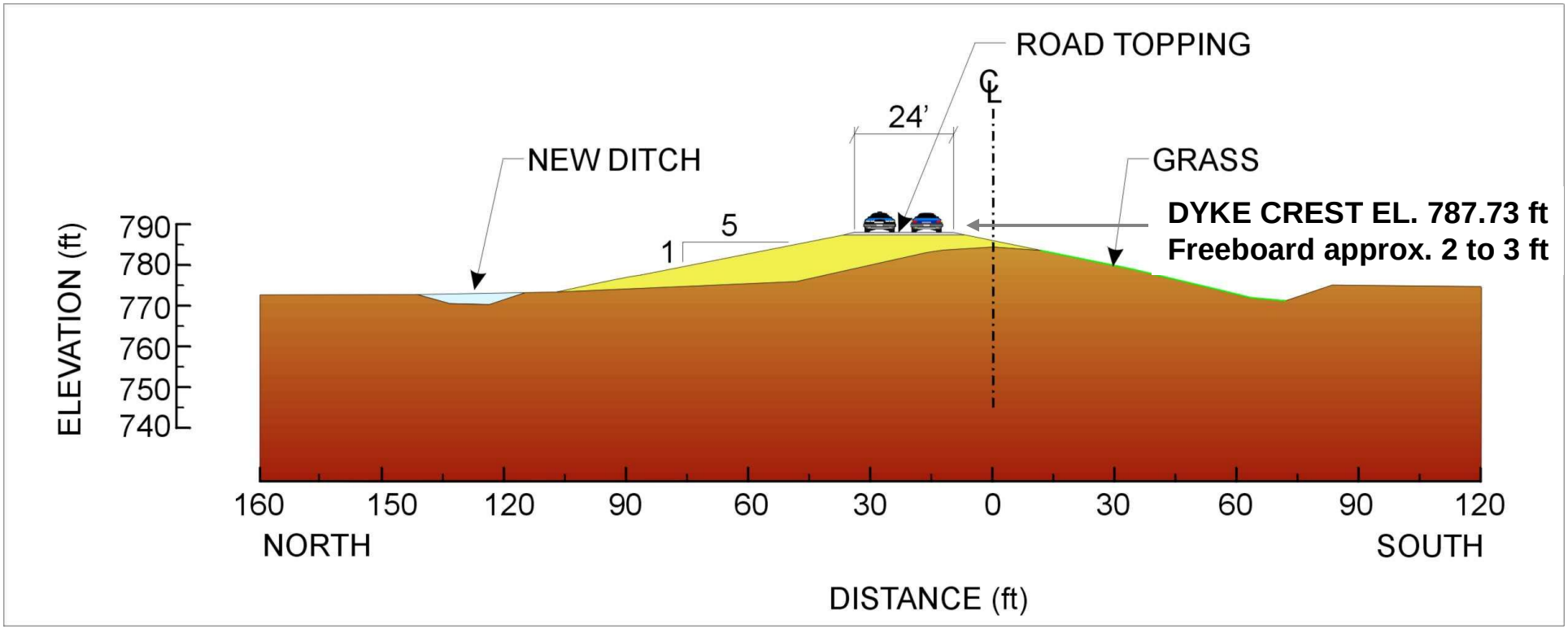
West Dyke – Section 2



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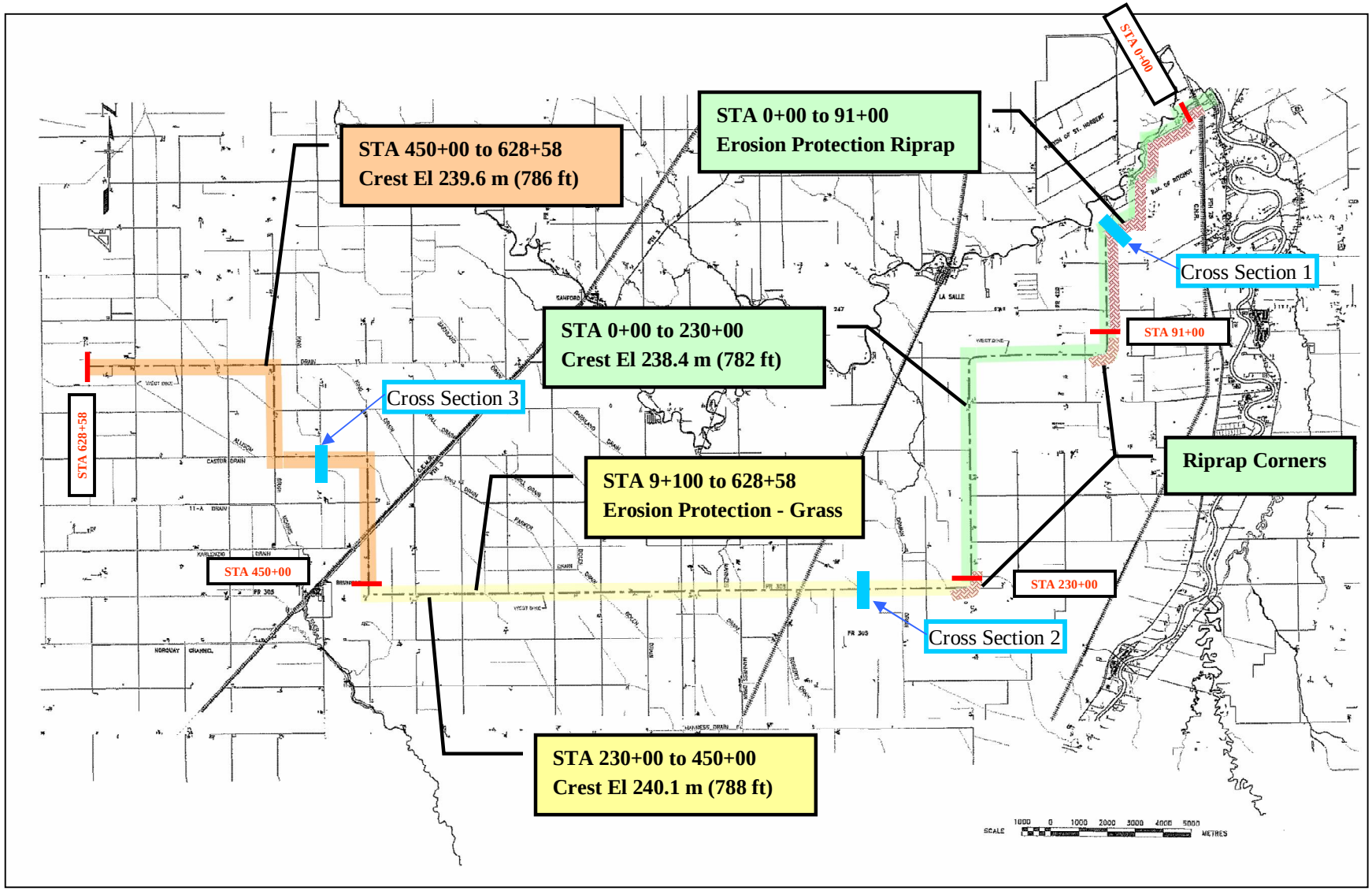
West Dyke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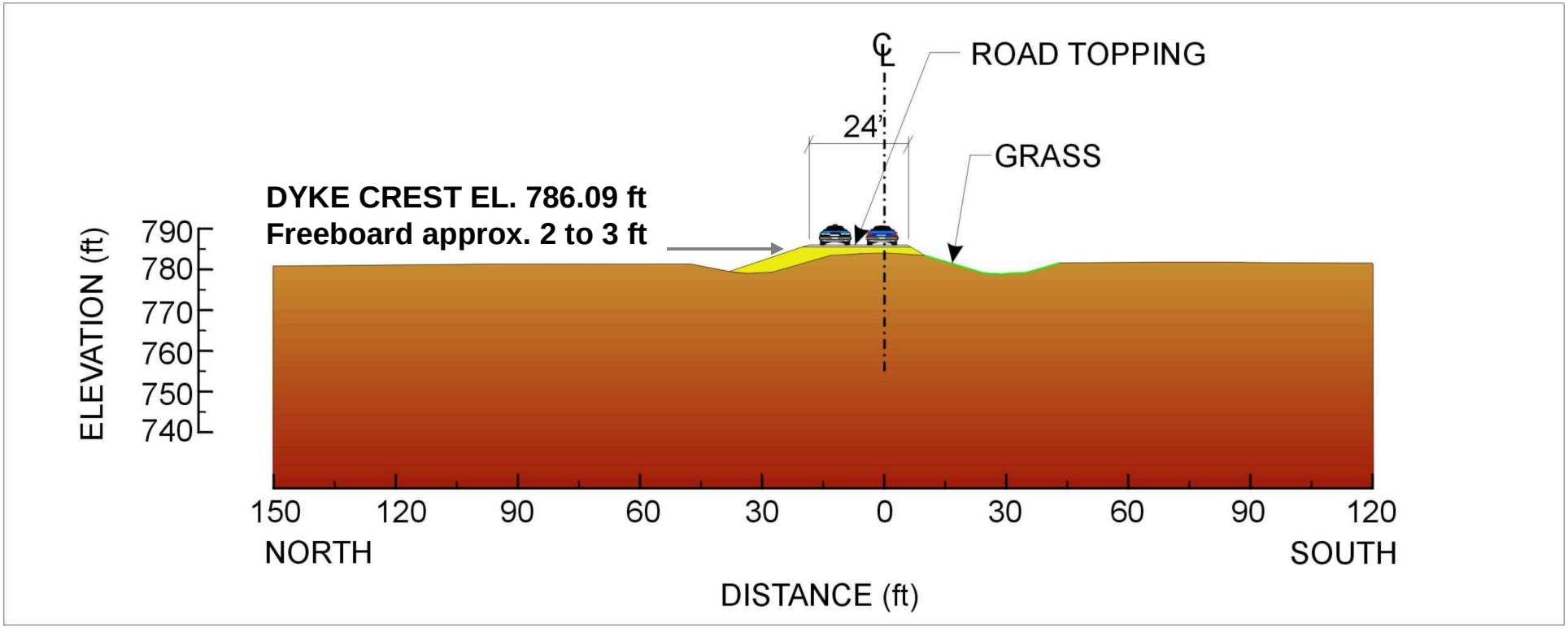
West Dyke – Section 3



KGS-Acres-UMA

Key Issues:

- 1. Emergency discharge capacity
- 2. Appropriate freeboard allowance

Emergency Discharge Capacity :

- ***SNC finding:*** “Additional discharge capacity could have value if in an emergency situation arising from..., it can be used to prevent upstream water levels from rising significantly above the design water levels at the Floodway entrance.”

Criteria for excess flow release:

- **Remote location**
- **Shallow depth of flow**
- **Reliable activation method**
- **No compromise of structure integrity**
- **Minimum initial cost**
- **Reparable damage acceptable**
- **Include means to re-establish river control**
- **Means to prevent premature activation**

Two Concepts

- Alternative 1 : ***Creation of breach***
- Alternative 2 : ***Construct overflow section***

1. Creation of Breach:

- Option 1 : ***Erodible "fuseplug" approach***
- Option 2 : ***Breach by mechanical means***

2. Erodible Fuseplug

- *Has drawbacks:*
- additional costs
- unreliable

1. Mechanical Activation

- *Preferable because:*
- reliable, has precedents
- low cost
- able to be closed during flood recession

Alternative 1 - Create breach

- ***Advantages:***
- low cost
- capacity adjustable
- no surcharge req'd: minimum risk of overtopping elswhere

- ***Disadvantages:***
- Active intervention
  - to start
  - to re-establish control

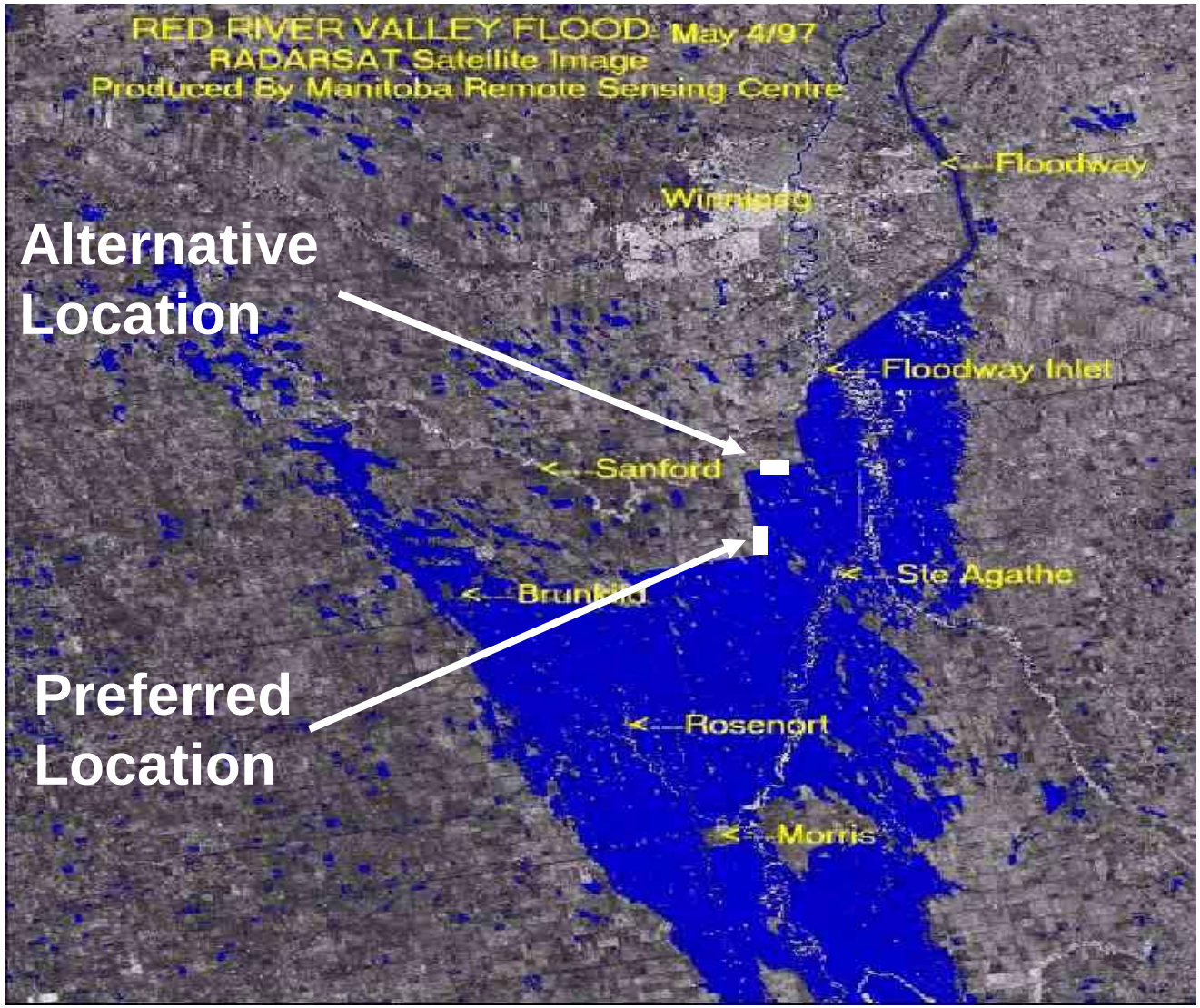
Alternative 2 : Overflow

- ***Advantages:***
- No action req'd to activate or re-establish control

- ***Disadvantages:***
- reservoir surcharge
- substantial cost
- may need Alt 1 anyways

Preferred Alternative:

- Mechanically Activated Breach



Freeboard at West Dyke

- Deficiency identified in review of flood risks for IJC (1999) : 1 to 4 ft.
- SAFE Study adopted :
  - 1 in 10 year wind coincident with peak of flood
  - Wind statistics based on window of 2 weeks in May - June

Implications of Overtopping of West Dike

- Major flooding in Winnipeg
- Probably considerable loss of life

Current Design Criteria

- 1 in 700 year flood event
- Superimpose 1 in 100 year wind event to determine wind setup, wave uprush

CDA Guidelines for Wind

- Non-flood conditions : wind speed with 1 : 1000 chance of being exceeded

- Flood conditions : 1 in 2 year wind speed coincident with peak of IDF

Options

1. As per SAFE Study (flood + wind)
2. Adopt extreme position
3. Adopt moderate position
4. Adopt a minimum position
5. Base on risk assessments

Option 1 :

- ***Standards- Based Selection (SAFE):***
- 1 in 700 year flood
- 1 in 10 year wind speed
- independent events
- Probability of simultaneous occurrence 1 in 7,000

Note on Wind Speeds

- ***1 : 2*** year for open water season equivalent to ***1 : 20*** year wind speed for 15 day window in May

Wind Speeds from South

- ***Based on analyses by Manitoba Water Stewardship:***
- 1 in 10 yr - 24 h - peak at 50 km/h
- 1 in 20 yr - 24 h - peak at 56 km/h
- 1 in 50 yr - 24 h - peak at 67 km/h
- *1 in 100 yr - 24 h - peak at 73 km/h*
- 1 in 1,000 yr - 24 h - peak at 80 km/h

Option 2 :

- ***Alternative Standards-Based Selection (extreme):***
- Extreme position from CDA Guidelines
- With loss of life, “PMF + 1: 20 yr wind”
- Say PMF ~ 1 in 100,000 (?)
- Combined probability of being exceeded of 1 in 2,000,000

Option 2 :

- With 1 in 700 year flood, equivalent probabilities are:
- 2,000,000 / 700 = 2,850 year wind speed

Option 2 :

- ***Wind Magnitude:***
- Caps at 1:100 year + 10% due to limit to probable maximum strength of pressure systems (MWS : Warkentin)

Option 3 :

- ***Used in PDEA pre-design of West Dyke (moderate design):***
- 1 in 700 yr flood
- 1 in 100 year wind (24 h) - 73 km/h

Option 4 :

- ***Alternative Standards-Based Selection (minimum protection):***
- Moderate position from CDA Guidelines:
- Non-flood situation, overtopping tolerated at 1:1000 year windspeed or greater
- I.e. limit of tolerance for loss of life is only 1 : 1000 ????
- So, then adopt 1000 / 700 = 1.4 years

Option 5

- ***Base on Risk Assessment :***
- probability of overtopping - % of waves
- probability of breach formation
- probability of flood magnitude
- damages due to breach formation
- cost of increments in freeboard

Summary of Standards-Based Options

	Option 1	**Option 2**	**Option 3**	**Option 4**
Flood Level	1:700 year	1:700 year	1:700 year	1:700 year
Wind Speed	1 in 10 year	1:1000 year +	1:100 year	1:1.4 year
Probability of Overtopping	1:7,000 year	1:700,000 year +	1 :70,000 year	1:1,000 year

Summary of Costs

	Option 1	**Option 2**	**Option 3**	**Option 4**
Direct Costs	$20 m	>$55 m	$43 m	~$15 m

Goal Today

- Get perspectives for MFA to consider for future direction