Report

HALIFAX GRAIN ELEVATOR – HALIFAX, NS

Land Use Risk Assessment Study

PREPARED FOR

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Halifax Regional Municipality
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Summary

The Halifax Grain Elevator is located in close proximity to established low and high-density residential land uses, and interest in residential development is expected to continue in the surrounding area. Grain elevators are considered high-hazard industrial occupancies under the National Fire Code of Canada and present an inherent dust explosion risk given the high quantities of combustible materials handled. Based on the adjacent land uses, the need was identified to perform a land use risk assessment study for the existing facility.

A quantitative risk assessment approach was employed by Jensen Hughes to estimate the risk posed to the public due to the operation of the grain elevator and the dust explosion hazards it presents. The risk assessment was conducted based on the worst-case dust explosion event identified for the facility. The dust explosion scenario was identified based on significant dust explosions that occurred at the SEMABLA grain storage facility in Blaye, France, and the DeBruce grain elevator in Wichita, Kansas in the 1990's (as described in Section 6 of this report). Stemming from an evaluation of these events, it was considered that the highest risk to the public in the surrounding area would result from a dust explosion that occurs within or propagates to one or more of the silos located in the outermost row on the western side of the facility.

The risk based approach was used to determine the individual risk to the public based on the event frequency and associated consequences. The frequency is representative of the probability of ignition resulting in a dust explosion event. The explosion frequency was determined based on the methodology outlined in the paper "A quantitative risk assessment tool for the external safety of industrial plants with a dust explosion hazard" (Klein et Al, 2006). The consequences represent the impact to the public and are based on probability of fatality due to the effects of the dust explosion. The explosion effects that were evaluated include: blast overpressure, fireball and thermal radiation, bulk outflow, and projectiles. An overview of the quantitative risk assessment process that was followed is shown in Figure I. The risk analysis methodology is presented in Section 7 of this report.

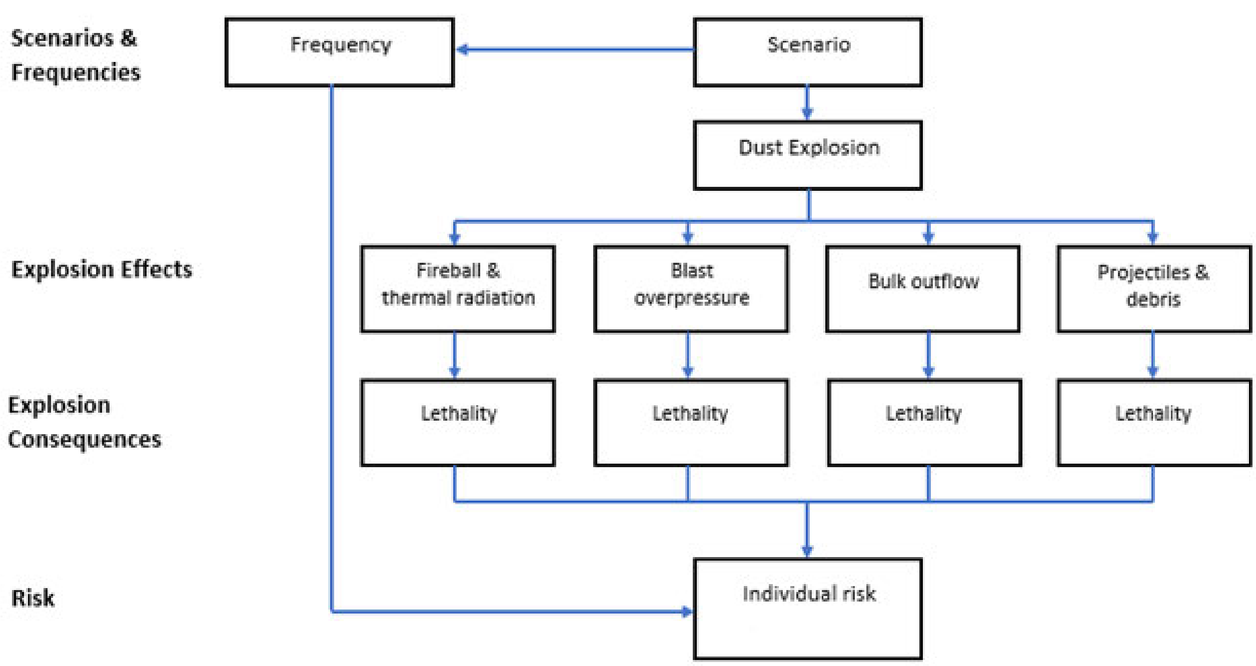


Figure I: Overview of the quantitative risk assessment process.

Stemming from completion of the risk assessment, the risk presented by each individual silo was estimated and a risk contour was developed. It is important to note that the risk posed to an unprotected person in the area surrounding the grain elevator is equivalent to the risk posed by all silos whose risk contours intersect the location of said person. As such, the cumulative risk posed to the public by a potential dust explosion event was estimated at five meter intervals (from 5 m to 120 m) extending outward from the exterior walls of the grain elevator. The cumulative risk was estimated by the risk contours from the adjacent silos on the exterior wall that intersect an imaginary zone placed central to the silos. A summary of the cumulative individual risk posed to the public in the external area surrounding the grain elevator is summarized in Figure II and Figure III. The Figures display the decay in risk as the distance from the facility is increased from 5 to 120 m. It is important to note that the figure shows the curves for the area surrounding Annexes 1-3 and the area surrounding Annex 4 as the risk associated with these areas varies due to the size and configuration of the silos. Within Figures II and III, the risk acceptance criteria for restricted, low-density, high-density, and sensitive land uses are shown. The risk assessment is documented in Section 8 of this report.

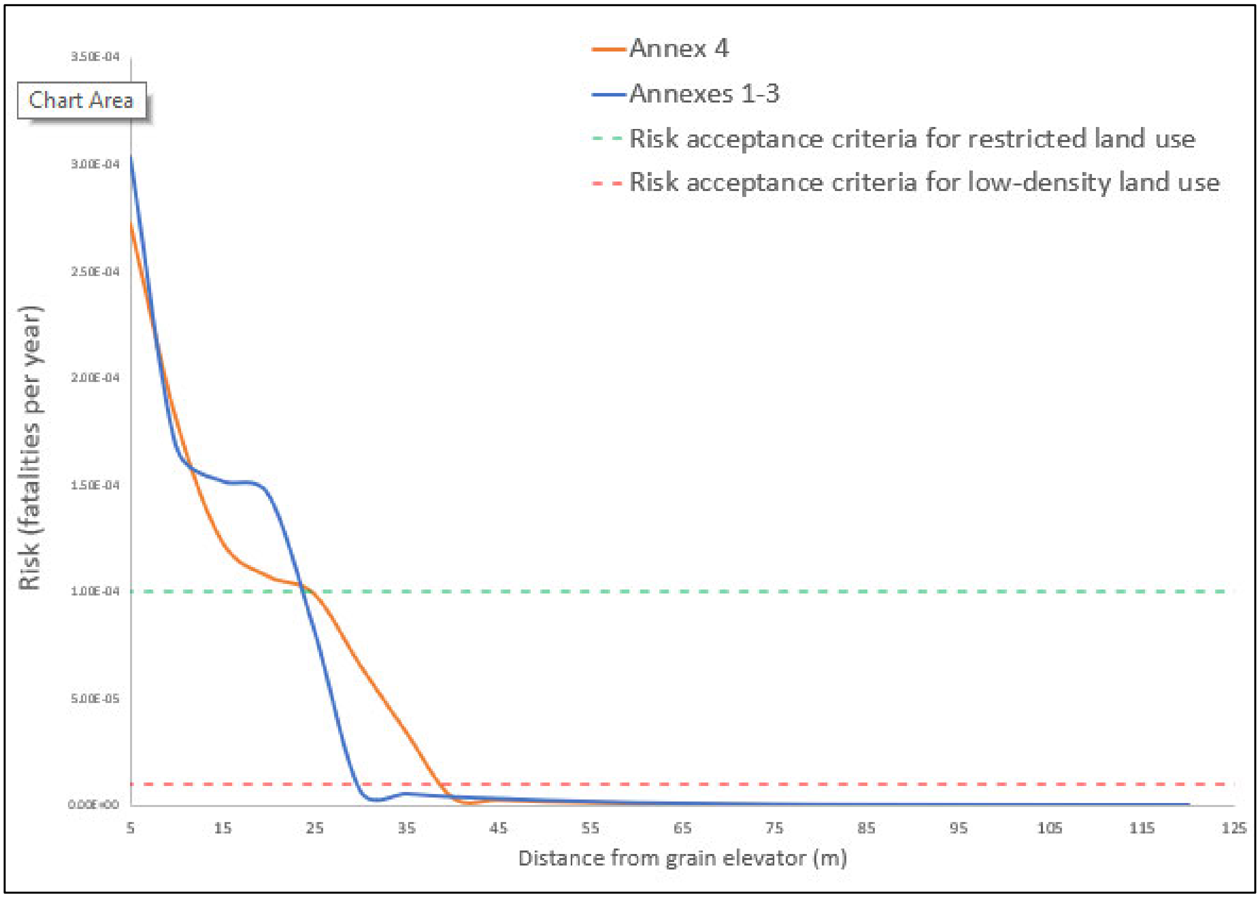


Figure II: Decay in individual risk at increasing distance surrounding the grain elevator (5 m to 120 m).

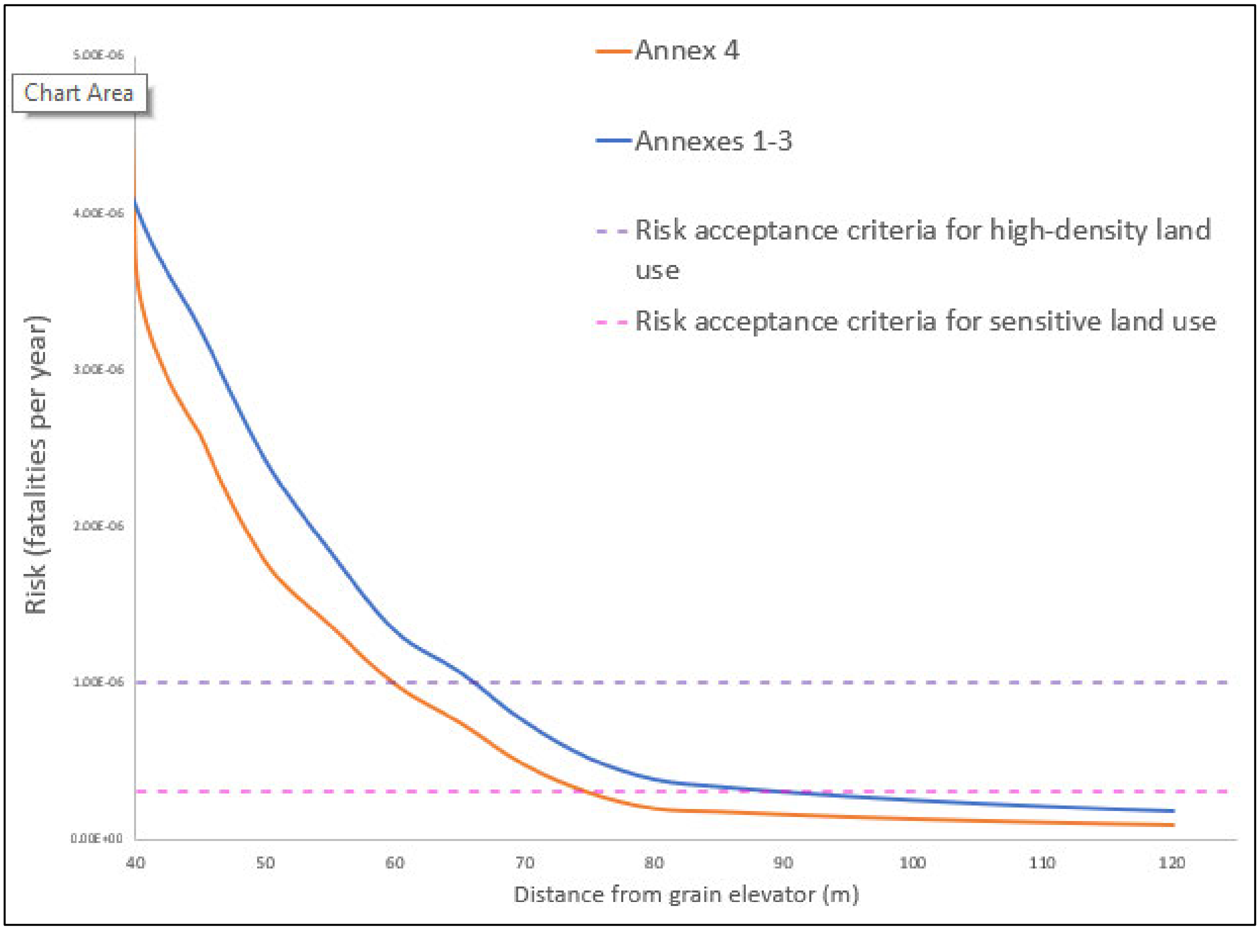


Figure III: Decay in individual risk at increasing distance surrounding the grain elevator (40 m to 120 m).

With respect to land use planning, risk acceptance criteria was obtained from the MIACC Risk-based Land Use Planning Guidelines. The guidelines outline acceptable levels of individual risk associated with specific land uses surrounding industrial facilities. The risk acceptance criteria outlined in the MIACC guidelines is summarized in Figure IV.

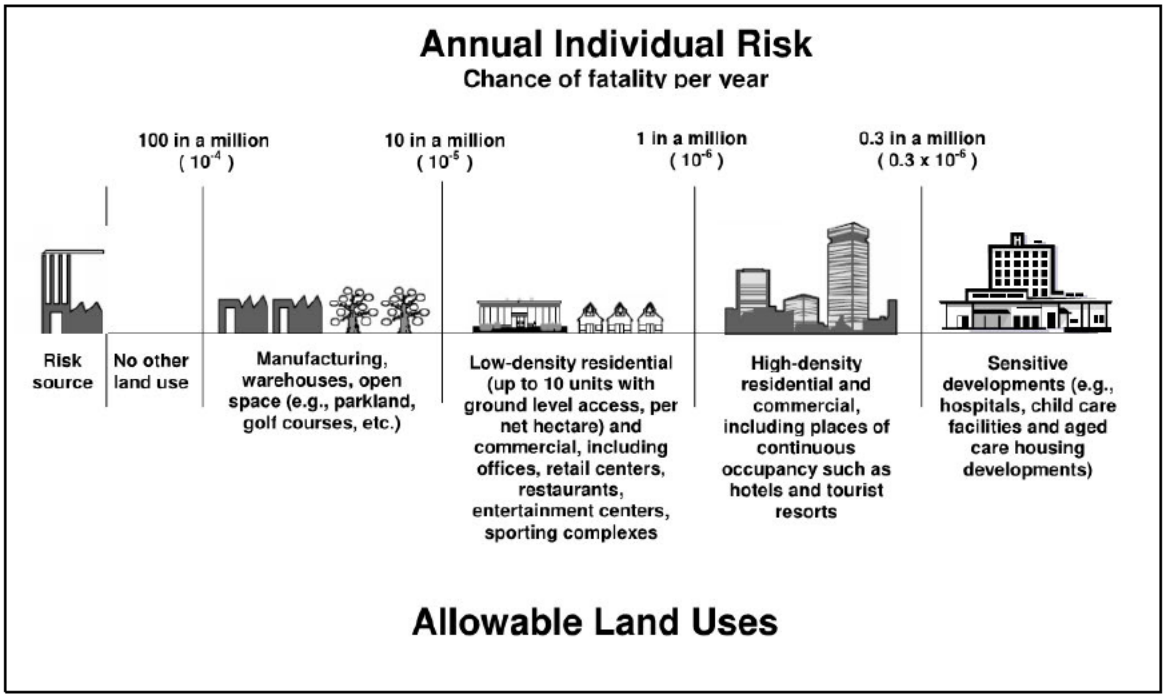


Figure IV. MIACC risk acceptance criteria for land uses adjacent to industrial facilities.

With respect to residential developments, the MIACC Guidelines outline that low-density residential uses are allowable in areas where the individual risk to the public is less than 1×10^{-5} fatalities per year while high-density residential developments are allowable in areas where the individual risk to the public is less than 1×10^{-6} fatalities per year. The risk acceptance criteria was used to identify required buffer zones between the Halifax Grain Elevator and adjacent land uses. A summary of the required buffer zones is outlined in Table I. Requirements for adjacent land uses are documented in Section 9 of this report.

Table I: Required buffer zones between the grain elevator and adjacent land uses based on MIACC guidelines.

Location	Allowable land use (MIACC)	Risk associated with allowable land use (fatalities/year)	Applicable distance (m)
Annexes 1-3	Restricted – no land use	$> 1.0 \times 10^{-4}$	0 – 25
	Manufacturing, warehouse, & parkland use	$< 1.0 \times 10^{-4}$	>25
	Low-density residential & commercial	$< 1.0 \times 10^{-5}$	>30
	High-density residential & commercial	$< 1.0 \times 10^{-6}$	>70
	Sensitive developments (hospitals, etc.)	$< 0.3 \times 10^{-6}$	>90
Annex 4	Restricted – no land use	$> 1.0 \times 10^{-4}$	0 – 25
	Manufacturing, warehouse, & parkland use	$< 1.0 \times 10^{-4}$	>25
	Low-density residential & commercial	$< 1.0 \times 10^{-5}$	>40
	High-density residential & commercial	$< 1.0 \times 10^{-6}$	>60
	Sensitive developments (hospitals, etc.)	$< 0.3 \times 10^{-6}$	>75

Based on the buffer zones outlined in Table I, a risk contour drawing was developed to demonstrate the required separation distances between the Halifax Grain Elevator and adjacent low-density residential, high-density residential, and sensitive land uses based on the individual risk to the public. The risk contour drawing is shown overlayed on a CAD drawing of the site map in Figure V. It is important to note that the contours shown on the drawings may not be to scale and are subject to a site survey. As shown on Figures V, all properties located within 100 meters of the facility have the potential to experience significant property damage in the event of an explosion. At increased distance, the potential for property damage is due to projectiles as discussed in Section 9 of this report.

Figure V: Site plan showing risk zones for restricted (green), low-density residential (red), high-density residential (blue), and sensitive (pink) land uses and the area with potential for significant property damage.

Any new residential land uses located in the vicinity of the grain elevator should be limited by the buffer zones and associated uses as outlined in Table I and Figure V. With respect to existing land uses, the primary concern is the Grainery Lofts development which is located within 10 meters of Annex 4 at its closest point as shown in Figure VI. The Grainery Lofts structure is located inside the buffer zone for high-density land uses with a portion of the building located inside the restricted zone. Other land uses of concern include a commercial use (Formac Publishing) which is partially located within the restricted zone and several houses (low-density residential) located on Blue Willow Court which are partially located within the restricted zone.

In Figure VI, the exterior boundary of the zone in which property damage has the potential to occur is identified by the black contour line for legibility.

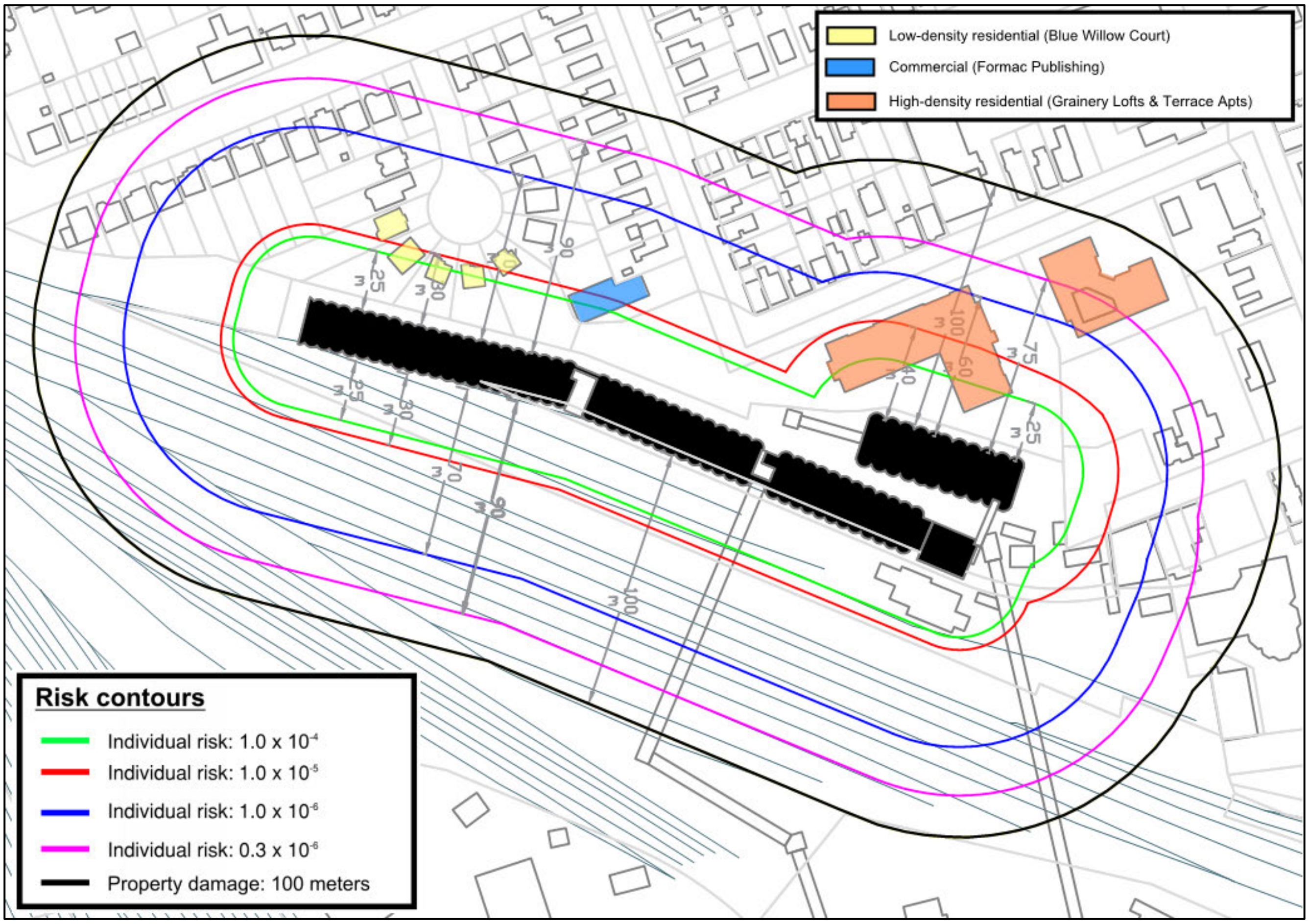
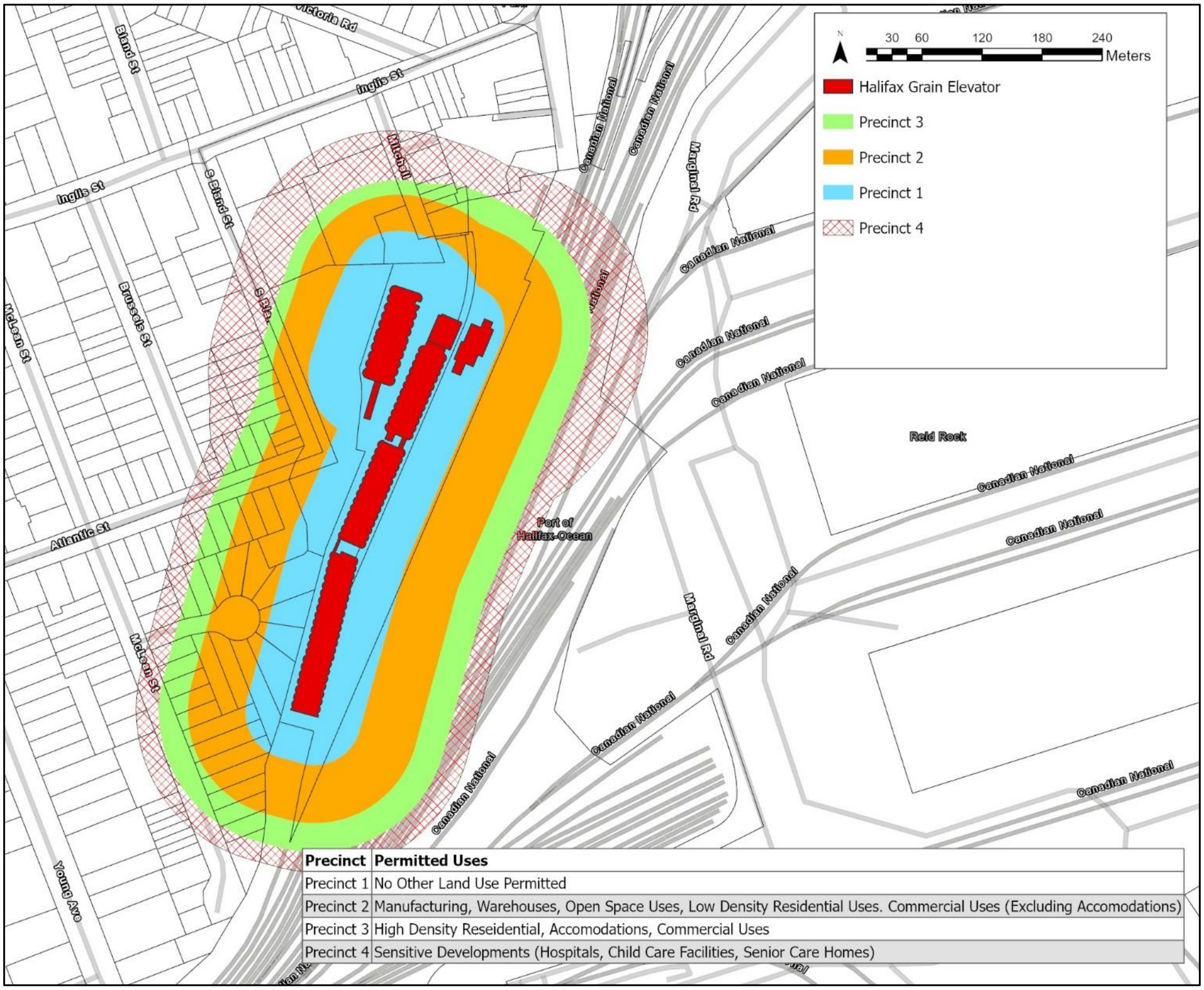


Figure VI: Low and high-density residential and commercial developments located in nonacceptable areas based on the MIACC risk acceptance criteria.

Stemming from completion of the land use risk assessment study, recommendations were offered with respect to dust hazard mitigation strategies and land use planning to reduce the risk to the public. These recommendations are outlined in Section 10 of this report. With respect to land use planning, three categories of recommendations were provided which include: establishing risk precincts, implementing build form guidelines for risk mitigation, and addressing non-conforming uses and structures. These recommendations are based upon the best practices for acceptable levels of risk. However, individual communities may have different acceptable levels of risk depending on demographic, economic, and sociological criteria, and therefore, final decision making pertaining to regulations within the Halifax Grain Elevator area should be developed in consultation with landowners and community members.

Separation of incompatible land uses remains the most effective risk mitigation strategy. Therefore, the primary recommendation is to adopt appropriate land use controls to exclude incompatible land uses in proximity to the Halifax Grain Elevator. Figure VII demonstrates how the land use precincts may be applied to lands in proximity to the Halifax Grain Elevator.



Precinct	Permitted Uses
Precinct 1	No Other Land Use Permitted
Precinct 2	Manufacturing, Warehouses, Open Space Uses, Low Density Residential Uses. Commercial Uses (Excluding Accomodations)
Precinct 3	High Density Reseidential, Accomodations, Commercial Uses
Precinct 4	Sensitive Developments (Hospitals, Child Care Facilities, Senior Care Homes)

Figure VII: Example of land use precincts surrounding the grain elevator.

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Acronyms & abbreviations

AHJ	Authority Having Jurisdiction
ALARP	As Low As Reasonably Practicable
CBA	Consequence Based Approach
CSA	Canadian Standards Association
CSCHE	Canadian Society of Chemical Engineers
COHSR	Canada Occupational Health and Safety Regulations
DHA	Dust Hazard Analysis
FEMA	Federal Emergency Management Agency
GEP	Good Engineering Practice
GSD	Generic Safety Distances
HGE	Halifax Grain Elevator
HGEL	Halifax Grain Elevator Limited
HPA	Halifax Port Authority
HRM	Halifax Regional Municipality
JH	Jensen Hughes
MIACC	Major Industrial Accidents Council of Canada
NBC	National Building Code of Canada
NFC	National Fire Code of Canada
NFPA	National Fire Protection Agency
OSHA	Occupational Safety and Health Administration
PSM	Process Safety Management
RBA	Risk Based Approach

Definitions

Acceptable level of risk	The determination by public authorities through a process involving industry and the public of levels of risk which are considered acceptable if all reasonably practical measures have been taken to reduce risks.
Buffer or transition zones	An area of land established around an industrial activity to separate other adjacent land uses, particularly residential areas, from the potential effects of an industrial accident. Buffer or transition zones are established through the determination of minimum separation distances between various land uses and through the determination of "buffer" land uses within these areas.
Combustible dust	A finely divided combustible particulate solid that presents a flash fire hazard or explosion hazard when suspended in air or other oxidizing medium over a range of concentrations. The NFPA standards outline a size criterion of 500 micrometer as the threshold for combustible dust.
Dust deflagration	A combustion that propagates by heat and mass transfer through the unreacted medium (combustible dust) at a velocity less than the speed of sound.
Dust explosion	A rapid combustion of dust particulate suspended in air within an enclosed location that results in a release of energy that causes a pressure discontinuity or blast wave. A dust explosion event will often result in the burst or rupture of an unprotected enclosure.
Dust hazard analysis (DHA)	A systematic review to identify and evaluate the potential fire, flash fire (deflagration), or explosion hazards associated with the presence of one or more combustible particulate solids in a process or facility.
Enclosure burst pressure	The maximum overpressure that an unprotected enclosure can withstand before structural failure or rupture.
Event frequency	The number of occurrences of an event per unit time (e.g., 1 event in 1000 years = 1×10^{-3} events per year).
Event consequence	The potential outcome of the event often expressed in terms of human fatality.
Good engineering practice (GEP)	Proven and accepted engineering methods, procedures, and practices that provide appropriate, cost-effective, and well-documented solutions to meet user-requirements and compliance with applicable regulations, safety, environments protection, and operability. GEP is defined as a combination of standards, specifications, codes, regulatory and industrial guidelines as well as accepted engineering and design methods.
Hazard	A condition with the potential for causing an undesirable consequence.
Individual risk	The annual frequency at which an individual may be expected to sustain a given level of harm (i.e. death) from the realization of specified hazards.
Maximum pressure (P_{max})	The maximum pressure developed in a contained deflagration of an optimum mixture.
Minimum separation distances	A distance to be maintained between different land uses or constructions. The separation distance determines the width of a buffer zone.
Probit	A unit of probability based on deviation from the mean of a standard distribution.

Probit functions	Probit functions account for the variation in tolerance to harm for an exposed population. The fatality rate of personnel exposed to harmful agents over a given period of time can be calculated by use of probit functions and probit transformation tables.
Reduced pressure	The maximum pressure developed in a vented enclosure during a vented deflagration.
Risk	A measure of the frequency and severity of an adverse effect due to a hazard.
Risk assessment	The characterization of the likelihood and importance of risks.
Risk contour	A contour around a hazardous site connecting locations with equal probability of risk. The contours usually represent powers of 10, i.e., 1 chance in 1000 (10^{-3}) per year of fatality, 1 chance in 10,000 (10^{-4}) of fatality per year, etc.

1.0 Introduction

The Halifax Grain Elevator is located at 951 South Bland Street in Halifax, Nova Scotia. The grain elevator is situated on land owned by the Halifax Port Authority (HPA) and is leased to Halifax Grain Elevator Limited (HGEL) who operates the facility. The grain elevator was constructed as part of a larger development project, known as the Ocean Terminals Complex. The main facility consists of four annexes with the Halifax Port Ocean Terminals located to the east and residential and commercial developments located on the west side. The existing structure was built in progressive stages with Annex 1 being constructed in 1923, Annex 2 in 1929, Annex 3 in 1953, and Annex 4 in 1966. The structure currently acts as a divide between the residential and industrial uses of the southern portion of the Halifax waterfront. Figure 1.1 shows a photograph of the east side of the grain elevator facility.

Figure 1.1: Photograph of the eastern side of the grain elevator site facility.

The grain elevator is currently used for bulk storage of various agricultural grains and wood pellets that are transported to the facility from external sources. The existing facility contains a combination of 365 silos and intermediate bins that provide a total storage capacity of approximately 140,000 tons of wheat. Given the high quantities of combustible material that are handled, grain elevators are considered high-hazard industrial occupancies (Group F, Division 1) under the National Building Code of Canada (NBC). It is known that agricultural grain dusts are explosive in dust cloud form under certain conditions. As such, grain elevators pose potential combustible dust fire, deflagration, and explosion hazards. If combustible dust hazards are not adequately managed, it could result in a significant dust explosion event that could have a severe impact on the facility and the surrounding area.

Established low and high-density land uses are present on the western side of the facility. The adoption of the Regional Centre Municipal Planning Strategy and Land Use Bylaw in 2021 has resulted in a more permissive land use planning context than what has previously been applied to properties in proximity to the Halifax Grain Elevator. Under the Regional Centre Plan framework and applied land use zoning, a higher intensity of residential development is permitted in the area. This change in land use permission coupled with a low vacancy rate in the area, has spurred an interest in higher intensity residential development in the area, which is expected to continue.

In the event of a large scale dust explosion event, there is the potential that the explosion could impact existing and new developments located in the external area and present a significant risk to the public. Given the potential hazards associated with operation of the grain elevator, further study was needed to better understand and manage potential public safety risks and incompatible uses associated with the elevator and its proximity to residential and institutional uses. As such, Jensen Hughes was engaged by the Halifax Regional Municipality (HRM) to perform a land use risk assessment study for the external area surrounding the grain elevator.

The land use risk assessment study was conducted to determine the allowable land use surrounding the grain elevator based on the Major Industrial Accidents Council of Canada (MIACC) Guidelines [1]. To determine the allowable land use in accordance with the MIACC, a quantitative risk assessment was conducted for the worst-case dust explosion event that has the potential to affect the surrounding area. This report completely documents all work that was performed as part of the land use risk assessment study and is organized as follows:

- Section 1 provides an introduction, outlines the scope of work and objectives, and identifies the project team.
- Section 2 gives a description of the grain elevator site, facility layout and a process description.
- Section 3 includes a review of the current state of the grain elevator and highlights the current operations and the findings of the DHA that was completed by Jensen Hughes.
- Section 4 gives an overview of regulatory analysis for grain elevators and other industrial facilities that present a similar level of hazard to the surrounding area. The regulatory analysis includes an overview of best practices with respect to dust hazard mitigation and land use planning.
- Section 5 provides an overview of the MIACC Risk-based Land Use Planning Guidelines and associated risk acceptance criteria.
- Section 6 identifies the worst-case dust explosion that has the potential to occur based on loss-history data and operational knowledge of grain elevators.
- Section 7 describes the risk assessment methodology employed to conduct the analysis.
- Section 8 documents the findings of the risk analysis and presents the risk contours.
- Section 9 outlines land use planning requirements stemming from completion of the risk assessment and development of the risk contours and buffer zones.
- Section 10 provides recommendations with respect to combustible dust hazard mitigation and land use planning.
- Section 11 outlines assumptions and limitations.
- Section 12 provides conclusion to the report.
- Section 13 outlines the references used to develop this report.
- Appendices A through D provide supplemental information, calculations, and design drawings referenced throughout this report.

1.1 SCOPE OF WORK

The scope of work for this project included performing a land use risk assessment study for the existing Halifax Grain Elevator facility. The purpose of the study is to identify the minimum separation distances (buffer zones) surrounding the grain elevator that are required to separate adjacent land uses (particularly new residential uses) from the potential consequences or effects of an industrial accident. With respect to the grain elevator, the industrial accident is represented by a large-scale dust explosion.

The allowable land uses surrounding the grain elevator are based on the acceptable level of risk outlined in the MIACC Risk Based Land Use Planning Guidelines [1]. To determine the level of risk posed to the public in the external area surrounding the grain elevator, a quantitative risk assessment was conducted to evaluate the risk that would be presented by the worst-case dust explosion event.

1.2 GOALS AND OBJECTIVES

The scope of work for this project was achieved by completing the following primary objectives:

+ The basis for acceptable risk to the public and allowable land uses was identified based on the criteria outlined in the MIACC Risk-based Land Use Planning Guidelines.
+ A credible design event (dust explosion scenario) that is expected to present the highest level of risk to the public was identified based on loss history for grain elevator facilities of a similar scale.
+ A quantitative risk assessment was conducted based on the design event to identify the event frequency and severity of the consequences. The risk assessment was used to identify the risk posed to the public in the areas surrounding the grain elevator. Risk contours were developed stemming from completion of the risk assessment.
+ Based on the MIACC Guidelines and the findings of the risk assessment, the minimum separation distances between the grain elevator and adjacent land uses (residential, commercial, sensitive, etc.) were identified. The separation distances were expressed on contour maps to demonstrate the required separations and identify appropriate locations for new residential and commercial developments.
+ Stemming from the findings of the risk assessment, recommendations on land use planning mitigation strategies such as zoning, setbacks, land use controls and built form safety features were provided.

1.3 PROJECT TEAM

The team for the land use risk assessment study consisted of individuals from the Halifax Port Authority, Halifax Regional Municipality, Jensen Hughes, and ZZAP Architecture + Planning. Table 1.1 lists the individuals who participated in the project.

Table 1.1: List of project participants.

Company	Name
Jensen Hughes (JH)	Adrian Pierorazio, P.Eng., CFEI, FEC Martin Clouthier, M.Sc., P.Eng. Parker MacNeil, P.Eng.
Halifax Port Authority (HPA)	Darlene Page, CLO
Halifax Regional Municipality (HRM)	Ross Grant, MCIP, LPP Ben Sivak, MCIP, LPP
ZZAP Architecture + Planning (ZZAP)	Chris Markides, MCIP, LPP

Jensen Hughes was responsible for conducting the risk assessment while ZZAP was responsible for the scope of work related to land use planning. HRM and HPA were responsible for providing information that was used in completion of the analysis.

2.0 Facility & process description

2.1 SITE LAYOUT

The Halifax Grain Elevator is located at 951 South Bland Street in Halifax, Nova Scotia with the Halifax Port Ocean Terminals located to the east and residential and commercial developments located on the west side. The land that the facility is located on is currently owned by the Halifax Port Authority and is leased to Halifax Grain Elevator Limited. The main structure consists of four annexes used for material storage that were built in progressive stages with Annex 1 having been constructed in 1923, Annex 2 in 1929, Annex 3 in 1953, and Annex 4 in 1966. At the time of its construction, the southern portion of the Halifax Waterfront was predominantly dedicated to industrial land uses. However, in recent years, the buffer between the grain elevator and its neighboring residential developments has significantly declined with the construction of the Grainery Lofts development and multiple single-family houses. As shown in Figure 2.1, the grain elevator abuts established residential areas to the west with the closest structure being the Grainery Lofts apartment building.

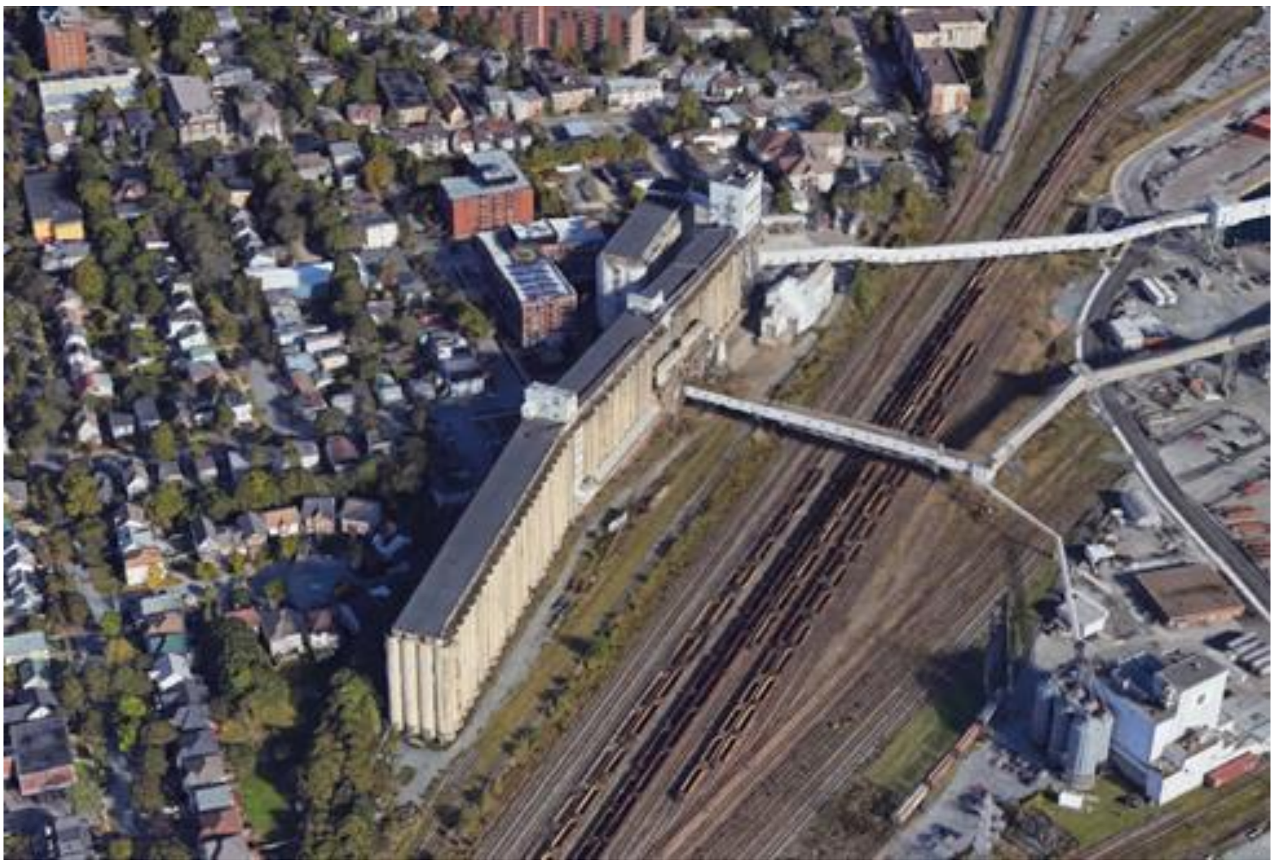


Figure 2.1: Image of the grain elevator site facing north (obtained from Google Earth).

The structure is located at an imaginary border between the residential and industrial uses of the southern portion of the Halifax waterfront. Low and high-density residential developments and neighborhoods are situated on the western side of the facility with some commercial and institutional uses intermingled within the area. Additional residential and commercial uses are located on the north side of the facility where Barrington Street meets Inglis Street.

Existing land uses surrounding the grain elevator are highlighted on the map shown in Figure 2.2. The complete map is shown in Appendix C.

Figure 2.2: Existing land uses surrounding the Halifax Grain Elevator.

As shown in Figure 2.2, established low-density residential developments are located on the western side of the facility with the closest developments being located along South Bland Street, Atlantic Street, McLean Street, and Blue Willow Court. The established high-density residential developments in close proximity are located on South Bland Street and include the Grainery Lofts and The Terrace Apartments.

The Grainery Lofts is a six-story multi-unit apartment building that was constructed in 2012. The building is a high-density land use and directly abuts Annex 4 of the grain elevator. In some areas, the building is less than 10 meters from the Annex 4 silos.

2.1.1 Halifax peninsula policy and zoning summary

Prior to the adoption of the Regional Centre Planning Strategy, the Halifax Grain Elevator was located in the South End Detailed Plan Area of the Halifax Peninsula Municipal Planning Strategy. Designated as Industrial land, there was little reference to the Halifax Grain Elevator specifically, though compatibility and mitigation of industrial uses abutting residential was to be considered during the review of development proposals. Similarly, the residential objectives outlined in the Halifax Peninsula Municipal Planning Strategy required residential uses to be buffered from non-residential uses as demonstrated in the following excerpt from the document: "1.2 Residential uses should be buffered from non-residential uses which are inappropriate to a stable, healthy, enjoyable living environment."

The Halifax Grain Elevator was zoned Industrial (C-3) in the Halifax Peninsula Land Use Bylaw. Table 2.1 outlines the specific requirements of the zone, including the setbacks for development abutting residential uses. Low and medium density residential were permitted in this zone, alongside various industrial uses unless they created a nuisance or hazard to neighboring residential zones.

Table 2.1: Halifax Land Use Bylaw industrial zone requirements.

C-3 Zone	Requirement
Max. building height	Dependent upon use
Min. front/flank setback	25 ft when abutting city street opposite a residential zone
Side setback	25 ft where adjacent to a residential zone
Rear setback	No rear setback

The zones applied to the lands surrounding the Halifax Grain Elevator consisted of a variety of residential, including R-1, R-2, R-3, RC-3, and a business service zone, C-3A, that also permitted residential uses. Buffering between residential and non-residential uses, while mentioned above in the Halifax Peninsula Municipal Planning Strategy, was not a requirement in any of the residential zones.

It is important to note that the municipality has no jurisdiction over Provincial and Federal government owned properties. While the municipality may apply land use planning regulations on these properties, higher levels of government are under no obligation to abide by them.

2.1.2 Regional center planning policy and zoning summary

In the Regional Centre Secondary Municipal Planning Strategy, Policy ED-6 groups multiple lots abutting the Halifax Grain Elevator into a Special Area, permitting residential development only by development agreement. This is meant as a precautionary measure to assess development proposals against risk assessment studies associated with the Halifax Grain Elevator. Figure 2.3 highlights the Grain Elevator Special Area and applicable zoning for the area.

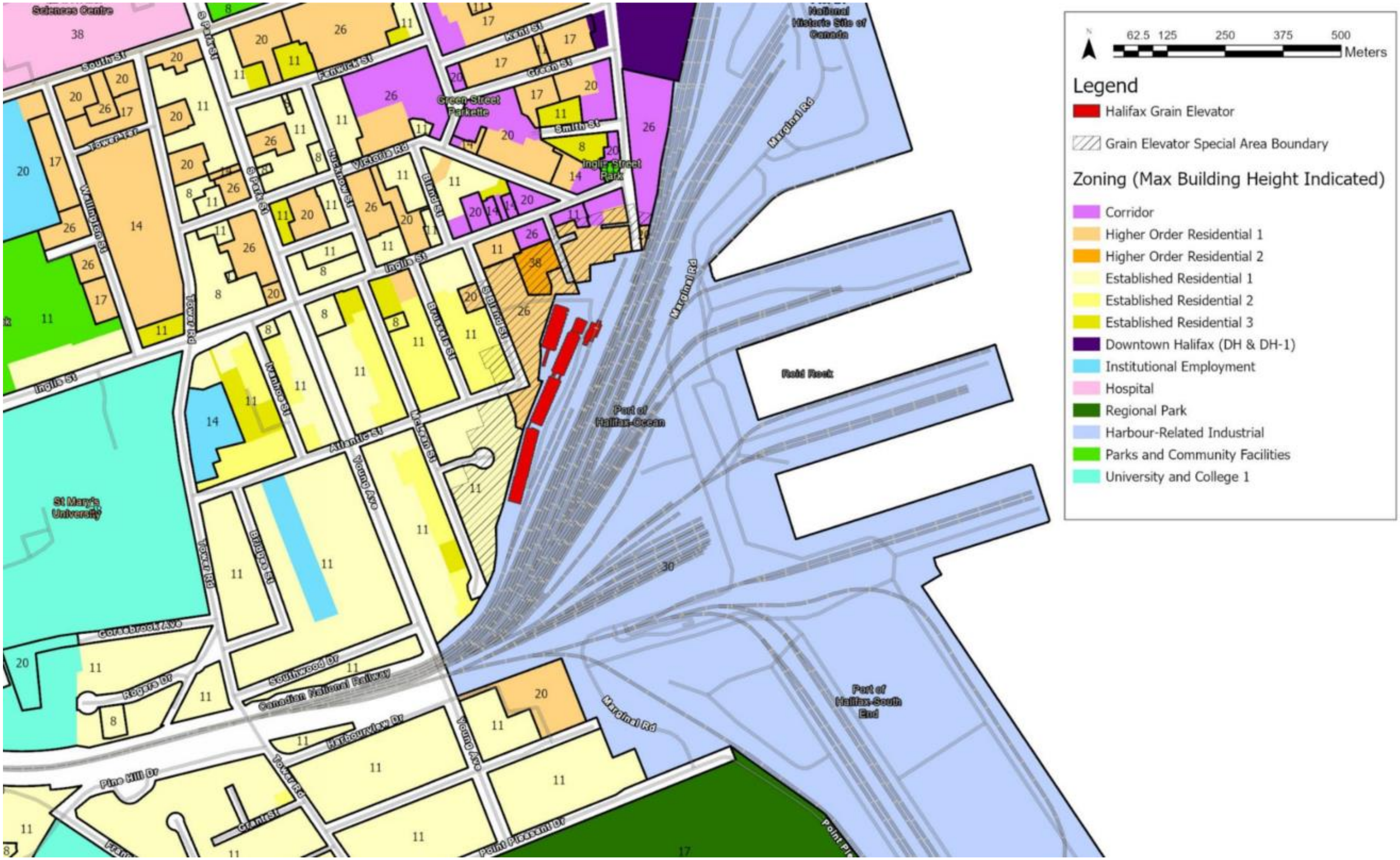


Figure 2.3: Regional Center land use bylaw zoning.

In this Special Area, there is an underlying mix of Higher Order Residential (HR-1 & HR-2) zones and Established Residential (ER-1 & ER-2) Zones and any proposed development must conform to the requirements of the applicable zone. Table 2.2 outlines the general zoning requirements for each adjacent zone. A range of residential uses are permitted by development agreement, including single-unit, semi-detached, townhouse, two-unit, three-unit, multi-unit dwellings.

Table 2.2: Residential zone requirements.

	HR-1	HR-2	ER-1	ER-2
Max. building height	26m	38m	11m	11m
Min. front/flank setback	1.5m	1.5m	2m	2m
Side setback	3m abutting low rise ER-1, 2.5 m elsewhere	3m abutting low-rise ER-1, 2.5m elsewhere	No setback requirement	1.25m
Rear setback	6m from lot-line abutting ER-1, ER-2, 4.5m for tall-mid-rise buildings, 3m elsewhere	6m from lot-line abutting ER-1, ER-2, 4.5m for tall-mid-rise buildings, 3m elsewhere	6m	6m

There are no landscape buffers or extended setbacks required for new residential developments abutting industrial zones. Instead, buffering between industrial and residential zones is the responsibility of development in industrial zones only, through the use of building setbacks, as outlined in Table 2.3 below.

Table 2.3: HRI zone requirements.

HRI Zone	Requirement
Max. building height	30m
Min. front/flank setback	7.5m if across a street from any HR-2, HR-1, ER-1, ER-2, ER-3 zone
Side setback	10m where a lot line abuts an HR-2, HR-1, ER-1, ER-2, ER-3 zone
Rear setback	10m where a lot line abuts an HR-2, HR-1, ER-1, ER-2, ER-3 zone

2.2 FACILITY OVERVIEW

The grain elevator functions as a bulk storage facility for various agricultural grains and wood pellets and has the capacity to store approximately 140,000 tons of wheat. The main structure is comprised of the four annexes that are oriented in a north-south direction with Annexes 1 and 4 being located adjacent to one another on the north end of the facility and Annexes 2 and 3 being located to the south. In addition to the annexes, a receiving building is located on the eastern side of Annex 1 along with the receiving and shipping galleries. The receiving and shipping galleries are connected to marine terminals for ship loading and unloading purposes. The receiving gallery is connected to Annex 1 workhouse while the shipping gallery is connected to the Annex 3 workhouse. A simplified diagram of the grain elevator that outlines the various structures and building areas is shown in Figure 2.4.

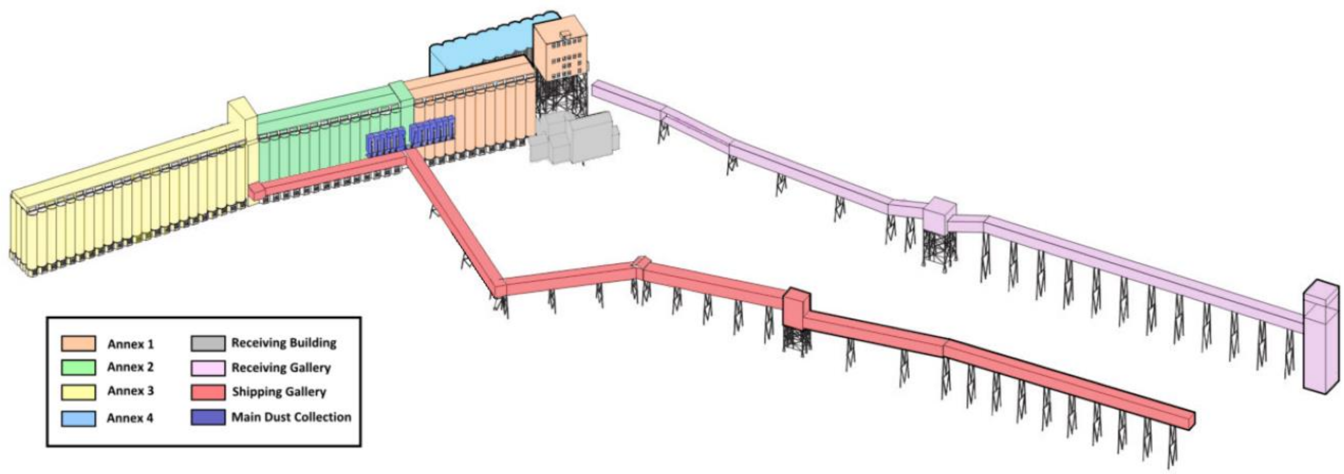


Figure 2.4: Simplified site diagram highlighting the various sections of the facility.

The structure of each annex is composed primarily of the silos and intermediate bins used for material storage. The silos are reinforced concrete structures approximately 33 meters in height and are configured in rows of four cells running the length of each annex. The intermediate bins are located in the interstitial located between the silos. A total of 210 silos and 155 intermediate bins are located throughout Annexes 1-4. The silos in Annex 4 have metal cones.

Bin level galleries are located above the groups of silos and extend the length of each annex. The galleries contain the bin level belt conveyors and associated process equipment used for transporting material to the silos. The gallery floors consist of concrete slabs comprising the tops of the silos. The gallery roof and walls are also constructed from concrete with windows and vent openings running the length of each gallery along the exterior walls. The bin level galleries in Annexes 1-3 have ceiling heights of approximately 10-feet and are approximately 46-feet wide. The lengths of the bin level galleries range from approximately 210-feet (Annex 1) to 420-feet (Annex 3). The Annex 4 bin level gallery has a ceiling height of 12-feet in the main area, a width of approximately 52-feet and a length of approximately 225 feet. Photographs of the Annex 1 bin level gallery are shown in Figure 2.5. It should be noted that the gallery roof in Annex 4 is constructed from steel.


Figure 2.5: Exterior (left) and interior (right) of the Annex 1 bin level gallery.

Basement level galleries are situated below the groups of silos and are constructed primarily of concrete with windows and vent openings located along the exterior walls. The basement level galleries are used to transport bulk material discharged from the silos and intermediate bins using belt conveyors and other process equipment. The basement level galleries have the same length and width as the bin level galleries. However, the ceiling heights vary throughout each basement level gallery. Photographs of the exterior of the Annex 2 basement gallery and interior of the Annex 3 basement level gallery are shown in Figure 2.6.


Figure 2.6: Exterior of Annex 1 basement gallery (left) and interior of Annex 3 basement gallery (right).

Annexes 1-3 have workhouse areas that contain bucket elevators, garners, weigh scales, and other process equipment used to transport incoming and outgoing materials. Workhouse #1 consists of a tower located at the north end of the facility and is connected to Annexes 1 and 4 via galleries. Workhouses #2 is located between Annexes 1 and 2 while Workhouse #3 is located between Annexes 2 and 3. The workhouse areas consist of multiple levels and floors containing various process equipment. Photographs of the exteriors of Workhouse #1 and Workhouse #2 are shown in Figure 2.7.


Figure 2.7: Workhouse #1 tower (left) and Workhouse #2 area (right).

The grain elevator utilizes various process equipment to tranport and store material throughout the facility which includes, but is not limited to, bucket elevators, garners and weigh scales, belt conveyors, silos and intermediate bins, and dust collection systems. A schematic of a grain elevator facility similar to the Halifax Grain Elevator is shown in Figure 2.8.

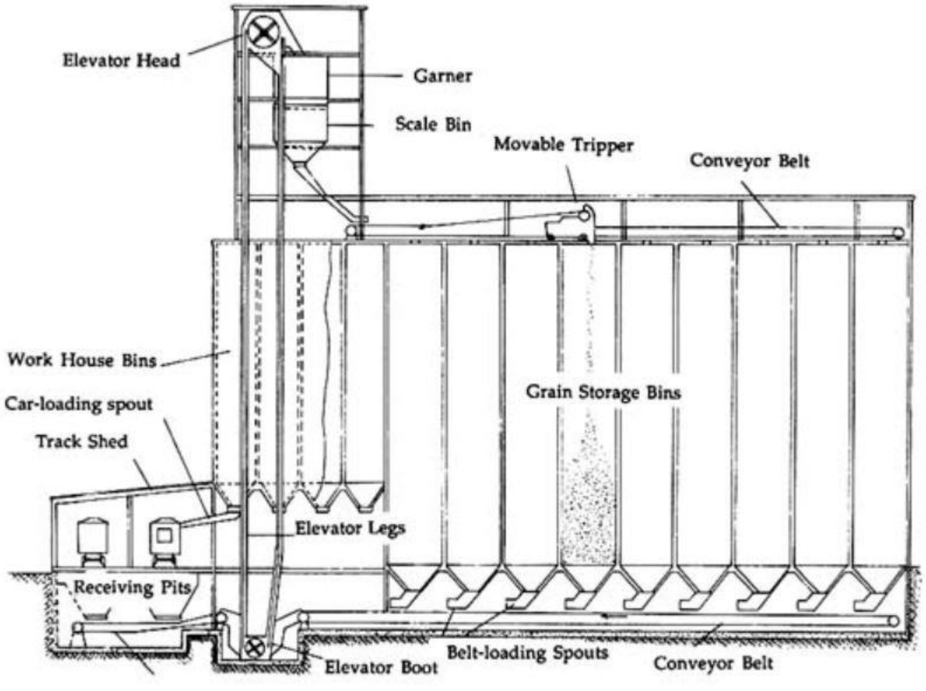


Figure 2.8: Schematic of a typical grain elevator facility.

An overview of the main process equipment that is located within the facility is shown in Table 2.4. It should be noted that the table does not include all process equipment located within the facility.

Table 2.4: Overview of main process equipment located in the facility.

Building section	Process equipment	Status
Annex 1	Bucket elevators (S1, S2, R1, R2)	Operational
	Upper garners & weigh hoppers (S1, S2, R1, R2)	Operational
	Basement & bin level belt conveyors	Operational
	Silos (50) & intermediate bins (33)	Operational
	Dust fines reclaim baghouse	Decommissioned
Annex 2	Bucket elevators (S5, S6)	Decommissioned
	Upper garners, weigh hoppers & shipping garners (S5, S6)	Decommissioned
	Basement & bin level belt conveyors	Operational
	Silos (56) and intermediate bins (39)	Operational
	Pneumatic system to P&H Milling	Operational
Annex 3	Bucket Elevators (S7, S8)	Operational
	Upper garners, weigh hoppers & shipping garners (S7, S8)	Operational
	Basement & bin level belt conveyors	Operational
	Silos (92) & intermediate bins (66)	Operational
Annex 4	Basement & bin level belt conveyors	Operational
	Silos (12) & intermediate bins (17)	Operational
Receiving/Loading Building	Receiving hoppers (100 ton & 50 ton)	Operational
	Tunnel belt & disc conveyors	Operational
	Railcar & truck loading hoppers	Operational
Receiving Gallery	Ship unloading hopper, dust collector and conveyor	Operational
	Marine tower bucket elevator	Operational
	Baghouse #1 (services bucket elevator)	Operational
	A-Tower belt, B-Tower belt	Operational
Shipping Gallery	Baghouses #15, #16, #17, #18	Operational
	H-belt, G-belt, F-belt, E-belt and loading spouts	Operational
Dust Collection	Baghouses #2 – #14	Operational
	Drag chain conveyor	Operational
	Bucket elevator	Operational
	Dust storage tanks	Operational

2.3 PROCESS DESCRIPTION

The following sections provide a summary of the process flow within the grain elevator.

2.3.1 Receiving building and receiving gallery

Materials are transported to the facility by railcars and trucks and are unloaded in the receiving building into the two receiving hoppers (100-ton and 50-ton capacities). The material is fed through ladder gates to tunnel belt conveyors. The tunnel belts have the capacity to transfer 500–550 tons of grain per hour and convey the material to the basement of Annex 1 where the material is transferred to the R1 and R2 bucket elevators. Figure 2.9 shows a simplified block flow diagram for the truck/railcar unloading operations.

Figure 2.9: Simplified block flow diagram for the truck/railcar unloading operations.

Grain can also be transferred to the facility via the Receiving Gallery. Ships unload grain into an unloading hopper located in the Marine Tower. The grain is gravity fed from the hopper into the marine leg bucket elevator that transfers the material to the B-Tower and A-tower belts and to a three-way splitter. From the splitter, the material is gravity fed through chutes and transferred to the R1, R2, or S2 bucket elevators. It should be noted that the receiving gallery (marine vessel unloading) is only used one or two times per year and only handles grains. Based on information provided by HGEL, when using the receiving gallery, the unloading rate is approximately 1140 metric tons per hour. Figure 2.10 shows a simplified block flow diagram for the receiving gallery operations.

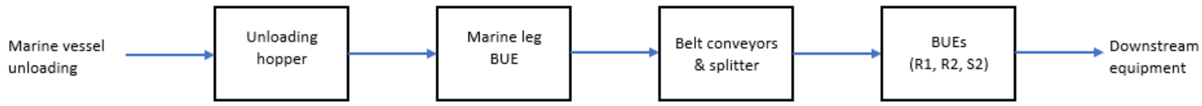


Figure 2.10: Simplified block flow diagram for receiving gallery operations.

2.3.2 Inward material flow

Grain and wood pellets from the receiving gallery and unloading hoppers are transferred to the R1, R2, and S2 bucket elevators in the basement of Annex 1. The bucket elevators transfer the material vertically to the top level of Workhouse #1 where the material is discharged into the Upper Garners. The material is held within the upper garners before being gravity fed to the weigh hoppers which operate as scales and weigh the material before it is transferred downstream. The material is discharged from the weigh scales to a system of interconnected bin floor belt conveyors that are used to transfer the material to the desired Annex. When the material reaches the desired Annex, movable trippers are utilized to transfer the material from the belt conveyors into the desired silo or intermediate bin through floor grates. The materials are then stored in the silos and intermediate bins until they are ready to be shipped.

Based on information provided by HGEL, the wood pellets are contained primarily in the Annex 3 silos with some stored in the Annex 1 silos. It should be noted that the wood pellets are only stored within silos and are not stored in the intermediate bins. Figure 2.11 shows a simplified block flow diagram for the inward material flow.

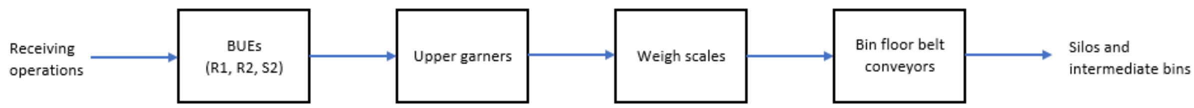


Figure 2.11: Simplified block flow diagram for the inward material flow.

2.3.3 Outward material flow

When material is ready to be shipped, it is discharged from the storage silos and intermediate bins to the basement belt conveyors. Discharge of material from the bins is conducted manually using a wheel lock system to initiate material flow. A system of red and green lights is used to determine if the flow condition on the belt is sufficient for operation and the flow rate is adjusted by an operator until the light becomes green.

The material is transferred from Annexes 1–4 by a series of basement belt conveyors to the S1 and S2 bucket elevators. These bucket elevators transfer the material vertically to the respective upper garners and weigh scales. The material from the weigh scales can be diverted to a chute and transferred to the weigh hoppers located in the truck/railcar loading building and is subsequently loaded into trucks and railcars. It should be noted that the R1 bucket elevator system can also feed the chute to the truck/railcar loading hoppers. Figure 2.12 shows a simplified block flow diagram for the outward material flow for the truck/railcar loading operations.

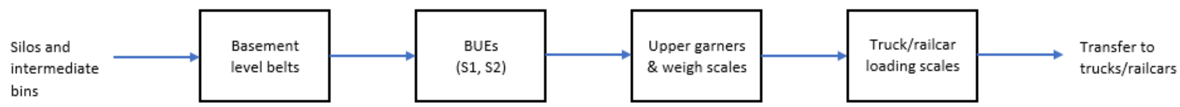


Figure 2.12: Simplified block flow diagram for the truck/railcar loading operations.

The material can be transferred from the silos and intermediate bins to the shipping gallery. The basement level belt conveyors receive the material discharged from the silos and convey the material to the S7 and S8 bucket elevators located in Annex 3. The bucket elevators convey the material vertically and discharged to the upper garners. From the upper garners, the material is gravity fed to the weigh scales and subsequently to the shipping garners before being transferred to the shipping gallery belt conveyors (H-belt & G-Belt). These belt conveyors transfer the material through the shipping gallery to the ship loading spouts. The S5 shipping garner is also still used as a surge bin and can feed material to E-belt for transfer to the shipping gallery.

It should be noted that the shipping gallery is only operated two to four times per year. Based on information provided by the HGEL, when using the shipping gallery, the loading rate is approximately 670 metric tons per hour. Figure 2.13 shows a simplified block diagram for the material flow to the shipping gallery.

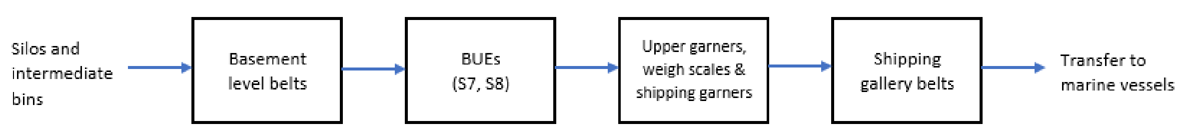


Figure 2.13: Simplified block flow diagram for the shipping gallery operations.

2.3.4 Dust collection

Collection of dust fines in Annexes 1–4 and in the receiving/loading building is performed by baghouse dust collection systems (Baghouses Nos. 2–14). These dust collection systems are located outdoors on an elevated platform in the vicinity of Annex 2. The ductwork systems are connected to pick up points located through the facility and there are dropout cyclones (beehives) located on the ductwork upstream of the baghouses to remove large particulate from the air stream. Booster fans are provided in Annex 3 to increase the air transport velocity as these pickup points are located the furthest from the duct collection systems. The baghouse configurations range from 8–12 rows of filters with each row containing eight filters. The filters are equipped with pulse jet cleaning mechanisms. The material collected in the baghouses is discharged through rotary valves into a drag chain conveyor. The conveyor transfers the material to a bucket elevator located on the exterior of the facility. The bucket elevator is used to convey the dust fines to a chute where it is discharged and gravity fed to the dust collection tanks. The tanks are emptied into a truck when filled and the dust fines are transported off-site. Figure 2.14 shows a simplified block flow diagram for the main dust collection systems material flow.

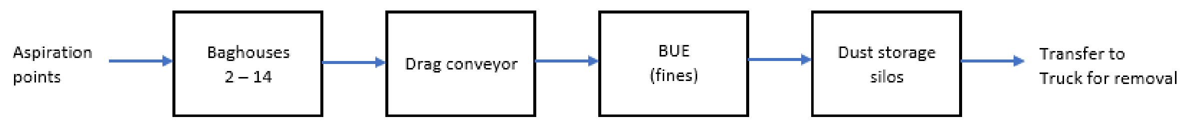


Figure 2.14: Simplified block flow diagram for the main dust collection material flow.

The receiving gallery is equipped with two dust collection systems located in the Marine Tower. Baghouse #1 is used to provide dust aspiration for the marine leg bucket elevator and the B-Tower belt. The collected material is returned to the B-Tower belt while the exhaust air is discharged to the atmosphere. The second dust collector is used to provide dust aspiration during filling of the ship unloading hopper. The material collected in this baghouse is returned to the bucket elevator via a screw conveyor and chute.

The shipping gallery is equipped with four dust collection systems that service the belt conveyors. Baghouses #15, #16, #17, and #18 are primarily located on the exterior of the shipping gallery. However, the hoppers and discharge chutes are located inside N-Tower. The material collected by the baghouse units is discharged through rotary valves and gravity fed back to the shipping gallery belt conveyors.

There is an additional dust collection system located on the penthouse level of Annex 1 that was previously used for dust fines reclaim. However, this dust collection system is no longer in use and has been decommissioned.

3.0 Review of current state

This section provides a review of the current state of operations at the Halifax Grain Elevator and summarizes the findings of the dust hazard analysis (DHA) that was conducted for the facility by Jensen Hughes. The complete DHA is available in the Jensen Hughes Report No. 4H2102690.000 – HGE DHA – FINAL – R0. The following sections summarize the dust handling operations, material-hazard evaluations, equipment-hazard evaluations, public safety events that occurred at the grain elevator. Photographs of the facility are shown in Appendix D of this report.

3.1 STORAGE CAPACITY

The facility is equipped with 210 storage silos and 155 intermediate bins used for bulk material storage. The silos in Annexes 1-3 are used for storage of grains and wood pellets while the silos in Annex 4 are only used for grains. It is important to note that the intermediate bins are not used to store wood pellets. An overview of the location of the silos and intermediate bins is given in Table 3.1.

Table 3.1: Locations of silos and intermediate bins.

Location	Number of silos	Number of intermediate bins	Material stored/handled
Annex 1	50	33	Grains & wood pellets
Annex 2	56	39	Grains & wood pellets
Annex 3	92	66	Grains & wood pellets
Annex 4	12	17	Grains
Totals	**210**	**155**	**-**

The silos in Annexes 1-3 are reinforced concrete structures with circular cross-sections. The silos in Annex 4 are also reinforced concrete structures and have metal cones. The intermediate bins are located within the interstitial space between the silos. The dimensions of the silos were obtained from design drawings and information obtained during a site visit at the facility. The silo dimensions are summarized in Table 3.2.

Table 3.2: Summary of silo and bin dimensions.

Location	Height (m)	Inside diameter (m)	Wall thickness (m)	Roof thickness (m)	Volume (m^3)
Annexes 1-3	32.9	5.1	0.18	0.18	672
Annex 4	32.9	9.95	0.2	0.18	2560

The silos and intermediate bins provide a total storage capacity of approximately 140,215 tons (5,125,000 bushels) of wheat. Based on information provided by HGEL, the silos in Annexes 1-3 have the capacity to store 500 tons of wheat while the intermediate bins have the capacity to store approximately 100 tons of wheat. The storage capacity of the Annex 4 silos and bins was not provided. However, the Annex 4 silos have a volume that is approximately 3.8 times larger than the silos in Annexes 1-3. As such, it was estimated that these silos and bins can store approximately 1900 and 380 tons of wheat, respectively. The storage capacities of the silos and bins in Annexes 1-4 are provided in Table 3.3. The storage capacity estimated in Table 3.3 is slightly higher than the maximum storage capacity communicated by HGEL.

Table 3.3: Approximate storage capacities of the silos and intermediate bins in Annexes 1-4.

Equipment	Number of silos/bins	Storage capacity (ton)	Total storage (ton)
Annex 1 silos	50	500	25,000
Annex 1 bins	33	100	3,300
Annex 2 silos	56	500	28,000
Annex 2 bins	39	100	3,900
Annex 3 silos	92	500	46,000
Annex 3 bins	66	100	6,600
Annex 4 silos	12	1900	22,800
Annex 4 bins	17	380	6,460
Total storage capacity (ton)			**142,060**

3.2 FREQUENCY OF OPERATIONS

Based on information provided by HGEL, the facility is in operation 24/7 with the main operations (material receiving and shipping) occurring during the day shift. The frequency of operations is important as a dust deflagration or explosion event would only be expected to occur while the equipment is in use and material is being transported throughout the grain elevator. The grain elevator primarily handles wood pellets, wheat, and soya beans with 60% of the total throughput being wood pellets. With respect to silo loading and unloading operations, HGEL has outlined the following frequency of use:

+ Silos containing wood pellets are filled and emptied three times per year.
+ Silos containing wheat are filled and emptied twice per year.
+ Silos containing soya beans are filled and emptied once per year.

Wood pellets are primarily stored within Annex 3 with some pellets stored within Annex 1. Based on information provided by HGEL, wood pellets are never stored within Annex 4 or in the intermediate bins in Annexes 1-3. Given this information, it was conservatively assumed that the silos in Annexes 1-3 are each filled and emptied three times per year while the silos in Annex 4 are filled and emptied twice per year.

The bin level belt conveyors have the capacity to transport 500 – 550 tons of material per hour. As such, it was assumed that the silos are filled at a rate of approximately 500 ton/hour. Using the estimated fill rate, the time associated with silo filling operations was calculated as follows:

$$Fill\ time\ (h) = \frac{Silo\ capacity}{Silo\ filling\ rate} = \frac{Silo\ capacity}{500\frac{ton}{h}} \qquad (1)$$

The material discharge rate during silo emptying is unknown. To be conservative, it was assumed that material discharge operations from the silos and bins takes 1.5 times as long as filling operations. To calculate the total time that each silo or bin is filled/emptied per year the following equation was used:

$$Operational\ time\ per\ silo\ (h/year) = N * (Fill\ time + Empty\ time) \qquad (2)$$

Where, *N* is the number of times the silo is filled and emptied per year. The total time that the silos and bins are being filled and emptied was calculated as follows:

$$Operation\ time = (No.\ of\ silos)(Operation\ time\ per\ silo) + (No.\ of\ bins)(Operation\ time\ per\ bin) \quad (3)$$

Given the information outlined above, the frequency of use for the silos and intermediate bins was calculated based on percent time in operation per year. The results of the calculations are summarized in Table 3.4.

Table 3.4: Estimated operation time per silo/bin per year.

Equipment	Operation time per silo/bin (h/year)	Percentage of time in use (%)	Corrected time in use (%)
Annex 1-3 silos	7.5	0.10	1.0
Annex 1-3 bins	1	0.01	1.0
Annex 4 silos	19	0.20	1.0
Annex 4 bins	4	0.05	1.0

As outlined in Table 3.4, each silo and bin was conservatively assumed to be in operation (filling/emptying) approximately 1% of the total operation time of the facility per year. It is important to note that the galleries and handling towers will be in operation at all times during silo filling and emptying operations. This is equivalent to 1919 hours per year or 22% of the operational time. To be conservative, the operational time of the galleries and handling towers was rounded to 25%.

3.3 DUST HAZARD ANALYSIS

A dust hazard analysis was conducted in accordance with NFPA 652, "Standard on the Fundamentals of Combustible Dust [2]," for the Halifax Grain Elevator facility as part of a separate project. A technical report titled "4H2102690.000 – HGE DHA – FINAL – R0" was prepared by Jensen Hughes to completely document the DHA process and summarize the findings.

The purpose of the DHA was to identify hazards in the process and document how those hazards are being managed. Each part of the process was considered in the DHA and the specific hazards addressed were fire, flash-fire (i.e. deflagration) and explosion hazards of combustible dust. The DHA consisted of three main parts as shown in Figure 3.1.

Figure 3.1: Main parts of the dust hazard analysis.

The following sections summarize the main findings of the DHA. For the detailed evaluations and documentation of the DHA, refer to Report No. 4H2102690.000 – HGE DHA – FINAL – R0.

3.3.1 Material hazard evaluation

The Halifax Grain Elevator handles wood pellets and a variety of agricultural grains including wheat, barley, corn, and soya beans. The grains and wood pellets that are handled have a relatively large particle size (greater than 5 mm in length) and based on information provided by the HGEL, less than one percent of the material weight is expected to consist of fine dust (sub-500 µm particulate). However, based on the handling capacity of the grain elevator, it is expected that select process equipment will handle significant quantities of fine dust particulate.

The grain elevator handles a wide variety of materials from various suppliers. Given the storage capacity of the facility, it is difficult to obtain representative material samples. Due to the difficulty with obtaining representative samples, explosibility testing was not performed by Jensen Hughes. However, it is important to note that the explosibility parameters for wood dust and agricultural grains are well defined in literature. As such, reference data from the IFA GESTIS-DUST-EX database and NFPA 61 were obtained for the purpose of material hazard characterization.

The detailed material hazard evaluations and assessment of potential ignition sources are provided in Section 3 of Jensen Hughes DHA Report No. 4H2102690.000 – HGE DHA – FINAL – R0. A summary of the material hazard analysis is provided in the following sections.

3.3.1.1 Wood dusts

Approximately 60% of the material handled by the grain elevator is wood pellets. Wood pellets are typically produced from compacted sawdust generated as waste material from other industries. Literature explosibility data for wood materials was obtained from the IFA GESTIS-DUST-EX database. The reference data is summarized in Table 3.5.

Table 3.5: Literature explosibility data for wood dusts.

Material	Moisture content (%)	Median diameter (µm)	K_{St}* (bar-m/s)	P_{max} (bar)	MEC (g/m³)	MIE (mJ)	MIT (°C)	LIT (°C)
Wood, sawing, dust deposits (10525)	8.6	83	63	7.4	20	30 – 100	410	330
Wood pulp, dust deposits (7889)	0.5	50	89	6.9	30	30 – 100	Not available	Not available
Wood, sawdust (5481)	2.7	<63	149	8.9	30	Not available	Not available	Not available
Wood (6151)	2.2	25	169	8.7	30	10 – 30	410	320

Notes:
(1) Data obtained from literature: GESTIS DUST-EX database (https://staubex.ifa.dguv.de/exploergebnis.aspx?lang=e)

The data outlined in Table 3.5 shows that combustible dusts generated from wood are typically St-1 dusts. These dusts have relatively low minimum ignition energies and are considered to be ignitable by electrostatic discharge. As such, the dust produced by wood pellets at the grain elevator is considered to be explosible in dust cloud form.

3.3.1.2 Agricultural grain dusts

Literature explosibility data for various agricultural dusts was obtained from NFPA 61 and the IFA GESTIS-DUST-EX database. The reference data is summarized in Table 3.6.

Table 3.6: Literature explosibility data for agricultural dusts.

Material	Moisture content (%)	Median diameter (µm)	K_{St}* (bar-m/s)	P_{max} (bar)	MEC (g/m³)	MIE (mJ)	MIT (ºC)	LIT (ºC)
Wheat grain dust[1]	n/a	80	112	9.0	60	Not available	Not available	Not available
Grain dust – mixed (wheat, corn, beans)[1]	4.4	33	170	8.3	60 - 75	10 – 30	Not available	Not available
Wheat (3466)[2]	n/a	<10	120	7.5	30	>10	490	Not available
Barley (3014)[2]	n/a	<63	83	7.7	125	>100	400	Not available
Soya bean (168)[2]	n/a	95	53	8.5	250	Not available	450	290
Grain, mixed dust, dust deposits (105)[2]	n/a	172	79	8.7	60	Not available	420	290
Grain, residues, from silo (10294)[2]	n/a	23	92	8.2	60	30 – 100	350	290

Notes:
(1) Data obtained NFPA 61 Table A.5.2.2 [2].
(2) Data obtained from literature: GESTIS DUST-EX database (https://staubex.ifa.dguv.de/exploergebnis.aspx?lang=e).

The data outlined in Table 3.6 shows that combustible dusts generated from agricultural grains are typically St-1 dusts. These dusts have relatively low minimum ignition energies and are considered to be ignitable by electrostatic discharge. As such, the fine grain dust that is generated and handled at the grain elevator is considered to be explosible in dust cloud form.

3.3.1.3 Summary of material hazards

The materials handled at the grain elevator are expected to have a relatively large particle size and contain less than one percent dust (sub-500 µm particulate) by weight. However, given the high quantity of material stored and handled at the facility, a significant quantity of combustible dust is expected to be present during operation.

Based on the reference explosibility data outlined in Tables 3.5 and 3.6, it can be seen that agricultural grain and wood dusts are explosible in dust cloud form. It should be noted that the materials handled at the grain elevator consist of various types of grains and wood pellets that come from various manufacturers. As such, the explosibility parameters of the materials handled at the facility are expected to differ. For the purpose of the material hazard evaluation, the most severe explosion severity and ignition sensitivity parameters obtained from literature for wood and grain dusts were conservatively assumed to be representative of the materials handled at the grain elevator. These parameters are summarized in Table 3.7.

Table 3.7: Summary of expected explosion severity and ignition sensitivity data for the handled materials.

Material	K_{St}* (bar-m/s)	P_{max} (bar)	MEC (g/m³)	MIE (mJ)	MIT (ºC)	LIT (ºC)
Grain dust	170	9.0	30	10 – 30	350	290
Wood dust	169	8.9	20	10 – 30	410	320

Notes: The explosibility parameters outlined in this table are a combination of the most hazardous parameters outlined in Tables 3.3 and 3.4.

The explosibility parameters outlined in Table 3.7 were used in the hazard evaluations conducted as part of the DHA and in the risk assessment outlined in Section 8 of this report as appropriate.

3.3.2 Equipment hazards

Detailed equipment hazard evaluations were performed as part of the DHA for all process equipment that handles combustible particulate. The hazard evaluations are provided in Section 4 of the Jensen Hughes DHA Report No. 4H2102690.000 – HGE DHA – FINAL – R0. This section of the report provides a summary of potential hazards, existing mitigating features, and recommendations associated with the process equipment.

3.3.2.1 Equipment hazard evaluations

The hazard evaluations were performed for the process equipment based on the operating conditions, equipment specifications and safeguard configurations, the properties and concentration of material handled, and operating procedures. Where the conditions required to present a dust explosion hazard were found to have the potential to exist, the equipment was considered to present an explosion hazard. A summary of the equipment hazard evaluations is shown in Table 3.8 and the complete table is shown in Appendix B.

Table 3.8: Summary of equipment hazard evaluations.

Equipment type	Explosible dust	Dispersion	Concentration	Confinement	Credible ignition sources	Explosion hazard	Fire hazard
Bucket Elevators	Yes	Yes	Possible	Yes	Possible	**Yes**	**Yes**
Garners and scales	Yes	Yes	Unlikely	Yes	Possible	**Unlikely**	**Yes**
Conveyors	Yes	Possible	Unlikely	No	Possible	**Unlikely**	**Yes**
Silos & intermediate bins	Yes	Yes	Unlikely	Yes	Possible	**Unlikely**	**Yes**
Dust tanks	Yes	Yes	Yes	Yes	Possible	**Yes**	**Yes**
Dust collection systems	Yes	Yes	Yes	Yes	Possible	**Yes**	**Yes**
Receiving/loading hoppers	Yes	Yes	Unlikely	Yes	Possible	**Unlikely**	**Yes**

3.3.2.2 Existing mitigating features

Existing mitigating features and safeguards that were provided for the equipment at the time that the DHA was conducted were reviewed. Detailed evaluations of the existing safeguards are provided in the DHA report and a summary of existing high-level safeguards and protection features are provided in the following sections.

Bucket elevators

The main bucket elevators (S1, S2, R1, R2, S7, S8) located in the workhouses are equipped with explosion protection in the form of explosion suppression systems. Chemical suppression cannisters are also used to provide deflagration isolation between the bucket elevators and connected equipment. The bucket elevators are provided with bearing temperature monitors, belt and pulley alignment monitors, two stage under-speed monitoring, and anti-friction bearings. The devices are monitored from the control room.

The marine leg bucket elevator is provided with explosion protection in the form of deflagration venting. Deflagration vents equipped with vent ducts are provided in the head and boot sections and on the legs. The bucket elevator is provided with devices for monitoring bearing temperature, belt alignment, and under speed as outlined above. The elevator is also equipped with bearing temperature monitoring on the bend roller. The devices are monitored from the control room.

The fines collection bucket elevator is provided with under-speed monitoring and no other mitigating features.

Upper garners

The S1, S2, R1, and R2 upper garners are equipped with explosion protection in the form of deflagration vents that discharge through the roof of the facility. The upper garners on the S7 and S8 systems are not provided with deflagration vents as they are not located in close proximity to the bucket elevators and are considered to be effectively isolated through the use of chemical suppression. The garners are equipped with level sensors that are interlocked to shut down the equipment if necessary.

Belt conveyors

The belt conveyors are equipped with under-speed monitoring devices that trigger alarms if the speed slows by 18%. The under-speed devices are monitored from the control room. Select conveyors are equipped with chute blocks that are interlocked to the chutes or hoppers that they feed. If the chute or hopper reaches a fill point, an alarm is triggered and the equipment feeding the conveyor is shut down. Most belts are equipped with self-aligners and anti-friction bearing.

Silos

The silos in Annex 3 are equipped with thermocouples that monitor the temperature of the bulk material. The temperature sensors are monitored from the control room.

Dust collection systems

The baghouse dust collection systems located throughout the facility are provided with explosion protection in the form of deflagration venting. The inlet ducts to the Baghouse #2 – #14 systems that service Annexes 1-4 are provided with vent panels. It is important to note that vent size calculations were not available for these systems.

3.3.2.3 Gap assessments and recommendations

Stemming from completion of the hazard evaluations and the review of the existing safeguards, gap assessments were conducted for the process equipment based on the good engineering practice guidelines outlined in the applicable Codes and Standards. The purpose of the gap assessments was to identify required safeguards necessary to mitigate potential dust deflagration and explosion hazards. The gap assessment formed the basis for the development of recommendations. The main findings from the equipment gap assessments were as follows:

- Some process equipment that presents potential explosion hazards is not provided with explosion protection.
- Adequate explosion isolation is not provided for all process equipment that present a credible explosion hazard (i.e., the baghouse systems).
- The air transport velocities in the dust collection systems should be analyzed to ensure it is sufficient to remove fugitive dust and prevent the formation of combustible dust clouds or fugitive dust accumulation within the facility.
- Due to the age of the existing dust collection systems, vent size calculations should be conducted in accordance with NFPA 68 to determine if the deflagration venting is sufficient to provide explosion protection.

The detailed equipment-specific recommendations are provided in Table B.2 in Appendix B of this report.

3.3.3 Building hazards

Fugitive dust accumulation has the potential to present credible building flash fire and explosion hazards when the level of accumulation exceeds hazardous levels. It is important to note that fugitive dust accumulation located throughout a facility can become suspended in the event of an explosion and result in a series of secondary explosions that often are more severe.

A building hazard evaluation was conducted for the facility based on the conditions that were observed during a site visit performed by Jensen Hughes.

3.3.3.1 Building hazard evaluations

Based on literature resources, the bulk density of wood dust and grain dust is expected to be approximately 210 kg/m^3 (13.1 lb/ft^3). With respect to fugitive dust accumulation and building hazards, the layer depth criterion can be calculated using the following equation:

$$\mathrm{LD\ (in.)} = \frac{\left(\frac{1}{32}\,\mathrm{in.}\right) * \left(75\,\frac{\mathrm{lb}}{\mathrm{ft}^3}\right)}{\mathrm{BD}} \tag{4}$$

Where LD is the threshold layer depth and BD is the bulk density. Based on a bulk density of 210 kg/m^3 the layer depth criterion for the grain elevator is calculated to be approximately 1/6 of an inch. As such, fugitive dust accumulation is considered to exceeds hazardous levels where the layer depth exceeds 1/6 of an inch and the accumulation covers a significant area.

During the site visit, the primary area of concern with respect to building deflagration hazards was the shipping gallery as significant dust accumulation was observed in this area. The other areas of the facility were relatively clean and did not appear to present credible building deflagration hazards. It is important to note that the facility was not in operation at the time of the site visit and as such, the conditions in other areas of the facility may not have been representative of normal conditions when operation capacity is high.

3.3.3.2 Existing mitigating features

To protect against potential explosion hazards, the exterior walls in the workhouse areas are provided with explosion release cladding that is tethered to the steel building structure. Based on information provided by HGEL, the cladding is designed to release at overpressures of approximately 0.5 – 1 psi (0.03 – 0.07 bar-g). Explosion release cladding is also found in the conveyor galleries connecting Annex 4 to Workhouse #1. Figure 3.2 shows a photograph of the cladding and restraints in the Workhouse #3. The intended function of the cladding is to release in the event of an explosion and prevent excessive overpressures from being developed within these areas. The addition of the tethers is expected to prevent the panels from being launched as projectiles.

It is important to note that documentation related to the design specifications of the cladding was not available. As such, an assessment of the effectiveness of the cladding for deflagration venting purposes should be conducted.

Figure 3.2: Photograph of the explosion release cladding on the exterior walls in Workhouse #3.

In addition to the rupture panels, the annexes are separated from one another by partitions at the bin and basement levels. Based on information provided by HGEL, these walls are rated for overpressures in the range of 0.5 to 1 psi (0.03 – 0.07 bar-g). However, it is unknown if these partitions would be effective for preventing propagation of an explosion between the annexes. A photograph of the partition located between Annexes 1 and 2 is shown in Figure 3.3. As shown in the photograph, there are openings in the partition that would allow for communication of flame and overpressure between the annexes.

Figure 3.3: Photograph of partition located between Annexes 1 and 2.

The bin level galleries are provided with windows and vent opening along the exterior walls as shown in Figure 3.4. The main structures of the galleries are constructed from concrete. It is unknown if the windows and vent openings would be sufficient to relieve overpressure developed in the event of an explosion as it is assumed that they were not designed for venting purposes.

Figure 3.4: Photograph of windows and vent opening along the exterior walls in Annex 1.

3.3.3.3 Gap assessments and recommendations

The main findings from the building hazard evaluations were as follows:

- A formalized housekeeping program should be developed and implemented site wide based on the good cleaning practice guidelines outlined in the applicable codes and standards. It is important to note that HGEL currently has a housekeeping schedule but the cleaning frequency and methods are insufficient.
- The dust collection systems should be evaluated to ensure that the air transport and capture velocities are sufficient to remove suspended dust and prevent material accumulation.
- Based on observations made during the site visit, the shipping gallery represented the primary area of concern.

The detailed recommendations associated with mitigation of building deflagration hazards are provided in Table B.2 in Appendix B of this report.

3.3.4 Management systems

A gap assessment was conducted between existing management system operations at the grain elevator and the good engineering practice guidelines outlined in the applicable Codes and Standards. It was found that existing management systems related to housekeeping, hot work, inspection, inspection, testing & maintenance (ITM), management of change, etc., were not in compliance with good engineering practice.

The detailed recommendations associated with management systems are provided in Table B.2 in Appendix B of this report.

4.0 Regulatory Analysis

This section provides a review of regulatory analysis with respect to grain elevator safety and land use planning strategies and includes the following:

+ A review of federal regulatory standards for grain handling facilities in Canada, the United States, and other relevant countries.
+ A review of regulatory standards for other industrial facilities that present deflagration or explosion hazards.
+ A review of best practices for land use planning surrounding industrial facilities with respect to risk mitigation of incompatible uses.
+ Industry best practices for residential built form standards that protect against industrial hazards.

4.1 REGULATORY SAFETY STANDARDS FOR GRAIN HANDLING FACILITIES

With respect to mitigation of combustible dust hazards in grain handling facilities, there are various codes and standards that represent good engineering practice.

4.1.1 NFPA standards

The National Fire Protection Association (NFPA) is a global self-funded non-profit organization devoted to eliminating death, injury, property, and economic loss due to fire, deflagration, electrical, or related hazards. NFPA delivers information and knowledge through more than 300 consensus codes and standards. The NFPA standards are widely adopted in the United States and when referenced, become legally enforceable parts of adopted codes. In the United States, the NFPA standards are considered to represent "good engineering practice" with respect to mitigation of fire, deflagration, and explosion hazards associated with combustible dust. The primary NFPA standards that outlined good engineering practice with respect to grain handling facilities include the following:

- NFPA 61, Standard for the prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities [3].
- NFPA 652, Standard on the Fundamentals of Combustible Dust [1].

In addition to the NFPA standards outlined above, the following supplementary NFPA standards are also applicable to dust hazard management in grain elevators:

- NFPA 51B, Standard for Fire Prevention During Welding, Cutting, and Other Hot Work [4].
- NFPA 68, Standard on Explosion Protection by Deflagration Venting [5].
- NFPA 69, Standard on Explosion Prevention Systems [6].
- NFPA 77, Recommended Practice on Static Electricity [7].
- NFPA 91, Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists, and Particulate Solids [8].
- NFPA 499, Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas [9].
- NFPA 654, Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids [10]

In Canada, select NFPA standards have been adopted under the National Building Code of Canada (NBC) [11] and National Fire Code of Canada (NFC) [12]. However, when NFPA Standards are not adopted, compliance is voluntary and the standards are enforceable by the local authority having jurisdiction. With respect to NFPA standards on combustible dust, the NFC makes reference to NFPA 61, NFPA 68, NFPA 69, NFPA 91, and NFPA 484 as good engineering practice but does not enforce compliance with the standards.

Although the NFPA standards on combustible dust are not enforceable in Nova Scotia, these standards are considered to be the best practice guidelines with respect to mitigation of combustible dust hazards. As such, the DHA that was conducted for the Halifax Grain Elevator was performed based on achieving compliance with the applicable NFPA standards.

4.1.1.1 NFPA 61

NFPA 61 is the governing NFPA standard for grain handling facilities and grain elevators. NFPA 61 outlines provisions for mitigating potential combustible dust hazards through the implementation of safeguards and controls, ignition source control methods, management systems and adequate housekeeping practices.

Responding to calls for an industrywide standard on grain elevator safety, NFPA appointed a committee on dust control in grain elevators. The committee, lacking sufficient information on certain aspects of the explosion problem, hired Underwriters Labs (UL) to investigate methods of controlling floating dust in terminal grain elevators. The results of the UL study formed the basis for the dust-control provisions in the early versions of the standard, which also contains general operation and design provisions. The standard has been revised multiple times over the years with significant changes in 1970, when country elevators were added to the scope of the standard, and in 1980, when NFPA responded to the threat of imminent government regulation by strengthening the ignition-control requirements for bucket elevators.

The standard became known as NFPA 61, Standard for the prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities in 1995 and has undergone several revisions since with the current revision being the 2020 Edition.

4.1.2 OSHA codes and standards

The Occupational Safety and Health Administration (OSHA) is part of the United States Department of Labor and acts to ensure safe and healthful working conditions for workers by setting and enforcing standards and by providing training, outreach, education, and assistance.

The OSHA Grain Handling Standard, 29 CFR 1910.272 [13], was implemented in 1987 following a significant number of grain dust explosions in the 1970’s and 1980’s. The standard was implemented as a means to mitigate and control potential combustible dust fire and explosion hazards in grain handling facilities. The OSHA grain handling standard does not apply to grain handling facilities in Canada. However, the OSHA standard recognizes NFPA 61 as accepted good engineering practice for mitigating dust hazards in grain handling facilities. NFPA 61 is considered to be a more rigorous combustible dust standard as it includes additional provisions not included in the OSHA standard.

In addition to the Grain Handling Standard, OSHA has developed many standards related to safety that are enforced within the United States and would be applicable to industrial facilities including grain elevators.

4.1.3 Fire and building codes

In Canada, the National Fire Code (NFC) and National Building Code (NBC) are developed at the federal level and are considered the minimum level of fire and life safety compliance. These codes are often adopted outright by jurisdictions or amended or supplemented to suit regional needs and then published as territorial or provincial codes. In Nova Scotia, the NBC and NFC model codes are adopted by the respective Nova Scotia Building Code Act and Nova Scotia Fire Safety Act and amended by the associated Regulations. It is important to note that the NFC and NBC are typically the code of reference on federal projects but are not enforceable on federal lands.

The NBC classifies grain elevators as high-hazard industrial occupancies (Group F, Division 1 or F1). High-hazard industrial occupancies are defined as industrial occupancies containing sufficient quantities of highly combustible and flammable or explosive material which, because of their inherent characteristics, constitute a special fire hazard. It is important to note that a definition for "special fire hazard" is not provided in the NBC. As such, the F1 occupancy classification is considered to be given to grain elevators due to the quantity of material handled and the inherent combustibility characteristics associated with the material. The NFC outlines compliance requirements for dust producing properties in Section 5.3 with grain handling and storage facilities included in Section 5.3.3. As previously mentioned, the NFC makes reference to select NFPA standards on combustible dust as good engineering practice but does not enforce compliance with the standards. NFPA 61 is considered to be a more rigorous standard as it includes additional provisions not included in the NFC.

4.1.4 Canada OHS Regulations

The Canada Occupational Health and Safety Regulations (COHSR) [14] is part of the Canada Labor Code and outline the general rights and responsibilities of the employer, the supervisor and the worker in the workplace. With respect to grain elevators, the following sections of the COHSR apply:

- COHSR, Part II entitled "Permanent Structures" contains requirements relating to grain elevators such as housekeeping and maintenance requirements (Section 2.14(2)).
- COHSR, Part VIII entitled "Electrical Safety" contains requirements relating to the use of intrinsically safe electrical tools and equipment as well as other safety requirements for electrical equipment.
- COHSR, Part XIII entitled "Tools and Machinery" sets out requirements for spark proof tools (Section 13.2) and for intrinsically safe portable power tools (Section 13.5) in areas where fires or explosions could occur.
- COSHR, Part X entitled "Hazardous Substances" contains Section 10.4 "Hazard Investigation" that prescribes requirements for conducting a hazard investigation for exposure to grain dust. As well, Section 10.14 "Employee Education" describes required aspects of an employee education program for occupational hazards. Sections 10.19 to 10.22 contain requirements for grain dust concentrations in air relative to the lower explosible limit.
- COHSR, Part XI entitled "Confined Spaces" outlines requirements in respect of grain elevators and grain bins, such as hazard assessment, confined space entry procedures, emergency procedures and equipment, and hot work. It also specifically addresses engulfment issues where solids are capable of flowing easily, such as bulk grain.
- COHSR, Part XII entitled "Safety Materials, Equipment, Devices and Clothing" contains requirements for the use of personal protective equipment (PPE) to protect employees from exposure to grain dust.
- COHSR, Part XIX entitled "Hazard Prevention Program" outlines requirements for identification, control, and prevention of other hazards presented by cleaning operations.

4.1.5 Other Countries

In the United Kingdom, good engineering practice guidelines with respect to combustible dust hazard management is outlined in "Safe Handling of Combustible Dusts: Precautions against explosions (2003)" published by the Health and Safety Executive (HSE). The document provides advice on the prevention and mitigation of dust explosions and fires and outlines the hazardous potential and common means to control the risk. Notable dusts include sugar, coal, wood, grain, certain metals and many synthetic organic chemicals.

In Australia and New Zealand, good engineering practice guidelines with respect to combustible dust hazard management is outlined in AS/NZS 4745:2012, "Code of Practice for Handling Combustible Dusts." This Code of Practice is intended to apply whenever combustible dusts are encountered in quantities sufficient to give rise to a fire and/or explosion. This would normally include, but is not limited to, manufacturing plants and processes and bulk storage and handling installations.

In the European Union, the ATEX directives stipulate that companies and organizations that operate in the EU member states must comply with the ATEX Equipment Directive 2014/34/EU and the ATEX Workplace Directive 99/92/EC. These directives regulate workplaces with potentially explosive atmospheres. More specifically, equipment and protective systems, and the safety and health of workers, respectively.

4.1.6 Summary

The NFC is not enforceable on federal lands and as such, the Halifax Grain Elevator is not subject to the NFC. The NFC is considered the minimum level of fire and life safety compliance. The NFC references select NFPA standards on combustible dust as good engineering practice. However, these Standards are not considered regulatory standards in Canada. With respect to grain handling facilities and grain elevators, NFPA 61 is considered the "best practice" standard to mitigate combustible dust fire, deflagration, and explosion hazards. As such, for the risk associated with grain elevators to be as low as reasonably practicable, they should be designed and operated in accordance with NFPA 61 and other NFPA standards applicable to handling of combustible dust.

4.2 REGULATORY STANDARDS FOR OTHER INDUSTRIES

The NBC classifies grain elevators as high-hazard industrial occupancies. Additional occupancies considered high-hazard under the NBC include wood handling facilities such as lumber mills, chemical manufacturing plants, and bulk plants for flammable liquids or vapors. The following sections outline regulatory standards for industrial wood processing facilities and propane storage facilities.

4.2.1 Wood handling facilities

Wood handling facilities such as oriented strand board (OSB) and lumber mills present fire and explosion hazards due to the presence of combustible wood dusts generated in the manufacturing processes. Similar to grain handling facilities, the NFPA standards represent good engineering practice for mitigation of combustible dust hazards with NFPA 664, Standard for the Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities [15]" being the governing standard in the United States. In Canada, the NFC and COHSR requirements would apply to wood handling facilities in jurisdiction where they have been adopted while being in compliance with the NFPA standards would be considered best practice.

4.2.2 Propane storage facilities

Propane storage facilities present fire and explosion hazards given the flammability characteristics of propane and the potential for vapor cloud explosions. In Canada, the NFC makes reference to CSA B149.1-10, "Natural Gas and Propane Installation Code" and CSA B149.2-10, "Propane Storage and Handling Code" as the governing codes for propane storage facilities.

In the United States, the following standards and guidelines exist for propane storage facilities:

- NFPA 58, Liquified Petroleum Gas Code.
- Risk Management Program Guidance for Propane Storage Facilities (40 CFR 68), United States Environmental Protection Agency.
- Fire code provisions at the state and federal levels.

4.3 BEST PRACTICES FOR LAND USE PLANNING

Select jurisdictions have enacted mandatory regulations for locating sensitive land uses near industrial facilities on a country-wide level. However, most countries have left this task to individual states, provinces, or cities. With respect to land use planning, there are three distinct approaches to determine the required separation distances between industrial facilities and adjacent land uses. The three approaches are as follows:

+ Consequence based approach (CBA)
+ Risk based approach (RBA)
+ Generic safety distances (GSD)

The following sections provide a summary of the three approaches to land use planning listed above.

4.3.1 Consequence based approach (CBA)

In the consequence based approach, only the severity of an incident is accounted for while the incident frequency and corresponding risk are ignored for land use planning purposes. The CBA considers the consequences of the worst-case scenario or event to define the required separation distances. This approach is based on the assumption that the separation distance associated with the worst-case scenario will be sufficient to protect against all other less severe events. Some jurisdictions utilize reference scenarios based on past incidents that have occurred at similar facilities to determine the worst-case scenario that should be considered. Table 4.1 provides a list of pros and cons associated with the CBA.

Table 4.1: Pros and cons of the CBA.

Pros	Cons
• Less time consuming than a risk-based approach. • Does not include the uncertain variable of frequency or large variance in calculated risk.	• Often results in significant areas of land being embargoed. • Difficult to determine suitable threshold levels for risk effects. • Does not account for frequency of the scenario. • Can be difficult to determine the worst-case scenario

The CBA does not use a risk variable in its determination of separation distances which eliminates the uncertainty surrounding the event frequency. While the CBA is a suitable approach for land use planning, not accounting for scenario frequency may lead to a larger area of land being embargoed than desired.

4.3.2 Risk based approach (RBA)

The risk based approach accounts for the consequences associated with a potential event and the frequency or likelihood that the event will occur. The RBA is considered to be more comprehensive than the CBA given the incorporation of the frequency variable. In the RBA, the risk is equal to the consequence (probability of a fatality) multiplied by the frequency of the event for a given period of time.

The primary objection for the RBA is the uncertainty of low probability, high consequence events as this can result in a catastrophe if a high-hazard event occurs and sensitive land uses are in close proximity to the source. As such, the inclusion of frequency can be both a positive and negative attribute depending on the land use planning approach and the type of industrial facility in question. Table 4.2 provides a list of pros and cons associated with the RBA.

Table 4.2: Pros and cons of the RBA.

Pros	Cons
• Most comprehensive method. • Accounts for event frequency. • Can be used to account for both individual and societal risk.	• There is some uncertainty related to the frequency of low probability, high consequence events • More extensive and time consuming than the CBA or GSD approach.

An additional positive attribute of the RBA is the ability to measure individual and societal risk. Individual risk is the frequency at which an individual may be expected to sustain a given level of harm (i.e. death) from the realization of specified hazards. Societal risk is often referred to as the relationship between frequency and consequences expressed on an F-N curve which shows the frequency of N or more fatalities per year. The use of an F-N curve typically incorporates three risk regions (unacceptable, tolerable, and acceptable) into land use planning evaluations.

4.3.3 Generic safety distances (GSD)

The generic safety distance approach is the simplest of the three methods and does not account for risks or consequences associated with major hazards at industrial facilities. Instead, separation distances are determined based on potential effects associated with operation of the facility. The main benefit of the GSD approach is its simplicity. Table 4.3 provides a list of pros and cons associated with the GSD approach.

Table 4.3: Pros and cons of the GSD approach.

Pros	Cons
• Simplest approach. • Does not include the uncertain variable of frequency or large variance in calculated risk. • Goal of zero harm to the public.	• Significant areas of land can be embargoed. • Safety characteristics, mitigation strategies, etc., of the facility are not accounted for. • Does not account for frequency of the scenario.

The GSD approach aims to ensure essentially zero harm to the public. However, this leads to large areas of land being embargoed to achieve the required separation distances. This approach also does not account for safety characteristics or facility-specific operation and as such, a facility with poor safety conditions can have the same required separation distances as a new facility that incorporates modern design and mitigating features that reduce the level of risk. This can result in separation distances surrounding new facilities being larger than required, while separation distances surrounding older facilities may not be large enough.

4.3.4 Approach by jurisdiction

This section provides a summary of the land use planning approaches that are employed by select countries. It should be noted that this section does not include Canada which is discussed in Section 4.3.5.

4.3.4.1 Europe

Specific legislation concerning risk assessment and land use planning and control has been in existence in Europe for many years. In the 1970's many countries in the European Union modified their legislation dealing with hazardous facilities (United Kingdom and Germany in 1974, France in 1976, the Netherlands in 1977). These new laws included the notion of "hazardous installations" and proposed appropriate classifications. They described the analyses of safety and of risk that should be undertaken, although the specific methodologies vary with the regulatory approaches used in each country. The European Economic Community Directive on Major Hazards of June 1982, often referred to as the "SEVESO Directive", unified and often strengthened these practices. The SEVESO II directive (1996) outlines land use planning provisions. The directive requires that the objectives of preventing major accidents and limiting their consequences be taken into account by the Member States in their land-use policies and/or other relevant policies. This requirement recognizes that planning policies can be directed towards the need, in the long term, for appropriate distances between establishments covered by the Directive and residential areas, areas of public use and areas of particular natural sensitivity or interest. The approaches employed by various jurisdictions including Germany and the UK are outlined in the following sections.

4.3.4.1.1 Germany

Germany has taken a decentralized approach to land use planning regulations with their system of national, state and local governments. The national and state governments provide the framework for land use planning policy while local governments establish land use plans. Germany has taken a unique perspective on the approach and methodology used for land use planning when compared to other countries. Germans have placed a significant emphasis on utilizing state of the art safety technology to minimize the effects of an incident. Germany is also one of the few countries who use GSD for land use planning. The goal of land use planning in Germany is for no serious hazard to reach the public population surrounding the industrial facility with emphasis placed on the application of state of the art safety technology. Federally recommended safety distances seek to prevent harm to the public, but they are only recommendations and not mandatory to be applied by the local governments in charge of land use planning. The criteria for acceptable safety distances are determined by each individual state but local levels of government can implement their own requirements.

4.3.4.1.2 United Kingdom

The UK utilizes a combination of a CBA and RBA for the evaluation of major incident hazards. For implementation of land use planning, the UK has published guidelines for acceptable risk levels, decision making procedures and its land use planning decision matrix to achieve their roles of advising local planning agencies and offering advice on proposed new developments. The area surrounding a hazardous facility is broken down into three zones based on established risk criteria as the first part of the decision matrix. The established risk relates to an individual sustaining a consequence called a “dangerous dose” or specified level of harm. The dangerous dose is quantified as causing the following:

- Severe distress to all;
- A substantial number of individuals needing medical attention;
- Some individuals requiring hospital treatment
- Some (about 1%) fatalities

The dangerous dose is quantified for each zone based on consequences from fire, explosion, or toxic release. Figure 4.1 outlined examples of the thresholds associated with each zone for fire, explosion, and toxic release effects.

Consultation zone	Fire (thermal radiation consequences)	Explosion (overpressure consequences)	Toxic release (Residual individual risk of dangerous dose or worse to a hypothetical house resident)
Inner	1800 TDU	600 mbar	greater than 10^{-5}
Middle	1000 TDU	140 mbar	10^{-5}–10^{-6}
Outer	500 TDU	70 mbar	10^{-6}–3.10^{-7}

Figure 4.1: Consequence thresholds used in the UK for land use planning purposes.

The second part of the decision matrix is the sensitivity of the proposed development. The UK has distinguished five levels of sensitivity to consider in the decision-making process. Level 4 is for the most sensitive populations such as large schools or hospitals while Level 0 is for developments that are usually unoccupied. Depending on the sensitivity of the proposed development within the zone, the federal department responsible for land use risk assessments will either provide a response of “advise against” or “does not advise against” based on their matrix.

The UK has employed different approaches depending on the substance and scenario in question. In cases of thermal radiation and explosions a CBA is used, while in the case of toxic releases an RBA is used. Although the UK is strongly centralized in respect to health, safety and the land use planning process, the final decision for permitting new developments is up to the local planning agency.

4.3.4.2 Australia

Australia utilizes the RBA based on established acceptability criteria for individual fatality and injury risk. For land use planning purposes, the acceptable individual fatality risk criterion is 10^{-6} fatalities per year to the residential population. The acceptable level of risk increases or decreases based on the sensitivity of the land use (e.g., 0.5 x 10^{-6} fatalities per year for schools and hospitals, 5 x 10^{-6} fatalities per year for sports arenas, and 50 x 10^{-6} fatalities per year for industrial facilities. The injury risk criterion states that certain threshold values of the physical effect causing injury should not be exceeded in residential areas at frequencies greater than 50 x 10^{-6} per year.

4.3.4.3 United States

Many of the federal laws and regulations passed in the United States have touched on the subject of land use planning, but none have directly addressed land use planning policy. The approach followed in the United States for emergency planning and communication to the public can broadly be considered as belonging in the “consequence based” category. However, there is a lack of guidance for risk assessments and addressing conflicts between land uses in laws in the United States.

4.3.4.4 Summary

As outlined in the previous sections, the approach to land use planning varies between jurisdictions. Table 4.4 summarizes the approaches to land use planning in the described jurisdictions.

Table 4.4: Summary of jurisdictional approaches to land use planning.

	Approach to land use planning		
Country/Jurisdiction	**GSD**	**CBA**	**RBA**
Australia			X
Germany	X		
United Kingdom		X	X
United States		X	

Generally, where federal frameworks have been established, state and local jurisdictions have followed that guidance. However, this is not the case in Canada which is discussed in the Section 4.3.5.

4.3.5 Approach to land use planning in Canada

Few provinces have specific legislation concerning the inclusion of risk assessment in land use planning and control. In general, most planning laws enable municipalities to specify land uses throughout their territory, although such plans are not obligatory in all provinces. As well, many planning laws allow municipalities, through their zoning bylaws, to ensure minimum separation distances between conflicting land uses. In some cases, provincial governments have established specific regulations.

While general planning and zoning powers exist, the absence of risk assessment in official plans, zoning bylaws and environmental assessment procedures can be explained by the lack of generally accepted guidelines for acceptable levels of risk and of methodologies for risk assessment. Several federal, provincial and Non-Government Organization entities have established guidelines for the co-location of sensitive land uses with hazardous facilities. This section will outline some of the entities and their corresponding guidelines as they relate to the Canadian context, specifically the Halifax Grain Elevator.

4.3.5.1 MIACC land use planning guidelines

The Major Industrial Accidents Council of Canada (MIACC) published the Risk-based Land Use Planning Guidelines, targeted at municipal planners responsible for land use plans who have limited expertise in the risk assessment field. The guidelines provide the reader with advice and background on risk acceptability criteria suitable for use in any jurisdiction in Canada. The MIACC guidelines provide risk acceptance criteria for land uses based on individual risk. However, unlike the RBA used by Australia and the United Kingdom, the risk contours developed by MIACC only factor in fatalities and not injury or damage to property. The MIACC approach is discussed in detail in Section 5.

4.3.5.2 Provincial and municipal regulations

Though varying in scope and degree of specificity, industrial land buffers exist in all the researched provincial and municipal jurisdictions and are a common tool to mitigate against potential, perceived, or existing conflicts between industrial uses and adjacent sensitive land uses. Municipal Plans and Land Use Bylaws generally include minimum separation distances or setback requirements alongside policy statements. While mitigation measures are present in all jurisdictions, there is no common or singular approach to defining and shaping a buffer.

In many cases specific land use designations are utilized in a Municipal Planning Strategy to create a transition or buffer zone between industrial and residential uses. Often, these transitional areas focus on employment uses that are more office-oriented and less industrial-oriented – or at least have greater restrictions on the range of permitted industrial uses. By geographically locating a transitional land use designation, buffering occurs at the city or neighborhood scale. Additionally, many municipal jurisdictions have developed land use policies that require on-site or site-specific buffering, or setbacks. However, in most cases the applied setbacks are in reference to siting new industrial or hazardous land uses in proximity to existing non-industrial uses, and not vice versa.

Locating sensitive land uses nearby existing hazardous uses is not something that is considered by most provincial or municipal planning departments. There are currently no provincial regulations regarding the siting and separation of sensitive land uses in proximity to hazardous land uses in Nova Scotia. However, the provinces of Alberta and Ontario have established guidelines for siting sensitive land uses in relation to existing hazardous uses.

The Ontario government has created a series of environmental land use planning guides, colloquially known as the D-Series regulations, to provide municipalities with a framework for land use compatibility in the province. Regulation D-6 specifically regulates compatibility between industrial facilities, and compatibility between industrial facilities and sensitive land uses. Ontario primarily utilizes a general separation distance approach (GSD) however, a consequence based approach is uses for compatibility analysis of land use conflicts in urban or infill areas. The current land use compatibility guidelines divide recommended general separation distances into three classes depending on the facility. Grain elevators and food mills fall under "Class II" which recommends a minimum separation distance of 70 meters between the existing use and new sensitive land uses. While these regulations contemplate explosion hazards, they also contemplate the compatibility impacts of noise, odor, dust, vibration and/or fugitive emissions when considering separation distances.

In Alberta, select county land use bylaws outline minimum buffer or separation distances between new agri-industrial uses and existing residential developments. Agri-industrial is defined a large-scale facility such as a weigh scale, grain handling facility or seed cleaning plant. For example, the Westlock County Land Use Bylaw (No. 04-2016) states that where a new agri-industrial use is proposed adjacent to an existing residential development, a minimum 100 meter buffer must be provided between the new agri-industrial, use and the property line of the residential parcel unless the residential development is owned by the proponent of the agri-industrial use.

4.3.5.3 NFPA 61

As previously discussed, NFPA 61 [3] is considered to represent good engineering practice with respect to mitigation of combustible dust hazards in grain handling facilities. NFPA 61 outlines that the separation of hazard areas from other hazard areas and from other occupancies is permitted to be used to limit the impact of a deflagration (dust explosion) hazard. Separation is only permitted if it is supported by an engineering evaluation and the minimum separation distance should not be less than 15 meters in any instance. NFPA 61 recommends a separation distance of 30 meters; however, the recommendation only contemplates uses that are accessory to the hazardous uses (but still personnel intensive).

The NFPA 61 standard is not a statutory requirement but was previously cited by the Halifax Port Authority in correspondence regarding the Development Agreement approval of "The Grainery" development. The NFPA 61 standard was cited as the minimum separation distance the Port Authority would be comfortable with for new residential development in proximity to the Halifax Grain Elevator. The HPA letter is included in Appendix C of this report.

4.3.5.4 Summary

For the purpose of the land use risk assessment study, the risk-based methodology outlined in the MIACC Risk-based Land Use Planning Guidelines was utilized to determine the minimum separation distances required between the Halifax Grain Elevator and adjacent sensitive land uses. The MIACC guidelines are discussed in detail in Section 5 of this report.

4.4 RESIDENTIAL BUILT FORM STANDARDS

Adequate physical separation is the clear best practice globally when considering the siting of new sensitive land uses near existing hazardous uses. However, where it is not possible to ensure adequate physical separation of uses, other built form regulations may be considered. Unfortunately, a body of research specifically for built form regulations relating to compatibility between hazardous and sensitive land uses is virtually non-existent. In the case of the Halifax Grain Elevator, where the hazards are fire and explosion related, some guidance can be taken from work completed by the United States Federal Emergency Management Association (FEMA) in response to potential terrorist attacks against buildings. FEMA has published the Buildings and Infrastructure Protection Series that outlines strategies and provides guidance for site planning and building design to mitigate the effects of potential terrorist attacks (i.e., explosions).

FEMA's guidelines emphasize that the most effective blast mitigation technique is physical separation between sensitive buildings and hazards. The guidelines outline several additional site design considerations for buildings in proximity to an explosion hazard, including:

- Prohibiting street parking nearby high risk buildings;
- Locating pedestrian entrances away from the potential hazard; and
- Undergrounding and protecting utilities.

4.4.1 Building siting, size, and orientation

FEMA's guidelines predominantly focus on the design of individual buildings rather than site design. The shape of the building can have a contributing effect on the overall damage to the structure. Re-entrant corners and overhangs are likely to trap a shock wave, which may amplify the effect of a blast (Figure 4.2). To reduce this trapping effect, in general, convex rather than concave shapes, directed toward the potential blast hazard, are preferred for the exterior of the building.

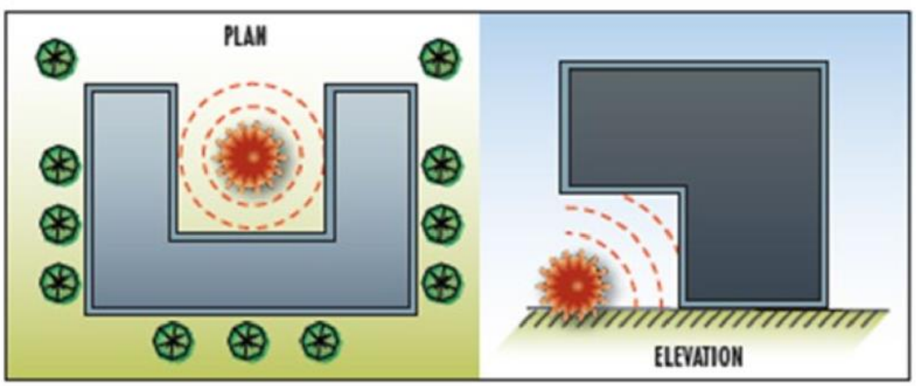


Figure 4.2: Blast impacts on building form.

Buildings should be oriented horizontally rather than vertically to reduce the building's profile and exposure and to facilitate the clearance of a blast wave. Low-rise buildings that have a large footprint relative to their floor area makes the collapse of an entire building form a single blast unlikely. Internally, FEMA recommends that unoccupied or limited occupancy spaces be placed on the building perimeter to add additional protection to occupied space further into the building interior (Figure 4.3).

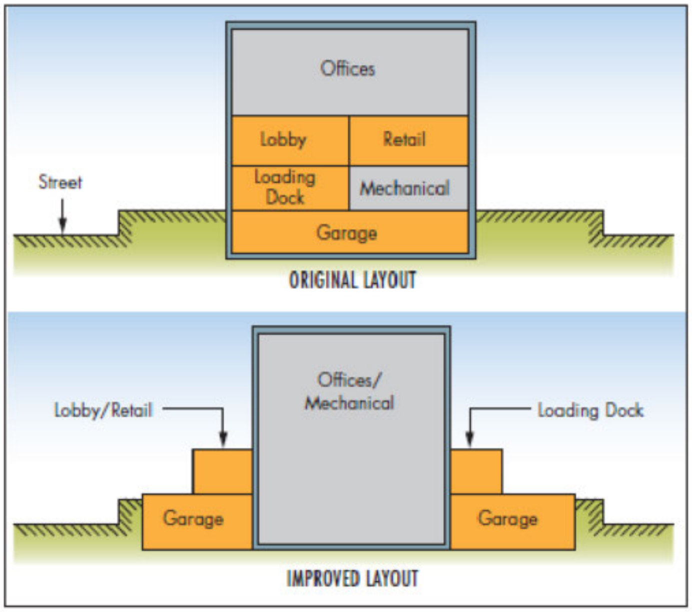


Figure 4.3: Placement of occupancies within a building.

4.4.2 Building façade design principles

In general, the number and size of windows in a façade should be minimized, especially on lower floors where blast pressures are higher during an external explosion. Major glazing's should be perpendicular to the façade facing the direction of the potential blast to reduce exposure to projectiles (Figure 4.4).

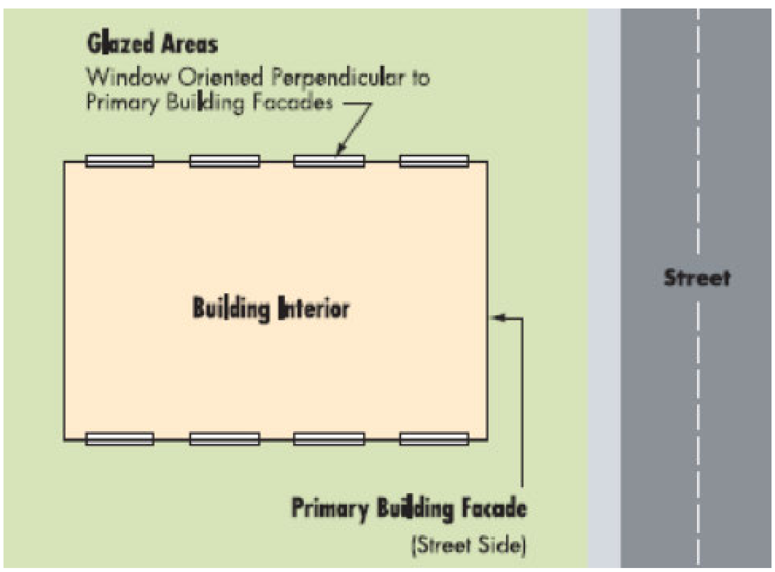


Figure 4.4: Glazing orientation with the primary façade facing the blast hazard.

Additionally, FEMA recommends simple building geometries, with minimal ornamentation (which may become flying debris during an explosion). When utilizing ornamentation on the façade, it should consist of lightweight materials such as timber or plastic which are less likely to become lethal projectiles in the event of an explosion than for instance brick, stone, or metal.

5.0 MIACC Guidelines

The MIACC Risk-based Land Use Planning Guidelines are formulated in terms of acceptable land uses in relation to specified levels of individual risk. For the purpose of the land use risk assessment study, the risk acceptance criteria outlined in the MIACC Guidelines was used to determine the acceptable land uses surrounding the Halifax Grain Elevator.

5.1 DEVELOPMENT OF THE MIACC GUIDELINES

The Major Industrial Accidents Council of Canada (MIACC) was established in 1987 and was a national leader for cooperative action to reduce frequency and severity of major industrial accidents involving hazardous substances. In 1995, the MIACC published the Risk-based Land Use Planning Guidelines [1] targeted at municipal planners responsible for land use plans who have limited expertise in the risk assessment field. The guidelines were proposed on the basis of European standards and discussions with experts in both Canada and abroad. The guidelines provided the reader with advice and background on risk acceptability criteria suitable for use in any jurisdiction in Canada.

The MIACC dissolved in 1999 but the land use planning guidelines were transferred to newly-formed Process Safety Management Division of the Canadian Society of Chemical Engineering (CSChE). In 2004, the CSChE PSM Division published an updated set of risk assessment guidelines which superseded the MIACC risk assessment guides titled "Risk Assessment – Recommended Practices for Municipalities and Industry [16]." In 2007, the CSChE PSM Division proposed a revised set of risk acceptability guidelines for land use, to take into account the experience gained across Canada with the 1995 MIACC guidelines. The MIACC publication is still valid in its generalities.

In general, risk management efforts are concerned with five different objectives as follows:

1. Risk reduction at the source
2. Risk reduction through better land use planning around industrial sites
3. Emergency preparedness
4. Emergency response
5. Risk communication and public participation

While efforts are required in all five areas, experts have noted that most efforts have been focused on Objectives 1 and 3 with less attention being paid to Objective 2. The MIACC Risk-based Land Use Planning Guidelines were developed to focus on how the potential impacts of an accident on surrounding human activities can be anticipated and limited through adequate land use planning and control. It is important to note that the MIACC Risk-based Land Use Planning document (1995) deals with the inclusion of risk assessment in land use planning rather than with appropriate methodologies for risk assessment itself. The CSChE PSM Division document (2007) build on the MIACC Guidelines and provides recommended practices on how to analyze risks of hazardous installations.

5.2 MIACC APPROACH TO RISK-BASED LAND USE PLANNING

Risk can be defined as the combination of the probability of occurrence of an undesired event and the possible extent of that event's consequences and risk assessment involves estimating the following:

- The likelihood or expected frequencies of undesirable events,
- Consequences to people due to these undesirable events,
- The associated risk in quantitative terms.

In public safety risk assessments, one must differentiate between individual and societal consequences. The individual consequences concern the chances that an individual exposed to a given hazardous event may suffer a particular effect (a fatality, an injury, etc.). The societal consequences can be estimated by adding up all the individuals suffering that given effect. The MIACC guidelines are formulated in terms of acceptable land uses in relation to specified levels of individual risk as the objective is to avoid the death of even a single person in the affected area. The individual risk is defined as the annual frequency at which an individual may be expected to sustain a given level of harm (i.e. death) from the realization of specified hazards. This approach implicitly provides a guideline for acceptable levels of societal risk without having to resort to the use of complex FN curves (frequency of events vs. number of fatalities). The first step in risk based land use planning is defining the risk.

As the level of individual risk is closely related to the distance from the potential accident source, the evaluation of a specific situation (whether a planned industrial site, an existing or a proposed plant) consequently generates a series of "risk contours" associated with various levels of individual risk. The distance separating the risk source and each risk contour will evidently vary depending on the characteristics of the source and on any mitigating measures.

Land use planning can take these risk contours into account by determining what land uses are (or not) appropriate in areas subject to various levels of risk (e.g. a higher level of risk may be acceptable for land uses involving the presence of fewer people than land uses which imply higher population densities). However, in order to propose such land uses, it is first necessary to determine what levels of risk are acceptable.

5.3 ACCEPTABLE LEVELS OF RISK

The definition of acceptable levels of risk is difficult and requires considerable efforts to achieve consensus. Like other sensitive land use questions, public information and participation are essential aspects of the process. The definition of acceptable level of risk is consequently a political exercise rather than a purely technical exercise. Decision-makers responsible for land use planning must balance the concerns of both the proponents of projects and of those affected by them. The acceptable levels of individual risk proposed in the MIACC guidelines are intended to serve as a basis for such choices and apply equally to risk from hazardous substances from all sources. The risk acceptance criteria outlined in the MIACC guidelines for various land uses are shown in Figure 5.1.

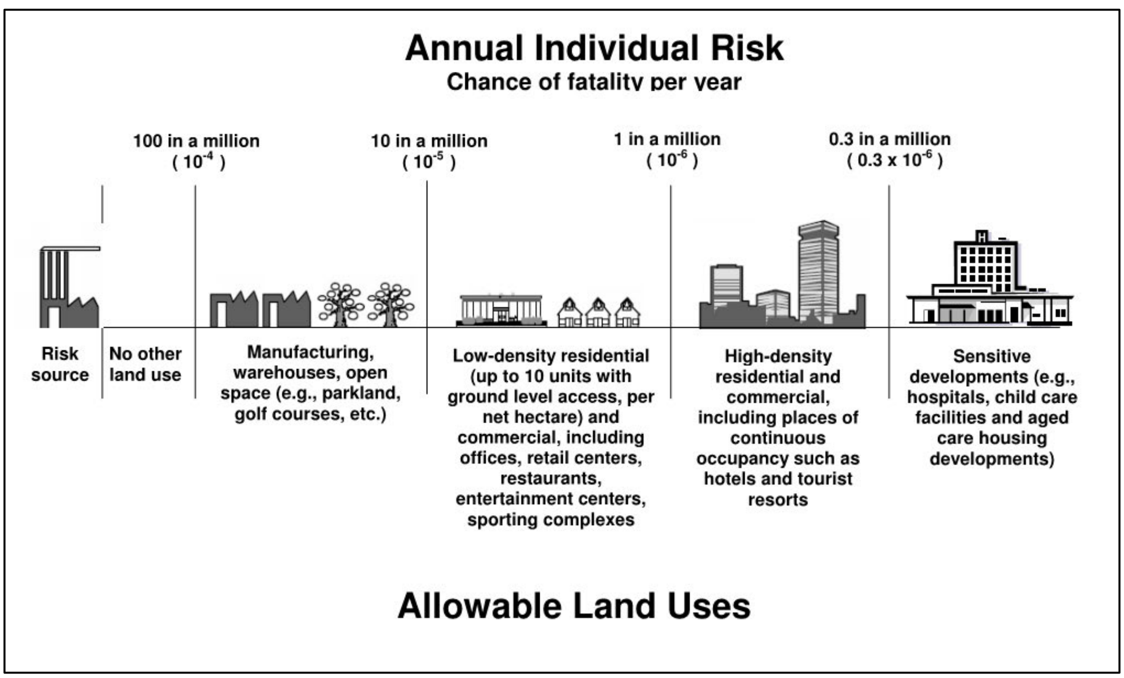


Figure 5.1: MIACC risk acceptance criteria.

The guidelines for acceptable levels of risk indicated in Figure 5.1 are as follows:

+ Land use should be restricted in all areas where the individual risk to the public exceeds 1 x 10^{-4} fatalities per year.
+ Manufacturing, warehouse, and parkland land uses are permitted in areas where the individual risk to the public is lower than 1 x 10^{-4} fatalities per year.
+ Low-density residential and commercial land uses are permitted in areas where the individual risk to the public is lower than 1 x 10^{-5} fatalities per year.
+ High-density residential and commercial land uses are permitted in areas where the individual risk to the public is lower than 1 x 10^{-6} fatalities per year
+ Sensitive land uses (hospitals, childcare facilities, etc.) are permitted in areas where the individual risk to the public is lower than 0.3 x 10^{-6} fatalities per year

As shown in Figure 5.1, the MIACC Guidelines quantify low-density residential land uses as buildings with up to ten units with ground level access per net hectare (1 unit per 100 square meters or approximately 10,000 square feet). High-density residential relates to land uses that exceed 1 unit per 100 square meters).

It is important to emphasize that these guidelines do not prohibit all activities or structures within the various risk contours, but rather restrict land use within each zone. As is the case for many other land use questions, the contours are used to define special restrictions on land uses. The guidelines are thought to be realistic in terms of existing practices of risk management and levels of risk. They are also compatible with criteria that have been selected and implemented in other industries and other countries

The acceptable levels of risk outlined in the MIACC Guidelines were used to determine the appropriate land uses and separation distances surrounding the Halifax Grain Elevator. The separation distances and risk contours were developed based on the findings of the quantitative risk assessment that was performed as documented in Sections 7 and 8 of this report.

5.4 COMPARISON OF RISK ACCEPTANCE CRITERIA

To provide context to the risk acceptance criteria outlined in the MIACC Guidelines, data associated with individual risk of accidental death is provided for comparison in Tables 5.1 and 5.2. The data was obtained from the CCPS Guidelines for Developing Quantitative Safety Risk Criteria [23]. The data in Table 5.1 is based on individual risk of accidental work related death in the United States in 2006. The data in Table 5.2 is based on individual risk of accidental death in the United States in 2003. Within Tables 5.1 and 5.2, a comparison of the individual risk of accidental death and the MIACC risk acceptance criteria is provided.

Table 5.1: Individual risk of accidental work-related death in the US (2006). Obtained from the US Bureau of Labor Statistics.

Industry	Individual risk (fatalities/year)	Comparison to MIACC risk acceptance criteria
Aircraft pilots	9.0×10^{-4}	Exceeds risk acceptance criteria for restricted land uses.
Coal mining	3.0×10^{-4}	Exceeds risk acceptance criteria for restricted land uses.
Taxi drivers	1.9×10^{-4}	Exceeds risk acceptance criteria for restricted land uses.
Wood products manufacturing	6.7×10^{-5}	Exceeds risk acceptance criteria for low-density land uses.
Chemical manufacturing	2.7×10^{-5}	Exceeds risk acceptance criteria for low-density land uses.

Notes:

- Where the individual risk exceeds the risk acceptance criteria for restricted land uses (1×10^{-4} fatalities/year), it is highlighted red.
- Where the individual risk exceeds the risk acceptance criteria for low-density land uses (1×10^{-5} fatalities/year), it is highlighted orange.
- Where the individual risk exceeds the risk acceptance criteria for high-density land uses (1×10^{-6} fatalities/year), it is highlighted yellow.
- Where the individual risk is lower than the risk acceptance criteria for sensitive land uses (0.3×10^{-6} fatalities/year), it is highlighted green.

Table 5.2: Individual risk of accidental death in the US (2003).

Cause of accidental death	Individual risk (fatalities/year)	Comparison to MIACC risk acceptance criteria
Falls, all types	5.9×10^{-5}	Exceeds risk acceptance criteria for low-density land uses.
Car occupant (crash)	5.4×10^{-5}	Exceeds risk acceptance criteria for low-density land uses.
Air travel (crash)	2.6×10^{-6}	Exceeds risk acceptance criteria for high-density land uses.
Lightening	0.16×10^{-6}	Below risk acceptance criteria for sensitive land uses.

Notes:

- Where the individual risk exceeds the risk acceptance criteria for restricted land uses (1×10^{-4} fatalities/year), it is highlighted red.
- Where the individual risk exceeds the risk acceptance criteria for low-density land uses (1×10^{-5} fatalities/year), it is highlighted orange.
- Where the individual risk exceeds the risk acceptance criteria for high-density land uses (1×10^{-6} fatalities/year), it is highlighted yellow.
- Where the individual risk is lower than the risk acceptance criteria for sensitive land uses (0.3×10^{-6} fatalities/year), it is highlighted green.

From the data shown in Tables 5.1 and 5.2, the following conclusions can be made regarding the MIACC risk acceptance criteria:

- The individual risk to aircraft pilots, coal mining personnel, and taxi drivers exceeds the risk acceptance criteria for restricted land use (1.0 x 10^{-4} fatalities per year).
- The individual risk to personnel in the wood products and chemical manufacturing industries exceeds the risk acceptance criteria for low density residential and commercial land uses (1.0 x 10^{-5} fatalities per year). The individual risk associated with falls and car accidents also exceeds the risk acceptance criteria for low-density land uses.
- The individual risk associated with airplane crashes exceeds the risk acceptance criteria for high-density land uses (1.0 x 10^{-6} fatalities per year).
- The individual risk associated with lightning strikes (0.16 x 10^{-6} fatalities/year) is lower than the risk acceptance criteria for sensitive land uses (0.3 x 10^{-6} fatalities/year).

It is important to note that the data outlined in Tables 5.1 and 5.2 is based on fatality data for the given years in the United States. The individual risk associated with these events may vary based on year and the geographical location. In addition to the data provided in Table 5.1 and 5.2, risk data from the US Department of Defence's (DOD) Risk Based Explosives Safety Criteria Team (RBESCT) is provided in Figure 5.2.

Figure 5.2: Risk data from the US Department of Defence's (DOD) Risk Based Explosives Safety Criteria Team (RBESCT).

6.0 Design Event

With respect to the Halifax Grain Elevator, the ``design event`` that would present the highest level of risk to the public is a large-scale dust explosion. A dust deflagration is a rapid combustion process in which flame propagates through a combustible medium at subsonic speeds, driven by the transfer of heat. The following four conditions are required for a dust deflagration to occur:

1. Combustible particulate of a dimension small enough to propagate a flame front is present.
2. The combustible particulate is suspended or dispersed in air or other oxidizing atmosphere.
3. A sufficient quantity of particulate is suspended to achieve the minimum explosible concentration.
4. A competent ignition source is present.

A dust explosion hazard exists when there is potential for all of the above four conditions plus a sufficient degree of confinement such that damaging overpressure may develop as a result of the rapid increase in temperature associated with the combustion process. The degree of confinement of a dust deflagration determines the resulting overpressure. The degree of confinement ranges from no confinement, through partial confinement, to complete confinement. If there is no or little confinement, a dust deflagration produces virtually no overpressure and is called a flash fire. Depending on the amount of partial confinement, damaging overpressure can occur. Total confinement results in the overpressure either reaching a maximum overpressure of the order of P_{max} for the specific material or rupture of the enclosure. Highly reactive dusts require relatively less confinement to produce higher overpressures.

Dust suspension can occur as a result of regular equipment operation, such as filling and emptying operations or pneumatic conveying. Suspension can also occur in the event of upset conditions such as equipment failure, improper maintenance activities, or as a result of fugitive dust being dispersed. Competent ignition sources include electrostatic discharge, mechanical sparks, frictional heating, hot work, and other sources that could be present in the event of upset conditions.

The conditions necessary for a fire, dust flash fire (or deflagration), and dust explosion are depicted in Figure 6.1.

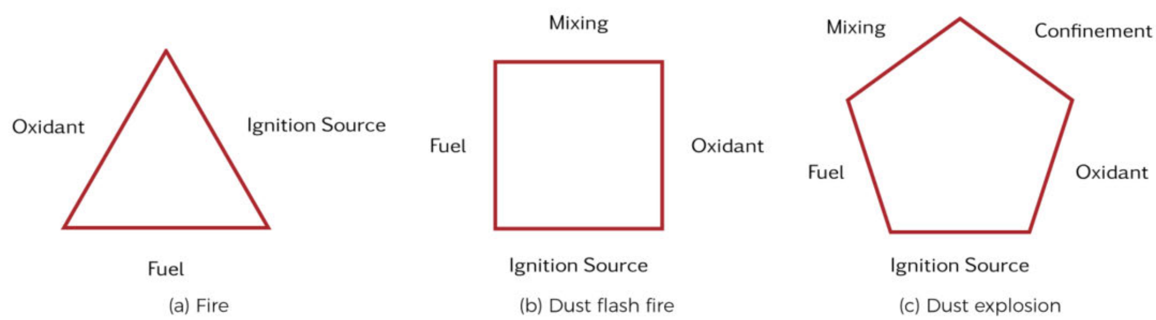


Figure 6.1: Elements needed for (a) fire, (b) dust flash fire, and (c) dust explosion.

To identify potential dust explosion scenarios that could occur at the Halifax Grain Elevator, loss history data and historical dust explosion events were reviewed as outlined in the following sections.

6.1 LOSS HISTORY FOR GRAIN ELEVATORS (OSHA)

Grain elevators present an inherent dust explosion hazard due to the quantity of combustible materials that are handled. A significant number of dust explosion events have occurred in grain elevators over the years as shown in Table 6.1. The data was obtained from the OSHA database and identifies dust explosion incidents that have occurred in grain elevators in the United States from 1976 – 2011.

Table 6.1: OSHA data for grain elevator dust explosion events.

Year range	Explosions	Injuries	Fatalities
1976 – 1980	126	281	106
1981 – 1985	91	160	37
1986 – 1990	79	46	12
1991 – 1995	59	49	6
1996 – 2000	65	82	10
2001 – 2005	37	28	5
2006 - 2011	46	31	8
Totals	**503**	**677**	**184**

6.2 LOSS HISTORY FOR THE HALIFAX GRAIN ELEVATOR

The Halifax Grain Elevator experienced a significant dust explosion event in August of 2003. The explosion originated in Workhouse #2 in the Shipper #6 (S6) bucket elevator system. The explosion destroyed cladding in the workhouse and caused severe damage to the S6 bucket elevator along with the garners and weigh scales. The explosion also damaged several lesser pieces of equipment including to the #7 and #8 baghouse systems. Figure 6.2 shows an image of the Workhouse #2 area where the explosion originated.

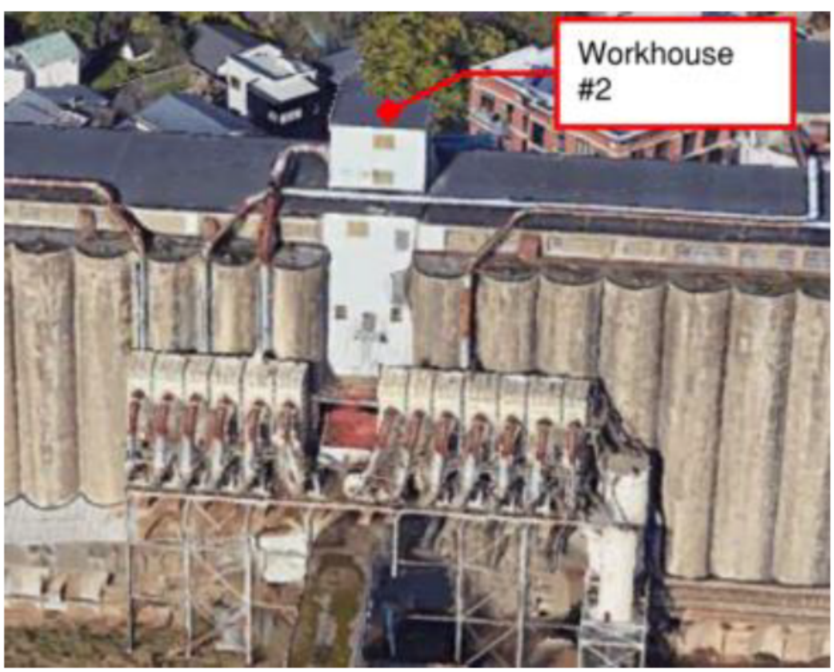


Figure 6.2: Image of the Workhouse #2 area of the facility (Google Earth).

An incident report (provided in Appendix C of this report) for the dust explosion stated that ``mechanical heat from friction`` was the most likely cause of ignition within the bucket elevator. The report stated that one of the bearings in Shipper #6 had failed due to a lack of maintenance and the elevator was off-centre. It was concluded that this would be a major factor in causing an ignition source. Shipper #5 was also examined and showed signs of friction at the drum shaft and its external cap that could have resulted in excessive heat generation. Additionally, it was found that the heat sensors on bearings within the elevators were not operating properly.

The consequences of the explosion were limited to equipment and building damage, and no fatalities or injuries occurred. Based on news reports, over 400 residents within a three block radius of the grain elevator were evacuated. It should be noted that the incident reports and news releases did not provide any information with respect to building damage in the surrounding areas.

Following the incident, the S5 and S6 systems were decommissioned and are no longer in use. The other bucket elevators in the facility were retrofitted with explosion protection systems and additional mitigating features. The workhouses were also retrofitted with explosion release cladding.

HGEL has indicated that some minor fire incidents have occurred at the facility. However, it should be noted that limited incident reports and data were available at the time this assessment was conducted.

6.3 HISTORICAL DUST EXPLOSION EVENTS

The 2003 explosion experienced at the grain elevator is representative of a bucket elevator explosion which propagated to connected equipment and building areas. To identify the worst-case dust explosion event that could occur during operation of the grain elevator, historical dust explosion events that occurred at similar facilities were reviewed to identify the probable cause and the resulting consequences. Two dust explosion events that occurred at facilities similar to the Halifax Grain Elevator include the following:

- **SEMABLA grain storage facility explosion in Blaye, France (1997)**. Information related to this incident was obtained from the summary report prepared for the Ministry of National and Regional Development and the Environment by F. Masson dated April 1998 [21].
- **DeBruce grain elevator explosion in Wichita, Kansas (1998)**. Information related to this incident was obtained from the OSHA incident report [22].

Incident reports and news releases for these events were reviewed and the probable causation and consequences associated with the explosion events are described in 6.3.1 and 6.3.2.

6.3.1 SEMABLA grain storage facility explosion

The Société d'Exploitation Maritime Blayaise (SEMABLA) grain storage facility was located in the port area of the commune of Blaye, France. The site was constructed in the 1970s and was primarily used for bulk storage of wheat, maize, and barley. The facility had the capacity to store 90,000 tons in ground level warehouses and 40,000 tons in vertical silo cells. The main structure was approximately 100 meters long, 20 meters wide, and 40 meters high and was comprised of 44 reinforced concrete silos arranged in rows of three. The silos had circular cross-sections with inside diameters of 6.2 meters and average storage heights of approximately 33 meters. In addition to the silos, 26 interspace chambers (intermediate bins) were positioned in the interstitial space between the silos.

There were two vertical towers located at the north and south ends of the structure that extended approximately 53 meters above ground level. The northern tower housed four bucket elevators along and some elements of the central dust removal circuit. The southern tower housed a set of two cleaner separators and a grading system. A gallery was located on top of the silo cells which connected the north and south towers. The area below the silos primarily housed the horizontal grain handling systems (chain and bucket elevators).

6.3.1.1 Explosion event

On August 20, 1997, a dust explosion event occurred at the facility while transporting maize to the storage silos. The explosion event is believed to have originated in the upper portion of the northern handling tower. The pressure could not be limited in the tower as there were no vent surfaces which resulted in destruction of the tower and propagation to connected building areas. The explosion propagated to the over-silo gallery where it is believed that fugitive dust was suspended, which resulted in secondary explosion events. The flame front was able to enter storage silos that were opened and entry of the jet of flames resulted in violent explosions within the silos. The explosion event resulted in destruction of the over-cell gallery which allowed communication between the gallery and the under-cell space through the interspace chambers. Figure 6.3 shows a photograph of the grain handling facility and outlines the expected path of explosion propagation.

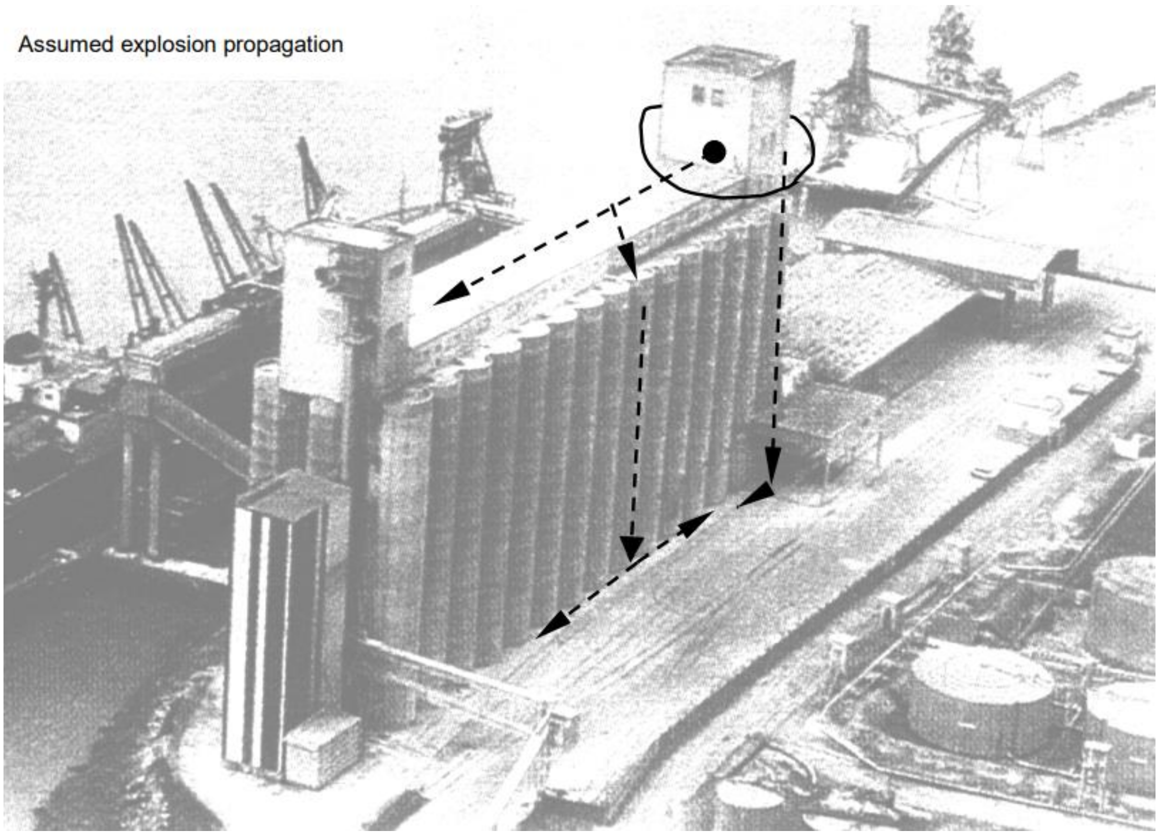


Figure 6.3: Assumed path of explosion propagation resulting from the dust explosion at the SEMABLA grain handling facility.

The exact cause of the dust explosion was not identified; however, it is believed that suspended dust in the northern handling tower may have been ignited from mechanical impacts or friction in the fan of the centralized dust removal circuit.

In general, the facility was not provided with building or equipment protection devices such as explosion vents or suppression systems, systems to remove foreign materials, or equipment temperature monitoring devices. The main structure was constructed primarily of concrete and did not allow for proper venting of the explosion and contributed to propagation.

6.3.1.2 Explosion consequences

The explosion resulted in the death of eleven individuals which included seven employees, three persons whose activity was connected to the facility, and one fisherman. The bodies of the ten individual on-site were found in the location of the administrative and technical buildings located at the base of the facility.

The event resulted in the destruction of 28 of the 44 concrete storage silos and complete destruction of the over-silo gallery. The northern handling tower was also almost completely destroyed. A photograph of the facility following the explosion event is shown in Figure 6.4.

Figure 6.4: Resulting damage to the SEMABLA grain handling facility following the dust explosion event.

With respect to other properties, the Société Chimique Routière et d'Enterprise Générale (SCREG) facility was located in the same port area with its closest point being approximately 40 meters away and its administrative building being approximately 250 meters away. The SCREG facility suffered some damage as projectiles hit some of their storage tanks and transfer pipes. During the investigation, projectiles (concrete, metal, glass) of a significant size were found at distances of up to 100 meters away. Pieces of concrete about a meter in size were found about 50 meters from the silos, and small pieces of debris weighing less than 1 kilogram were found up to 140 meters away. The closest residential areas were located approximately 230 meters from the facility and suffered minimal damage apart from broken windows reported in select locations.

6.3.2 DeBruce grain elevator explosion

The DeBruce Grain Elevator was located in Wichita, Kansas and was constructed in the 1950s. The elevator provided a total storage capacity of 20.7 million bushels and was comprised of 246 concrete storage silos and 164 intermediate bins separated into a north array and a south array. The silos were arranged in rows of three and had diameters of approximately 9.1 meters and heights of approximately 37 meters. The headhouse was located between the north and south silo arrays and stood approximately 60 meters above ground level. The headhouse contained four bucket elevator systems used to transport grain.

Bin level galleries were located above the north and south silo arrays that extended approximately 400 meters in length and 14 meters in width with ceiling heights of approximately three meters. The north and south silo arrays were each equipped with two continuous belts that were approximately 915 meters (3000 feet) in length. Each of the belts ran through one of the four tunnels located below the silos all the way up to the bin level galleries to service the silos. The area below the silos contained four 400 meter (1300 feet) tunnels for transporting grain.

6.3.2.1 Explosion event

On June 8, 1998, a dust explosion event occurred at the grain elevator while transporting grain. The event originated in the east tunnel of the south array of silos and was believed to have occurred when suspended dust particulate was ignited by frictional heat from a failed conveyor bearing. The explosion propagated north towards the headhouse and propagated into select silos along the path of travel. Within the headhouse, flame and the blast wave travelled upwards and propagated into the over-silo galleries in the north and south directions. A diagram showing the expected path of explosion propagation is shown in Figure 6.5.

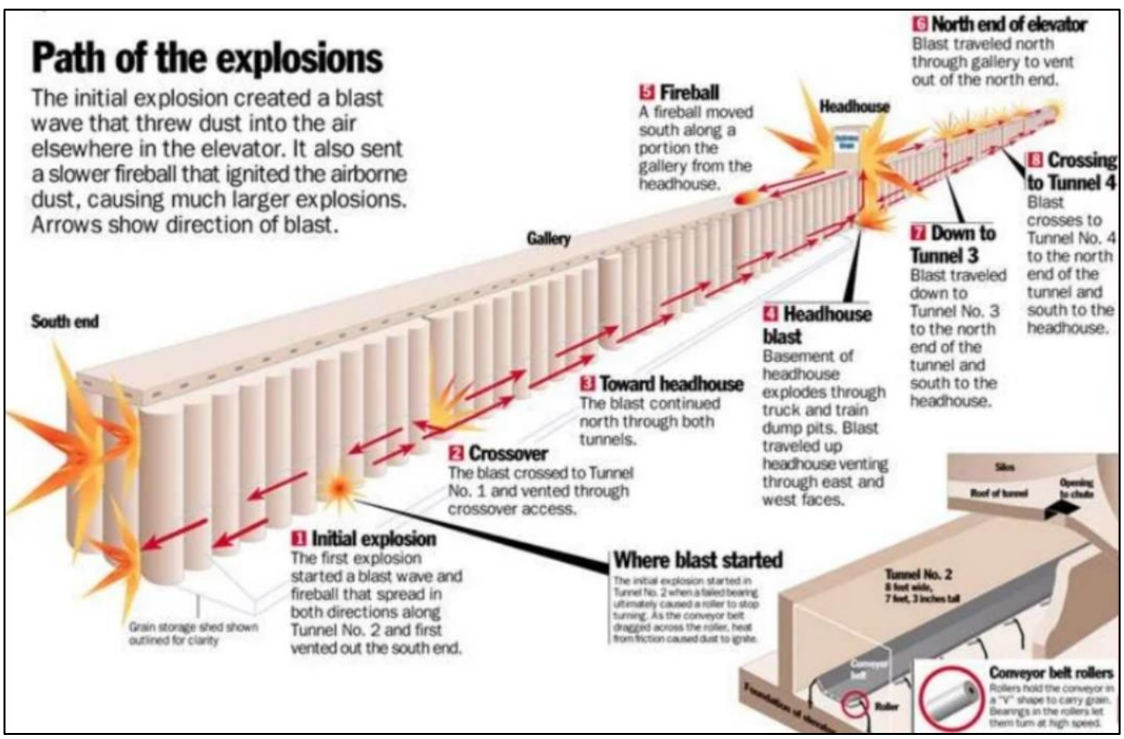


Figure 6.5: Assumed path of explosion propagation at the DeBruce grain elevator.

Witnesses reported that during elevator operation, the cloud of suspended grain dust within the tunnels was often so thick that during these times one could not see their hand in front of their face. Due to significant dust accumulation throughout the facility, the initial explosion in the east tunnel resulted in a series of secondary explosions of increasing severity as the flame jet propagated through the facility.

Limited venting provided by north gallery windows and bridges did not attenuate the blast wave. The resulting disintegration produced an extensive debris field of small fragments which were widely distributed. Based on conclusions drawn from the investigation, there may have been transition from deflagration (subsonic burning) to detonation (supersonic burning) in the combustion process.

Stemming from completion of the investigation, the following three factors were determined to be the main causation of the explosion event:

1. DeBruce grain allowed massive amounts of fuel to accumulate and distribute throughout the facility
2. DeBruce grain ignored the need to repair and restore log-failed grain dust control systems
3. DeBruce grain abandoned preventative maintenance of elevator equipment including conveying and dust control systems.

These three factors, voluntarily exercised by DeBruce in opposition to widely-known and recognized methodology for explosion prevention, were the primary factors leading to the explosion event.

6.3.2.2 Explosion consequences

The explosion resulted in the death of seven employees and injured ten. The south silo array, where the explosion originated, suffered the least amount of damage. However, it was still severely damaged as the explosion vented out the south end tunnels. The headhouse suffered significant damage as the blast vented out of the east and west faces of the structure. The over-silo gallery was significantly damaged along with a significant number of silos. The majority of the silos that were damaged had ruptured at the top while several were completely destroyed. A photograph of the facility following the explosion event is shown in Figure 6.6.

Figure 6.6: Resulting damage to the DeBruce grain elevator.

6.4 WORST-CASE EXPLOSION EVENT (HGE)

In both the SEMABLA and DeBruce explosion events, the dust explosion occurred while transporting grains in galleries and handling towers. These explosions resulted in propagation of flame jets and overpressure to other areas of the facility including galleries and storage silos which resulted in several secondary explosions. It is important to note that no grain elevator explosion has a singular cause and several factors lead to the dust explosions at both facilities including lack of explosion protection and control systems, neglected maintenance, and insufficient housekeeping. As outlined in Section 4, the workhouses at the Halifax Grain Elevator are equipped with explosion release cladding as a form of building deflagration venting. The bucket elevator systems in the workhouses are also equipped with explosion protection and monitoring devices. However, this does not eliminate the potential for a dust explosion event to occur within the facility and propagate to other areas or equipment.

Established residential areas are located on the western side of the grain elevator facility which include low-density and high-density land uses. As such, the outermost row of silos on the western side of each annex are the closest points to areas occupied by the general public. The silos contain high quantities of combustible material as each silo in Annex 1-3 can store up to 500 tons of wheat and each silo in Annex 4 can store up to 1900 tons of wheat. As such, a dust explosion event that occurs within or propagates into one or more of the storage silos would present the greatest external risk to the public in the area surrounding the Halifax Grain Elevator.

An explosion event involving one or more of the silos could occur under any of the following circumstances (refer to Figure 6.7):

1. Suspended dust particulate is ignited during silo filling or emptying operations resulting in an explosion within the silo.
2. A dust explosion in one of the silos propagates to the adjacent silo or gallery area resulting in secondary dust explosions.
3. A dust explosion in a bin level gallery, basement level gallery, or workhouse tower could propagate to one or more of the silos resulting in a secondary explosion.

Given the relatively large particle size distribution of the material handled by the silos, it is considered unlikely that an explosion would originate within one of the silos; however, it is not impossible as fine dust particulate could be suspended during loading and unloading operations. The more likely scenario is a dust explosion occurring in one of the galleries or workhouse towers and propagating to the silos resulting in a series of secondary explosions.

To account for the worst-case explosion scenario, it was conservatively assumed that the following conditions would be present in the silos in the event of an explosion:

- The silos are filled with the optimum concentration of combustible dust.
- All of the dust particulate within the silo takes part in the explosion (i.e. has a particle size distribution small enough to propagate flame).

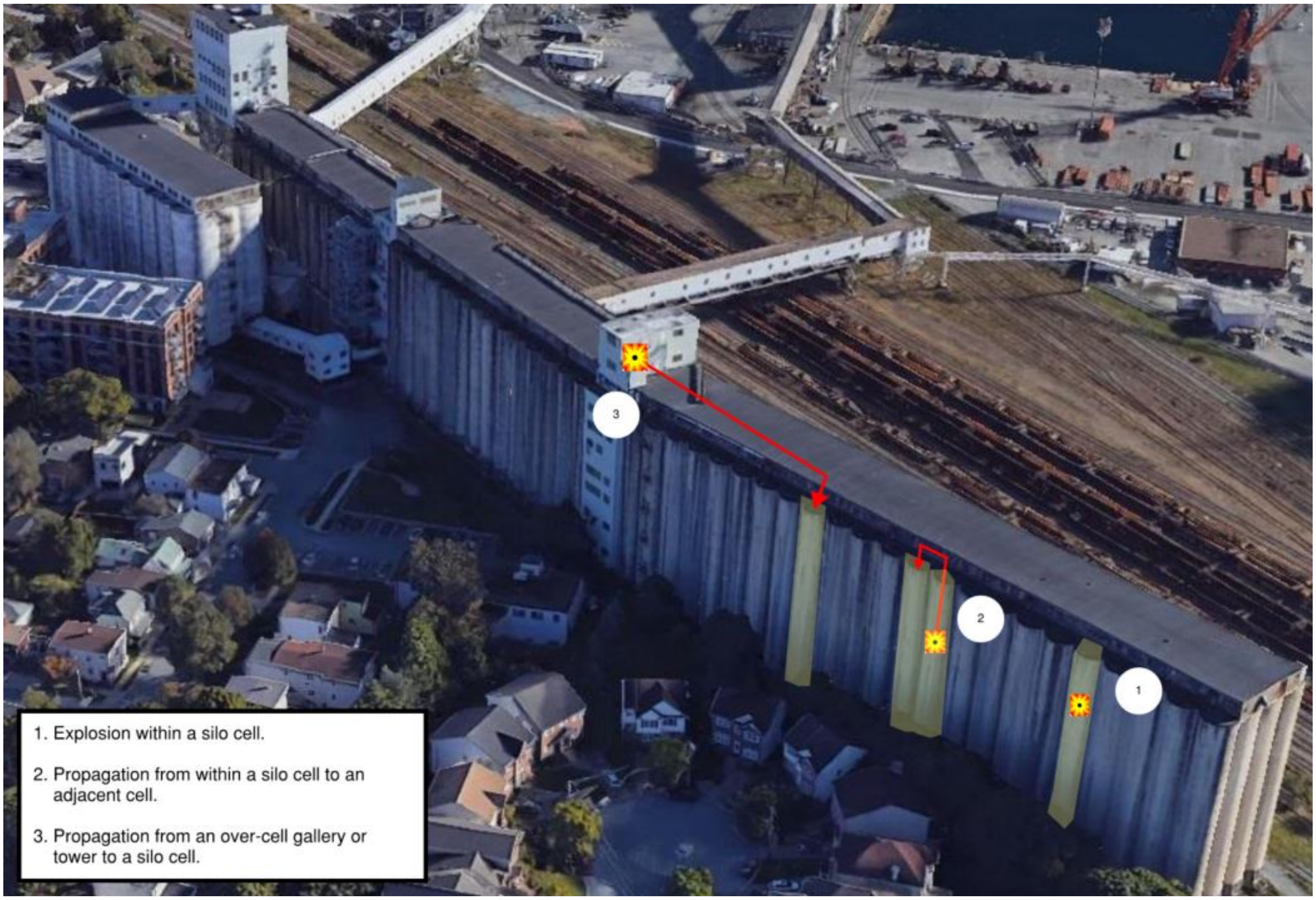


Figure 6.7: Potential scenarios resulting in silo dust explosions.

There is the potential that an explosion in one of the galleries, workhouse towers, or other process equipment would not result in propagation to the silos. As propagation to the silos is considered the "worst-case" event, it is considered to encompass the risk associated with any and all potential combustible dust explosion events that could occur within the facility.

7.0 Risk analysis methodology

The acceptable land uses and separation distances surrounding the Halifax Grain Elevator were determined based on the acceptable risk criteria outlined in the MIACC Guidelines. To determine the allowable land uses surrounding the grain elevator, it was necessary to determine the individual risk posed to the public in the event of a large-scale dust explosion as described in Section 6. The individual risk is defined as the frequency at which an individual may be expected to sustain a given level of harm (i.e. death) from the realization of specified hazards.

To determine the individual risk, a quantitative risk assessment was performed to estimate the following:

+ The likelihood or frequency of the dust explosion event.
+ The consequences (probability of fatality) posed to the public by the event.
+ The associated risk in quantitative terms (fatalities per year).

The individual risk was calculated using the following equation:

$$\text{Risk} = \text{Event Frequency } \times \text{Event Consequence} \quad (5)$$

The frequency represents the probability of ignition resulting in a dust explosion event and is defined as events per year. For the purpose of this assessment and in accordance with the MIACC guidelines, the consequences are defined in terms of fatalities per year. The consequences are based on the potential effects that would be presented in the event of the described dust explosion scenario. An overview of the quantitative risk assessment process with respect to the dust explosion event is shown in Figure 7.1.

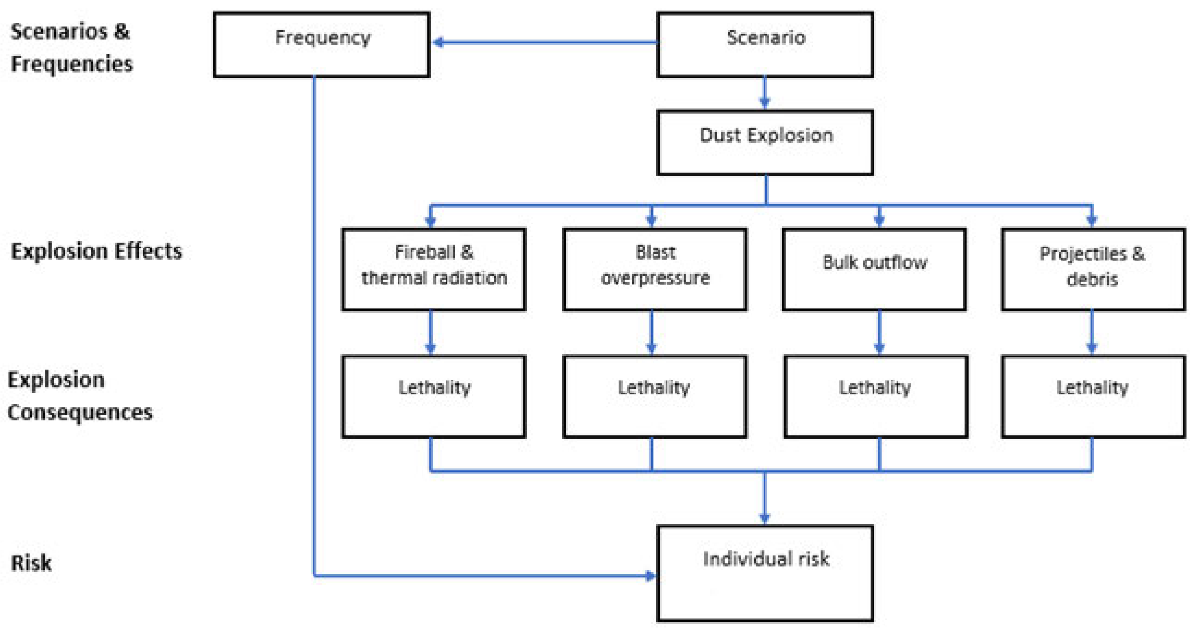


Figure 7.1: Overview of the quantitative risk assessment process.

The first step in the risk assessment process was identifying the scenario that could present consequences to the public on the exterior of the facility. As described in Section 6, a large-scale dust explosion event that occurs within or propagates to one or more of the silos is considered to present the worst-case with respect to public risk in the area surrounding the grain elevator. The next steps in the risk assessment process involve estimating the explosion effects, consequences, and frequency.

7.1 EXPLOSION EFFECTS AND CONSEQUENCES

In the event of a large-scale dust explosion, the potential explosion effects that could present a risk of fatality to the public in the vicinity of the grain elevator include the following:

- **Blast overpressure:** In the event of an explosion there is the potential that the silos will rupture resulting in a pressure wave being transmitted to the external area surrounding the silos.
- **Fireball and thermal radiation:** In the event of silo rupture due to an explosion, a flame jet would be expected to propagate to the external area surrounding the silos.
- **Bulk outflow:** In the event of silo failure due to an explosion, the bulk contents would be expected to be discharged from the silo into a conical pile at the base of the silo which presents a potential entrapment or engulfment hazard.
- **Projectiles and debris:** In the event of an explosion, it is expected that the ruptured silo will break into fragments that will be launched into the external area surrounding the silos. It is expected that the silo wall and the roof/over-silo gallery may contribute to projectiles.

Each explosion effect described above presents potential consequences to the public in the adjacent land uses. The consequences were estimated in terms of probability of fatality. Assessments of the individual consequences are outlined in Section 8 of this report. The risk associated with the explosion scenario is then equivalent to the risk associated with all of the consequences and is calculated as follows:

$$Risk = Risk_{fireball} + Risk_{overpressure} + Risk_{radiation} + Risk_{bulk\ outflow} + Risk_{wall\ debris} + Risk_{roof\ debris} \quad (5)$$

To obtain quantitative values (probability of fatality) for select explosion consequences including overpressure and thermal radiation, probit functions were used as described in the following section.

7.1.1 Probit functions to estimate probability of fatality

In order to estimate the level of harm posed to an individual by explosion effects it is necessary to provide a means to quantify the harm in terms of the intensity, duration of exposure and consequences of effect. This is usually achieved by an estimation of the received dose and a comparison of this against, statistically manipulated, experimental data to determine the probability of harm to an exposed population or individual. Vulnerability criteria can be established to determine dose levels that result in specific consequences. There are two main approaches for the determination of the effects of received dose: the use of Probit Functions and the Determination of Harmful Dose.

Probit functions account for the variation in tolerance to harm for an exposed population. The fatality rate of personnel exposed to harmful agents over a given period of time can be calculated by use of probit functions that typically take the following form:

$$Y = k_1 + k_2(lnV)$$

Where k_1 and k_2 are constants, and V is the product of intensity or concentration of received hazardous agent. The obtained probit, *Y*, has a value in the range of 2.67 to 8.09 which corresponds to a percentage of fatality from 1% to 99.9%. The fatality probability is determined by evaluation of Y on a probit transformation chart as shown in Figure 7.2.

Probit Table

Percentage affected - probit transformation (taken from Finney, D.J., 1971. probit analysis, p25).

%	0	1	2	3	4	5	6	7	8	9
0	-	2.67	2.95	3.12	3.25	3.36	3.45	3.52	3.59	3.66
10	3.72	3.77	3.82	3.87	3.92	3.96	4.01	4.05	4.08	4.12
20	4.16	4.19	4.23	4.26	4.29	4.33	4.36	4.39	4.42	4.45
30	4.48	4.50	4.53	4.56	4.59	4.61	4.64	4.67	4.69	4.72
40	4.75	4.77	4.80	4.82	4.85	4.87	4.90	4.92	4.95	4.97
50	5.00	5.03	5.05	5.08	5.10	5.13	5.15	5.18	5.20	5.23
60	5.25	5.28	5.31	5.33	5.36	5.39	5.41	5.44	5.47	5.50
70	5.52	5.55	5.58	5.61	5.64	5.67	5.71	5.74	5.77	5.81
80	5.84	5.88	5.92	5.95	5.99	6.04	6.08	6.13	6.18	6.23
90	6.28	6.34	6.41	6.48	6.55	6.64	6.75	6.88	7.05	7.33
%	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
99	7.33	7.37	7.41	7.46	7.51	7.58	7.65	7.75	7.88	8.09

Figure 7.2: Probit transformation table (Finney, 1971).

7.2 EVENT FREQUENCY

A combustible dust deflagration has the potential to occur when the following four conditions are present. A dust explosion has the potential to occur when all four conditions exist along with a sufficient degree of confinement.

1. Combustible particulate is present with a particle size small enough to propagate flame.
2. The particulate is suspended in air or other oxidizing medium.
3. The concentration of suspended particulate exceeds the minimum explosible concentration.
4. A competent ignition source is present.

Estimating the likelihood or frequency of a dust explosion in grain handling facilities can be difficult as there is no definitive or agreed upon methodology available. Explosion frequencies for grain storage facilities are outlined in the article "Frequency of Dust Explosion in Grain Storage" [17] and are based on historical data for grain dust explosions from US databases. The article provides estimated explosion frequencies for grain handling facilities based on the quantities of material handled, the material type, and the operative hours per year. The frequency data outlined in the article is summarized in Table 7.1.

Table 7.1: Estimated frequency of explosion in grain handling facilities [17].

	Estimated frequency of dust explosion (events per year)			
Tons handled per year	Barley	Corn	Oats	Wheat
50,000	3.61×10^{-7}	3.29×10^{-7}	1.10×10^{-6}	2.03×10^{-7}
250,000	1.81×10^{-6}	1.65×10^{-6}	5.48×10^{-6}	1.02×10^{-6}
500,000	3.61×10^{-6}	3.29×10^{-6}	1.10×10^{-5}	2.03×10^{-6}
750,000	5.42×10^{-6}	4.94×10^{-6}	1.64×10^{-5}	3.05×10^{-6}
1,000,000	7.23×10^{-6}	6.58×10^{-6}	2.19×10^{-5}	4.07×10^{-6}

The estimated data outlined in Table 7.1 is based on 2000 operative hours per year. Based on the handling capacity for wheat dust, the Halifax Grain Elevator would present an explosion frequency of approximately 1.02 x 10^{-6} events per year. The estimated frequency data outlined in Table 7.1 is based on historical data for various types of grain handling facilities. It is unknown if this frequency data is directly applicable to the grain elevator. As such, a more conservative approach was taken to estimating the frequency of a dust explosion at the facility.

A methodology for estimating the frequency of a dust explosion in a grain handling facility is outlined in the paper "A quantitative risk assessment tool for the external safety of industrial plants with a dust explosion hazard" [18]. The methodology is based on the explosion incident that occurred at the SEMABLA grain handling facility in Blaye, France, as described in Section 6.3 of this report. The paper provides an indication of the frequency of ignition in two types of modules which include inside a silo cell and in an over-silo gallery or handling tower. The frequencies are summarized in Table 7.2.

Table 7.2: Frequencies and probabilities of various events [18].

Event	Frequencies and probabilities
Ignition in a silo cell	1 x 10^{-5} per year
Ignition in an over-cell gallery or handling tower	1 x 10^{-4} per year
Propagation to a direct neighbouring module	10%
Propagation to a remote neighbouring module	1%
Propagation outside the group	0%

A group of four modules is shown in Figure 7.3. This group consists of a conveyor gallery (*i* = 1) connecting three individual silo cells (*i* =2, 3, and 4). The conveyor gallery is the direct neighbor of the silo cells while a remote neighbor relationship holds between the silo cells.

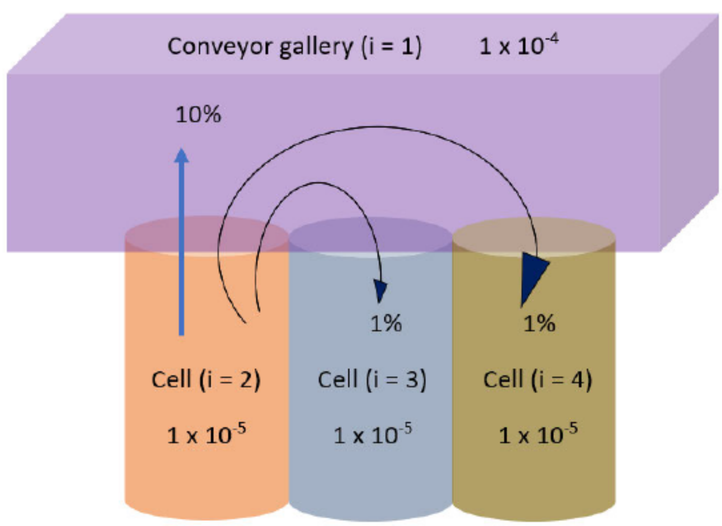


Figure 7.3: A group of four modules. The frequencies of ignition are indicated, as well as the probabilities of propagation from the leftmost silo towards the others.

Based on the information in Table 7.1, both a vector with the frequency of ignition (P_i) and a correlation matrix with the probabilities of propagation from module *i* to *j* ($P_{cor,\, ij}$) are defined as follows (Klein et al., 2006) [18]:

$$P_i = \begin{pmatrix} 1 \\ 2 \\ 3 \\ 4 \end{pmatrix} = \begin{pmatrix} 1 \times 10^{-4} \\ 1 \times 10^{-5} \\ 1 \times 10^{-5} \\ 1 \times 10^{-5} \end{pmatrix} \quad (6)$$

$$P_{cor,ij} = \begin{pmatrix} 11 & 12 & 13 & 14 \\ 21 & 22 & 23 & 24 \\ 31 & 32 & 33 & 34 \\ 41 & 42 & 43 & 44 \end{pmatrix} = \begin{pmatrix} 0 & 0.1 & 0.1 & 0.1 \\ 0.1 & 0 & 0.01 & 0.01 \\ 0.1 & 0.01 & 0 & 0.01 \\ 0.1 & 0.01 & 0.01 & 0 \end{pmatrix} \quad (7)$$

Based on the frequency of operations of the silos (Section 3.2), the ignition frequencies for the individual silos and the over-cell gallery can be modified as follows:

$$P_i = \begin{pmatrix} 1 \\ 2 \\ 3 \\ 4 \end{pmatrix} = \begin{pmatrix} 0.25 \times 1 \times 10^{-4} \\ 0.01 \times 1 \times 10^{-5} \\ 0.01 \times 1 \times 10^{-5} \\ 0.01 \times 1 \times 10^{-5} \end{pmatrix} = \begin{pmatrix} 2.5 \times 10^{-5} \\ 1 \times 10^{-7} \\ 1 \times 10^{-7} \\ 1 \times 10^{-7} \end{pmatrix} \quad (8)$$

The frequency of ignition in a module, not followed by propagation to any of the other modules (a mono scenario) can be calculated from:

$$P_{mono,i} = P_i \prod_j (1 - P_{cor,ij}) \quad (9)$$

The number of different domino scenarios increases rapidly with the number of silos in an annex or group, as can be shown with Newton's binomial theorem. The summed frequency of all domino scenarios equals:

$$P_{domino,total} = \sum_i (P_i - P_{mono,i}) \quad (10)$$

The explosion frequency estimation methodology outlined above accounts for four modules. With respect to the Halifax Grain Elevator, the silos in Annexes 1-3 are arranged in rows of four with intermediate bins located in the interstitial space as shown in Figure 7.4. As such, it has been conservatively assumed that a total of nine modules (six silos, two intermediate bins, and the over-cell gallery) could participate.

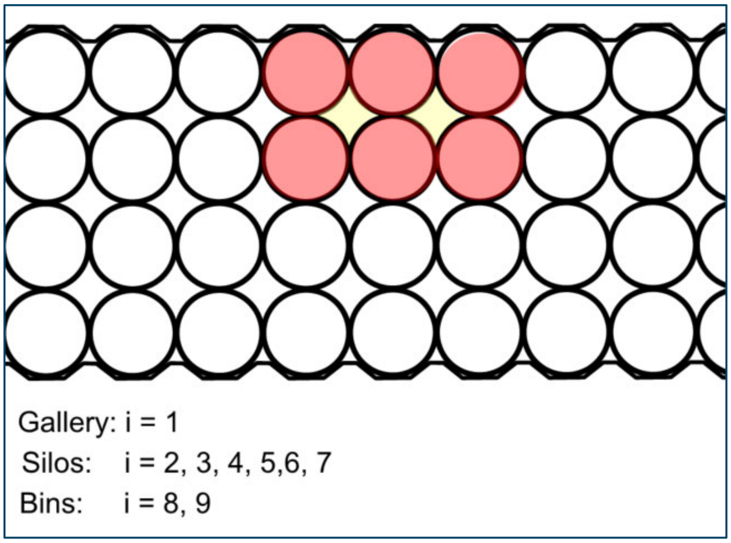


Figure 7.4: Modules considered for the purpose of explosion frequency estimation.

Using nine modules and accounting for the frequency of operation, the following vector and correlation matrix are obtained:

$$P_i = \begin{pmatrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \end{pmatrix} = \begin{pmatrix} 0.25 \times 1 \times 10^{-4} \\ 0.01 \times 1 \times 10^{-5} \\ 0.01 \times 1 \times 10^{-5} \\ 0.01 \times 1 \times 10^{-5} \\ 0.01 \times 1 \times 10^{-5} \\ 0.01 \times 1 \times 10^{-5} \\ 0.01 \times 1 \times 10^{-5} \\ 0.01 \times 1 \times 10^{-5} \\ 0.01 \times 1 \times 10^{-5} \end{pmatrix} = \begin{pmatrix} 2.5 \times 10^{-5} \\ 1 \times 10^{-7} \\ 1 \times 10^{-7} \\ 1 \times 10^{-7} \\ 1 \times 10^{-7} \\ 1 \times 10^{-7} \\ 1 \times 10^{-7} \\ 1 \times 10^{-7} \\ 1 \times 10^{-7} \end{pmatrix} \quad (11)$$

$$P_{cor,ij} = \begin{pmatrix} 11 & 12 & 13 & 14 & 15 & 16 & 17 & 18 & 19 \\ 21 & 22 & 23 & 24 & 25 & 26 & 27 & 28 & 29 \\ 31 & 32 & 33 & 34 & 35 & 36 & 37 & 38 & 39 \\ 41 & 42 & 43 & 44 & 45 & 46 & 47 & 48 & 49 \\ 51 & 52 & 53 & 54 & 55 & 56 & 57 & 58 & 59 \\ 61 & 62 & 63 & 64 & 65 & 66 & 67 & 68 & 69 \\ 71 & 72 & 73 & 74 & 75 & 76 & 77 & 78 & 79 \\ 81 & 82 & 83 & 84 & 85 & 86 & 87 & 88 & 89 \\ 91 & 92 & 93 & 94 & 95 & 96 & 97 & 98 & 99 \end{pmatrix} = \begin{pmatrix} 0 & 0.1 & 0.1 & 0.1 & 0.1 & 0.1 & 0.1 & 0.1 & 0.1 \\ 0.1 & 0 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 \\ 0.1 & 0.01 & 0 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 \\ 0.1 & 0.01 & 0.01 & 0 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 \\ 0.1 & 0.01 & 0.01 & 0.01 & 0 & 0.01 & 0.01 & 0.01 & 0.01 \\ 0.1 & 0.01 & 0.01 & 0.01 & 0.01 & 0 & 0.01 & 0.01 & 0.01 \\ 0.1 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0 & 0.01 & 0.01 \\ 0.1 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0 & 0.01 \\ 0.1 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0 \end{pmatrix} \quad (12)$$

Using Equations 11 and 12, the frequency of ignition for all domino scenarios involving nine modules was estimated as follows. The detailed calculations are provided in Appendix A.1.

$$\boldsymbol{P_{domino,total} = 1.44 \times 10^{-5} \; events\ per\ year}$$

As such, the frequency of a dust explosion event occurring at the Halifax Grain Elevator is considered to be 1.44 x 10^{-5} events per year for the purpose of the quantitative risk assessment.

8.0 Risk Assessment

8.1 BLAST OVERPRESSURE

In the event of an explosion in the silo causing a rupture, a pressure wave will be released into the external area surrounding the silo. It is assumed that for the unvented silo, the silo chute on the roof is its weakest member and will yield first, followed by the silo roof, and then the silo wall. As the silo chute only has a limited effect on the explosion pressure, the silo roof is expected to fail shortly after the silo chute has been blown off.

The maximum overpressure experienced in the external area surrounding the silo is dependent upon the maximum overpressure developed in the silo and the failure area (rupture size) created in the event of an explosion.

8.1.1 Silo burst pressure

The silos consist of cylindrical concrete structures that are reinforced with rebar. The silo burst pressure is the overpressure developed in the event of an explosion that results in structural failure (rupture). The burst pressures of the silos were calculated based on the tensile strength, diameters, and wall thicknesses. The burst pressure is commonly calculated using Barlow or Lame equations. The Barlow equation can be used to estimate either the burst pressure or yield pressure, depending on whether the yield strength or the ultimate tensile strength is used in the equation, which is given as:

$$P = \frac{2 \cdot t \cdot S}{d_o} \tag{13}$$

Where t is the silo wall thickness, S is the stress (ultimate tensile stress or yield stress) and d_o is the inner diameter of the silo. The ultimate tensile strength is used to find the bursting pressure or the point at which the structure ultimately fails. The ultimate tensile strength of the silos is based on the strength of the concrete and the reinforcements. The reinforcement details for the silos in Annexes 1-3 were obtained from the silo concrete design drawings provided by HPA (Appendix C) and the details are summarized in Table 8.1.

Table 8.1: Silo reinforcement details.

Silos	Reinforcement	Measurement	Description
Annexes 1-3	Longitudinal	$18\text{—}\frac{5''}{8}$ ϕ VERTS @ $24''$O.C.	Eighteen pieces of 5/8-inch (16 mm) diameter rebar spaced at 24-inches (0.61 m) centre-to-centre.
	Horizontal	$\frac{1''}{2}$ ϕ HOR @ $24''$O.C.	½-inch (12.7 mm) diameter rebar spaced at 31-inches (0.79 m) centre-to-centre.

Based on the information outlined in Table 8.1, the reinforcement ratio of the silo wall was calculated using the following equation:

$$Reinforcement\ ratio = \frac{Area\ of\ steel}{Area\ of\ concrete} \tag{14}$$

$$Reinforcement\ ratio = \frac{0.00016\ \mathrm{m}^2\ (in\ a\ unit\ length\ of\ silo\ wall)}{1\ \mathrm{m}\ \times 0.18\ \mathrm{m}} = 0.10\%$$

If the ultimate tensile strength of the concrete is taken as 2-5 MPa and the ultimate tensile strength of the rebar is 400 MPa, the ultimate tensile strength of the reinforced concrete is estimated as 5.7 MPa (57 bar). Using these estimates, the burst pressure of the reinforced concrete silos in Annexes 1-3 was calculated as follows:

$$P = \frac{2 \cdot 0.18 \cdot 5.7}{5.1} = \mathbf{0.40\ bar}$$

Based on the calculations, the burst pressure for the silos was estimated to be 0.40 bar. It is important to note that the reinforcement details for the Annex 4 silos were not able to be obtained from the provided design drawings. As such, the burst pressure of the silos in Annex 4 was assumed to be equivalent to the silos in Annexes 1-3.

8.1.1.1 Assumptions and limitations

The following assumptions were made to conduct the silo burst pressure calculations:

1. The silos at the HGE are configured in groups. To simplify the calculations, they were treated as stand-alone units.
2. The reinforcement details of the silos in Annex 3 were assumed to be representative of the silos in Annexes 1 and 2.
3. It was assumed that the burst pressure of the silos in Annex 4 is equivalent to the bust pressure of the silos in Annexes 1-3.
4. The deterioration of the silos due to exposure to humidity and saline environment, and potential concrete carbonation are not considered in this analysis.

8.1.2 Estimated rupture area

The failure size or rupture area that would be developed in the event of an explosion in one of silos was estimated by performing vent size calculations in accordance with NFPA 68, "Standard on Explosion Protection by Deflagration Venting" [5]. The input design parameters for the vent size calculations are summarized in Table 8.2. The explosion severity parameters (P_{max} & K_{St}) are based on a combination of the worst-case parameters obtained from literature for wheat and wood pellet dusts as described in Section 3 of this report.

Table 8.2: Design input parameters for the vent size calculations.

Equipment	P_{max} (bar-g)	K_{St} (bar- m/s)	P_{red} (bar-g)	P_{stat} (bar-g)	V (m^3)
Silos Annex 1-3	9.0	170	0.40	0.40	672
Silos Annex 4	9.0	170	0.40	0.40	2560

P_{red} is the reduced explosion pressure that is developed in a vented deflagration; however, in this case, P_{red} is considered to represent the burst pressure of the silos calculated in Section 8.1.1. P_{stat} is the static vent opening pressure. As the silos are unvented, P_{stat} is also set equal to the silo burst pressure.

The vessel length-to-diameter ratio is determined in accordance with NFPA 68. The maximum flame length along which the flame can travel, H, is the maximum distance, taken along the central axis of the silo, from the farthest end of the enclosure to the opposite end of the vent. The effective volume of the silo, V_{eff}, is the equipment volume that can participate in the explosion. The effective area, A_{eff}, is determined by dividing V_{eff} by H. The effective hydraulic diameter, D_{he}, for the silo is determined based on the general shape of the silo taken normal to the central axis. The L/D ratio was calculated using the following equation:

$$L/D = H/D_{he} \quad (15)$$

The calculated parameters outlined above are summarized in Table 8.3 for the silos. The detailed calculations are provided in Appendix A.2.

Table 8.3: Summary of calculated silo parameters.

Equipment	V_{eff} (m^3)	H (m)	A_{eff} (m^2)	D_{he} (m)	L/D
Silos Annex 1-3	672	32.9	20.4	5.10	6.45
Silos Annex 4	2560	32.9	77.8	9.95	3.31

The minimum required vent area was calculated using the following equation outlined in NFPA 68:

$$A_{v0} = 1 \cdot 10^{-4} \cdot (1 + 1.54 \cdot P_{stat}{}^{4/3}) \cdot K_{St} \cdot V^{3/4} \cdot \sqrt{\frac{P_{max}}{P_{red}} - 1} \quad (16)$$

Depending on certain design criteria of the silo, some correction factors may need to be applied to the minimum required vent size, A_{v0}. For L/D values greater than 2 and less than or equal to 6 (or 8 for silos), the required vent area, A_{v1}, is calculated as follows:

$$A_{v1} = A_{v0}\left[1 + 0.6 \cdot \left(\frac{L}{D} - 2\right)^{0.75} \cdot exp\left(-0.95 \cdot \left(\frac{P_{red}}{1 + P_{initial}}\right)^2\right)\right] \quad (17)$$

The effects of turbulence, panel inertia, partial volume, and vent ducts are not applicable for the silos. As such, the required vent area, A_{vf}, is equal to A_{v1}. The results of the vent size calculations are summarized in Table 8.4.

Table 8.4: Summary of required vent area (estimated failure size) calculations.

Equipment	Required vent area (failure size) (m^2)
Silos Annex 1-3	39.0
Silos Annex 4	67.2

The calculated vent areas outlined in Table 8.4 are assumed to be representative of the failure or rupture size that would be produced in the silo wall/roof in the event of an explosion.

8.1.2.1 Assumptions and limitations

The following assumptions were made to estimate the rupture area that would be developed in the event of a silo explosion:

1. The reduced pressure (P_{red}) and static vent opening pressure (P_{stat}) were set equivalent to the burst pressure (0.40 bar-g) as it was assumed that the silo would fail when the burst pressure is reached.
2. The maximum overpressure (P_{max}) and explosion severity (K_{st}) used in the analysis were based on reference explosibility parameters for wood and wheat dusts.
3. It was assumed that the explosion event would involve the entire volume of the silo and partial volume explosion effects were not considered.

8.1.3 External overpressure

It is conservatively assumed that the pressure wave that will be discharged to the external area will be radiated equally in all directions. Based on NFPA 68, the maximum external peak overpressure $P_{max,a}$ (bar-g) for a "vented" silo is calculated as follows:

$$P_{max,a} = 0.2 \cdot P_{red} \cdot A_v^{0.1} \cdot V^{0.18} \quad (18)$$

Where A_v is the area of the vent opening, P_{red} is the maximum pressure developed within the vessel (in this case the burst pressure), and V is the internal volume of the silo. In this case, the area of the vent opening is assumed to be equivalent to the failure (rupture) area that is expected in the event of an explosion.

To determine the horizontal and vertical distances from the silo where the maximum overpressure ($P_{max,a}$) will be experienced, the following equations are used:

$$R_{s-vertical} = \alpha \cdot D = 0.25 \cdot L_f \quad (19)$$

$$\mathrm{R_{s-horizontal}} = \alpha \cdot D = 0.20 \cdot \mathrm{L_f} \quad (20)$$

Where L_f is the maximum flame length (fireball diameter) that would be developed in the event of an explosion. The maximum flame length, L_f, is estimated in Section 8.2.

The maximum external overpressures and associated distances where the overpressure is experienced were calculated using equations 18 – 20 and are summarized in Table 8.5.

Table 8.5: Maximum external overpressure estimation.

Equipment	L_f (m)	$P_{max,a}$ (bar-g)	$R_{s-vertical}$ (m)	$R_{s-horizontal}$ (m)
Silos Annex 1-3	23	0.37	5.8	4.6
Silos Annex 4	36	0.50	9.0	7.2

According to NFPA 68, for distances longer than $(\alpha \cdot D)$, the overpressure *P* (bar) at a distance *r* (m) from the vent can be calculated as:

$$P_{max,r} = P_{\mathrm{max,a}}(\alpha \cdot D/r) = P_{\mathrm{max,a}}(R_s/r) \quad (21)$$

Using Equation 21, the maximum overpressures at various distances from the silos were calculated. The results of the calculations are summarized in Tables 8.6.

Table 8.6: External pressure in the vertical and horizontal directions around the silos.

Equipment	Distance from silo (m)	P_{max} – Vertical (bar-g)	P_{max} – Horizontal (bar-g)
Silos Annex 1-3	5	0.36	0.34
	10	0.21	0.17
	15	0.14	0.11
	20	0.11	0.09
	25	0.09	0.07
	30	0.07	0.06
	35	0.06	0.05
	40	0.05	0.04
	45	0.05	0.04
Silos Annex 4	5	0.50	0.50
	10	0.45	0.36
	15	0.30	0.24
	20	0.23	0.18
	25	0.18	0.14
	30	0.15	0.12
	35	0.13	0.10
	40	0.11	0.09
	45	0.10	0.08

8.1.4 Consequences of overpressure effects

The main parts of the body directly susceptible to the damaging effects of overpressure are the eardrums and lungs. Lung damage can be fatal and an example of the consequences in terms of probability of injury or fatality, as suggested by the Australian Petroleum Production & Exploration Association Limited (APPEA) [19] is shown in Table 8.7.

Table 8.7: Explosion overpressure effects.

Overpressure (bar-g)	Consequences
0.210	20% probability of fatality to personnel inside 0% probability of fatality in the open
0.350	50% probability of fatality inside 15% probability of fatality in open
0.700	100% probability of fatality inside or in unprotected structures

To be conservative, it was assumed that the developed overpressures will affect a person located indoors. To determine the consequences (probability of fatality) associated with the overpressure at various distances, probit functions were utilized to convert the overpressure to probability units. Based on the data outlined in Table 8.7, the following probit functions were utilized:

$$For\ P\ \leq 0.35\ bar: \quad Y = 6.727 + 1.645\ (\ln(\mathrm{P}))$$
$$For\ P\ > 0.35\ bar: \quad Y = 9.68 + 4.458\ (\ln(\mathrm{P})) \qquad (22)$$

Where *Y* represents the probit value and *P* is the overpressure. The constants were obtained through linear interpolation using the values outlined in Table 8.7. The probability of fatality was then determined by using a probit transformation table. The probability of fatality was estimated using the methodology outlined above and the results are summarized Figure 8.1.

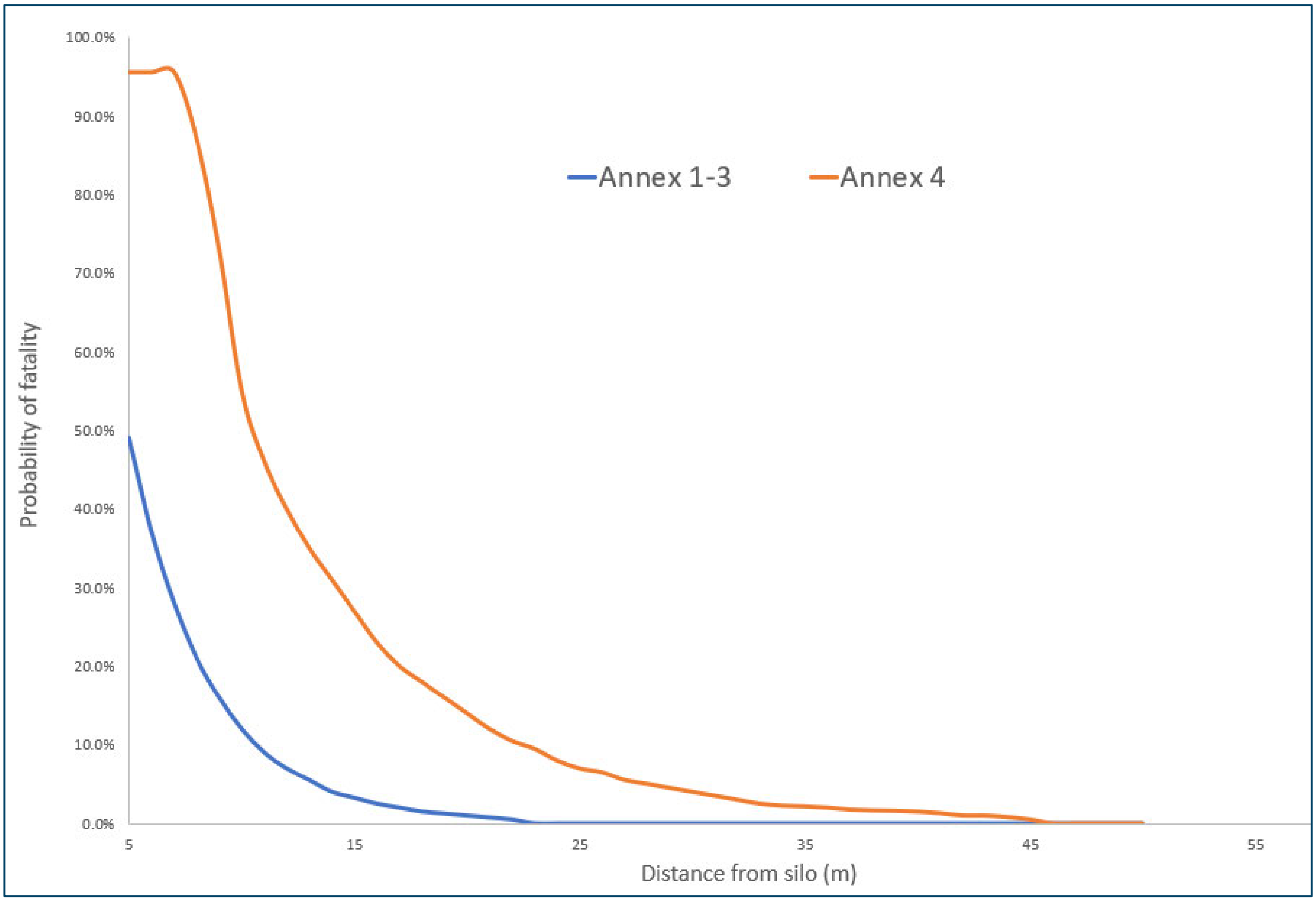


Figure 8.1: Probability of fatality associated with overpressure effects in the event of a silo explosion.

8.1.4.1 Assumptions and limitations

The following assumptions were made to estimate the probability of fatality associated with overpressure in the event of a silo dust explosion:

1. It was assumed that the individual affected by the overpressure would be located indoors as this results in a greater consequence.

8.1.5 Risk associated with overpressure effects

The risk associated with overpressure effects is based on the probability of fatality and the event frequency. The estimated risk associated with overpressure at various distances from the silos is communicated in fatalities per year and is summarized in Figure 8.2.

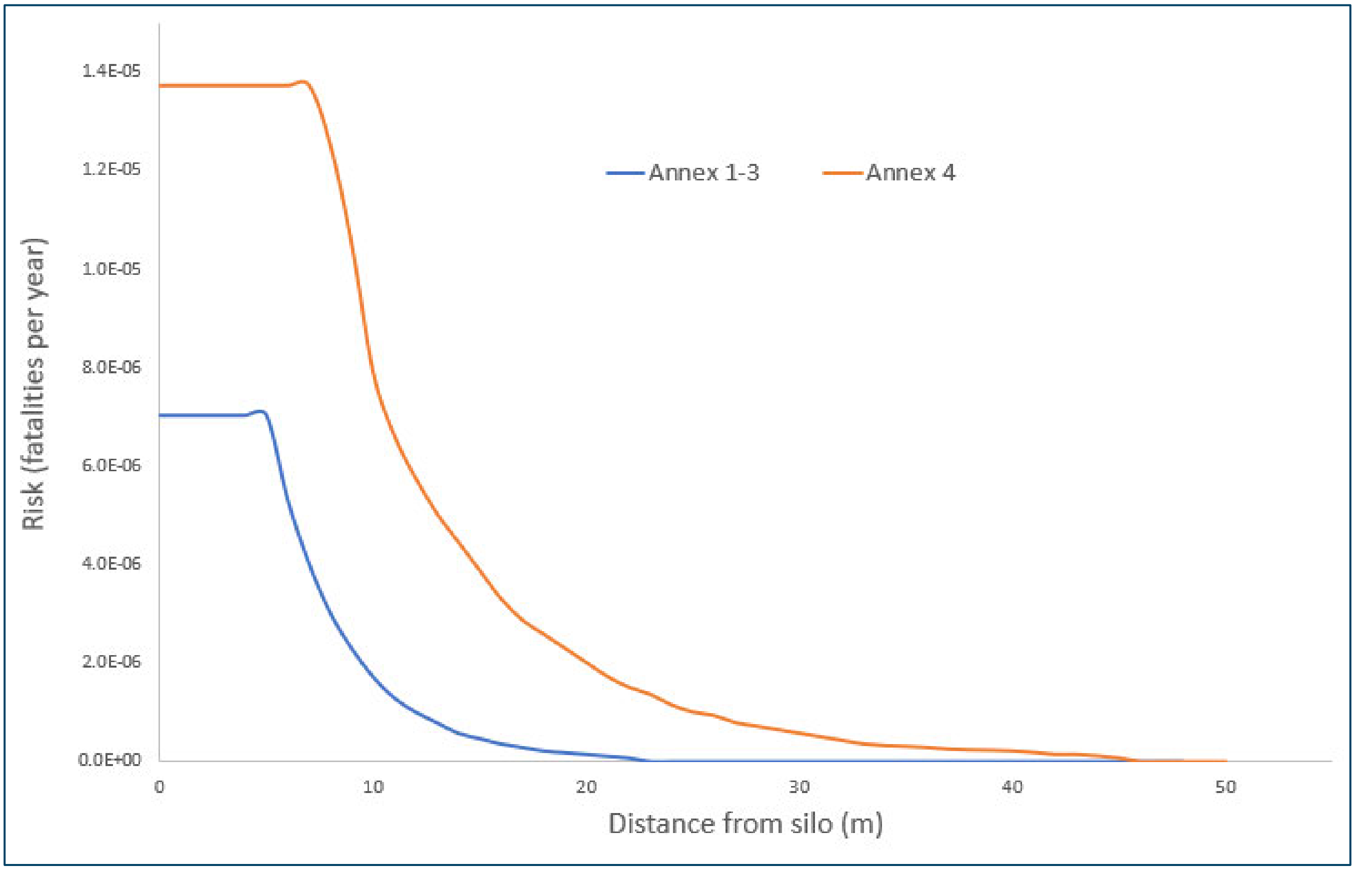


Figure 8.2: Risk associated with overpressure effects for each silo in the event of an explosion.

8.2 FIREBALL AND THERMAL RADIATION

8.2.1 Fireball dimensions

In the event of a dust explosion that ruptures a silo, a fireball will be discharged into the external area. As such, it is necessary to estimate the dimensions of the fireball so that the hazard zone or affected area can be determined. To estimate the size of a fireball that would be developed in the event of a silo explosion, the following assumptions were made:

- It was assumed that the silo will be filled to its maximum capacity.
- It was assumed that the material within the silo will consist entirely of combustible dust.
- It was assumed that complete combustion would occur.

The dimensions of the fireball were estimated using the ideal expansion ratio for combustible dust. Neglecting heat losses or incomplete combustion, the ideal expansion ratio for a typical combustible dust is in the range of 8 – 10 (Frank & Rodgers, 2012). Using an expansion ratio of 10, the fireball volume was estimated as follows:

$$Fireball\ volume\ (m^3) = Silo\ volume\ \times \text{Expansion Ratio} = Silo\ volume\ \times 10 \tag{23}$$

As the fireball would develop within the silo prior to rupture, it is appropriate to subtract the internal volume of the silo from the total fireball volume. Assuming a spherical volume, the radius and diameter of the fireball were estimated. The calculation results are summarized in Table 8.8.

Table 8.8: Summary of fireball dimension calculations.

Equipment	Silo volume (m^3)	Fireball volume (m^3)	Radius (m)	Diameter (L_f) (m)
Annex 1-3 silos	672	6049	11.3	23
Annex 4 silos	2560	23038	17.7	36

In the event that the fireball was discharged vertically through the roof of the silo, the radius would be representative of fireball length. However, in the event that the silo wall was to fail, the diameter would represent the maximum fireball length in the horizontal direction. Therefore, to be conservative, the fireball diameter is considered to represent the maximum flame length (L_f) that would be developed in the event of an explosion that ruptured the silo. It is important to note that the calculation ignores the effects of wind.

8.2.1.1 Assumptions and limitations

The following assumptions were made to estimate the fireball dimensions that would be expected in a silo explosion:

1. The effects of wind direction were not accounted for in the fireball dimension calculations.
2. It was assumed that the silos were filled with the optimal concentration of combustible dust particulate (sub-500 micrometer particulate) and complete combustion would occur.

8.2.2 Consequences of fireball effects

The consequences associated with fireball effects are based on a fictional unprotected person. Ideally, the fireball should only be relevant if the height of its origin is situated less than 5 m above the unprotected person, who is assumed to be at ground level. However, there are high-density and low-density residential buildings in the immediate vicinity of the silos. Hence, the unprotected person may not necessarily be located at the ground level, particularly for the high-density residential buildings which may be multi-story buildings. Hence, it is conservatively assumed that the fireball can impact the unprotected person regardless of the height of the fireball above the ground level. It is conservatively assumed that the probability of fatality is 100% for an unprotected person directly contacted by the fireball.

8.2.3 Consequences of thermal radiation

The fireball presents a danger to people and property in the external area surrounding the facility. The hazard from the flame itself is obvious, but personnel outside the direct flame area can be at risk of thermal radiation effects. The heat flux generated by the fireball and the distance from the fireball are two important variables that can be used to determine the risk from thermal radiation. The incident thermal flux (I) was calculated using the Stefan-Boltzmann equation:

$$I = \sigma \cdot \varepsilon \cdot T^4 \qquad (24)$$

Where σ is the Stefan-Boltzmann constant (5.67 x 10^{-11} kW/m^2K^4), ε is the emissivity of the hot dust cloud, and T is the absolute temperature of the hot dust cloud. The hot dust cloud is assumed to be sooty and with a sufficiently large optical path length. Consequently, the emissivity is assumed to tend to unity. The maximum fire (turbulent diffusion flame) temperature of the dust flame is assumed to be 1400 K. The maximum radiant heat flux at the extent of the fireball area was calculated as follows:

$$I = 5.67 \text{ x } 10^{-11} \cdot 1 \cdot (1400)^4 = 218 \text{ kW/m}^2$$

The thermal radiation dose (V) can be used to estimate the effects of thermal radiation from the following equation:

$$V = I^{4/3} \cdot t \qquad (25)$$

Where I is the incident thermal flux (kW/m^2) and t is time of exposure (seconds), which is assumed to be 10 seconds for the purpose of this evaluation. The thermal radiation dose at the extent of the fireball area was calculated as follows:

$$V = 218^{4/3} \cdot 10 = 13106 \left(\frac{kW}{m^2}\right)^{\frac{4}{3}} seconds$$

As thermal radiation follows the inverse-square law, the radiative heat flux decreases with the square of the distance from the fireball and is based on the equation:

$$I_2 = I_1 \cdot \frac{d_1^2}{d_2^2} \qquad (26)$$

Where I_1 is the thermal radiation flux at distance d_1 from the perimeter of the fireball, and I_2 is the thermal radiation flux at a further distance d_2 from the perimeter of the fireball.

The decay in thermal radiation flux and thermal dose as distance increases from the perimeter of the fireball is summarized in Table 8.9.

Table 8.9: Decay in thermal radiation flux and radiation dose with increasing distance.

Distance from fireball perimeter (m)	Radiation flux (kW/m^2)	Radiation dose in 10 seconds $(kW/m^2)^{4/3}.s$
0	218	13106
1	218	13106
2	54.5	2064
3	24.2	700
4	13.6	325
5	8.7	179
6	6.1	110
7	4.4	73
8	3.4	51
9	2.7	37
10	2.2	28
12	1.5	17
15	1.0	10

The Health and Safety Executive (HSE) "Methods of Approximation and Determination of Human Vulnerability for Offshore Major Accident Hazard Assessment" [19] document outlines probit functions for thermal dose estimation. The TNO probit equation was used to determine the probability of fatality associated with thermal radiation. The equation is based on the probability of fatality for an unprotected person with naked skin. Using the TNO equation, a 1% probability of fatality corresponds to a thermal dose (V) of 389 $(kW/m^2)^{4/3}$ s and a 50% probability of fatality corresponds to a thermal dose of 841 $(kW/m^2)^{4/3}$ s. The TNO equation [19] is as follows:

$$Y = -15.3 + 3.02\,(\ln(V)) \tag{27}$$

Based on the calculated probit, the probability of fatality was evaluated using a probit transformation table. The results are summarized in Table 8.10. It is important to note that the distances outlined in the table represent the distance beyond the extent of the maximum fireball length (L_f).

Table 8.10: Probability of fatality associated with thermal radiation beyond the fireball boundary.

Distance from extent of fireball (m)	Probability of fatality (%)
0	100
1	100
2	99.7
3	30.0
4	0.0
5	0.0

8.2.3.1 Assumptions and limitations

The following assumptions were made to estimate the probability of fatality associated with thermal radiation:

1. The turbulent flame temperature was assumed to be 1400 K based on reference data for agricultural dusts.
2. The hot dust cloud is assumed to be sooty with a sufficiently large optical path length resulting in an emissivity value of 1.
3. The time of exposure for an unprotected person was assumed to be 10 seconds.

8.2.4 Risk associated with fireball and thermal radiation effects

The risk associated with fireball and thermal radiation effects in the event of a silo explosion is estimated based on the frequency and the probabilities of fatality. The calculated risk associated with the fireball and thermal radiation at various distances from the silos is communicated in fatalities per year and is summarized in Figure 8.3.

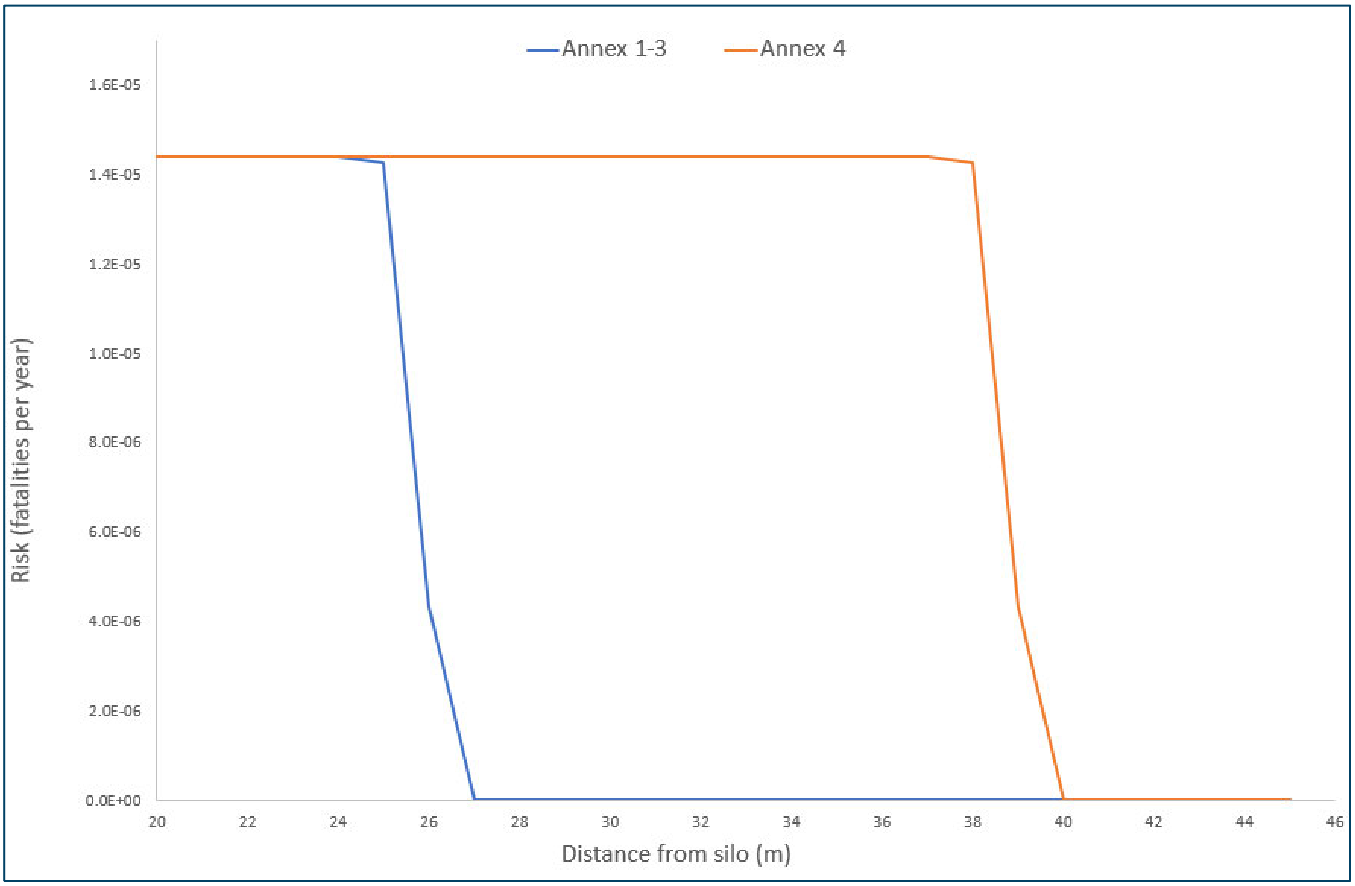


Figure 8.3: Risk associated with fireball and thermal radiation effects for each silo in the event of an explosion.

8.3 BULK OUTFLOW

In the event of silo rupture or failure following an explosion, the contents of the silo can be released into a large conical pile as shown in Figure 8.4. Grain entrapment or grain engulfment can occur when a person steps on the cone formed by the bulk material outflow or if a person is located in the area at the time of silo rupture. The described person may be fully or partially submerged in the grain heap and cannot get out without assistance. Grain engulfment presents a high fatality rate as it only takes two to three seconds to become helpless in flowing grain.

Figure 8.4: Example of bulk material outflow from a ruptured grain silo.

If a grain silo is breached and releases its content into the surrounding area, the dimensions of the cone or half-cone formed by the material can be estimated using the angle of repose. The angle of repose is the steepest angle at which a sloping surface formed of loose material is barely stable. As the loose material is poured out, it forms a cone shape, whose angle with the horizontal plane depends on the material parameters such as the grain size distribution, grain shape, moisture content, and internal friction angle. The angle of repose for wheat is taken as 27 degrees.

Two possible scenarios exist for the bulk outflow case. The first scenario is a silo being completely destroyed in the event of an explosion and releasing all its contents. In this scenario, it is assumed that the released bulk material does not participate in the explosion and is deposited in a cone structure in the area surrounding the silos. The second scenario involves rupture of the silo at mid-height by the impact of the explosion. In the second scenario, it is assumed that the released bulk material does not participate in the explosion and is deposited in a half-cone structure abutting the silo. To be conservative, it is assumed that the entire volume of the silo would be released into a cone-shaped pile of bulk material.

Based on the angle of repose of wheat (27^{o}), the relation between the height and base radius of the formed cone is estimated as:

$$Pile\ height = \tan(27°) \times radius = 0.51\ \times radius \qquad (28)$$

The height of the material pile is approximately half of its base radius. However, the height and radius of the cone are also constrained by the maximum volume of material that can be released from the breached silo. The volume of the conical pile is given as:

$$V_{cone} = \pi r^2 \frac{h}{3} \tag{29}$$

Based on the silo volumes and the relationship between the relationship between the height and radius, the dimension of the pile were estimated and are summarized in Table 8.11.

Table 8.11: Estimated dimensions of bulk material cone in the event of silo destruction.

Equipment	Silo volume (m^3)	Height of pile (m^3)	Radius of pile (m)
Annex 1-3 silos	672	5.5	10.8
Annex 4 silos	2560	8.6	16.9

8.3.1 Consequences of bulk outflow

If the height of an average adult human is approximately 1.6 – 1.7 m, the unprotected person buried in any portion of the material deposit deeper than 1.7 m is assumed to have a 100% probability of fatality. The probability of fatality due to bulk outflow effects at various distances from the silos is summarized in Table 8.12.

Table 8.12: Probability of fatality associated with bulk outflow.

Equipment	Distance from silo (m)	Heap height (m)	Probability of fatality (%)
Annex 1-3 silos	0	5.5	100
	2	4.6	100
	4	3.6	100
	6	2.5	100
	8	1.5	100
	10	0.5	0.0
Annex 4 silos	0	8.6	100
	2	7.6	100
	4	6.6	100
	6	5.6	100
	8	4.6	100
	10	3.6	100
	12	2.5	100
	14	1.5	100
	16	0.5	0.0

8.3.1.1 Assumptions and limitations

The following assumptions were made to estimate the probability of fatality associated with bulk outflow:

1. It was assumed that 100% of the contents would be released from the silo.
2. It was assumed that areas where the heap height exceeds or is close to the average height of a person (1.6 meters), engulfment would occur resulting in fatality.

8.3.2 Risk associated with bulk outflow

The risk associated with bulk outflow effects in the event of a silo explosion is estimated based on the frequency and probability of fatality. The calculated risk associated with the bulk outflow at various distances from the silos is communicated in fatalities per year and is summarized in Figure 8.5.

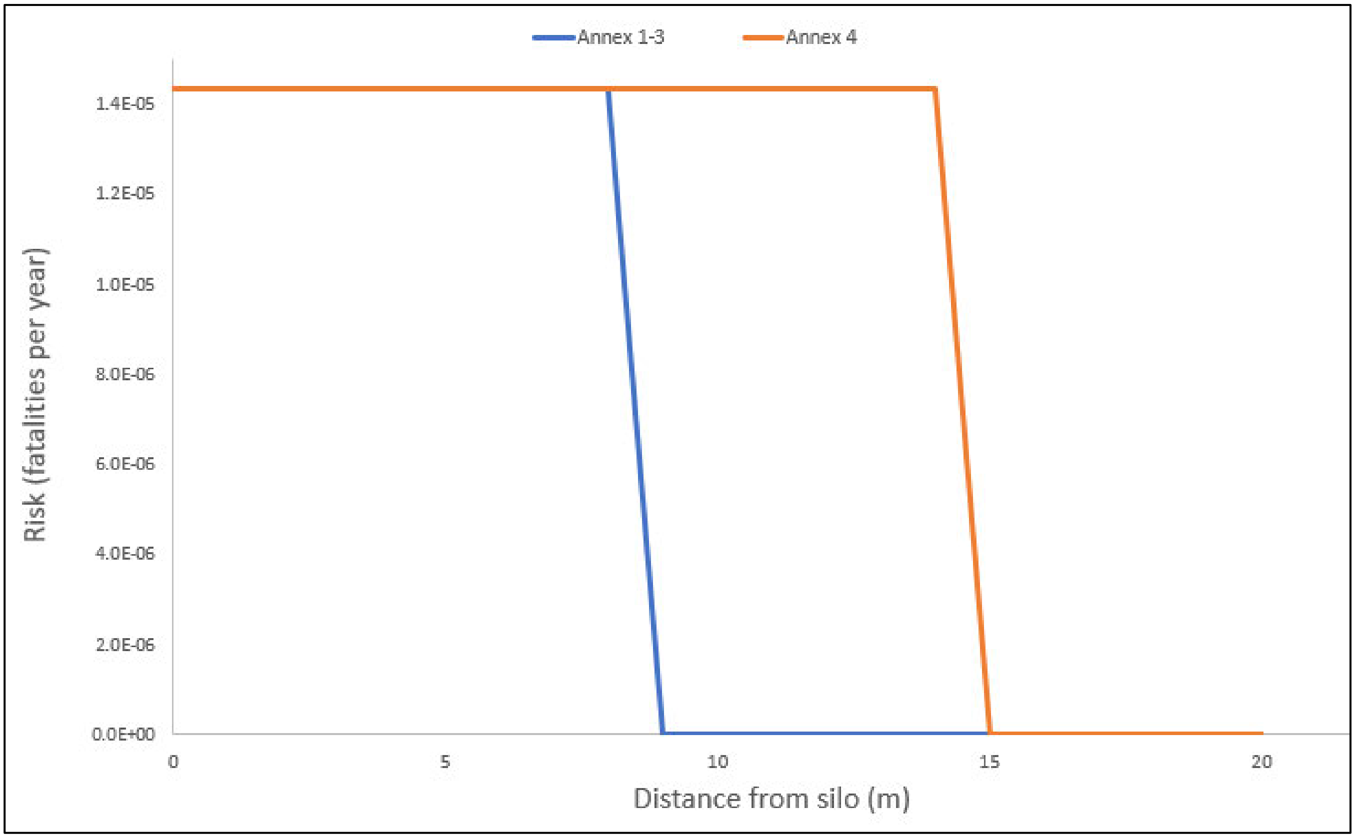


Figure 8.5: Risk associated with bulk outflow effects for each silo in the event of an explosion.

8.4 PROJECTILES AND DEBRIS

In the event of an explosion in one of the silos, it is expected that the silo will break into multiple fragments that will act as projectiles. Projectiles and flying debris hitting the human body present a significant fatality risk. For a fatality to occur, a person must first be struck by a projectile. To determine the probability that a person is struck with a projectile, the methodology from the European Commission's Joint Research Center (JRC) document titled "A survey of computational models for blast induced human injuries for security and defence applications (2020)" [20].

The probability that a person is struck with a projectile or fragment at a specific stand-off distance is estimated based on the following assumptions:

1. Hemispherical burst conditions exist.
2. The angular distribution of launched fragments is uniform.
3. In the vicinity of the detonation source the fragment trajectories are approximated by straight lines.

The Poisson distribution is employed to model the number of hits a person is subjected to. The areal density of fragments (q) at a stand-off distance (R_{so}) is calculated using the following equation:

$$q = \frac{N}{2\pi R_{so}^2} \qquad (30)$$

Where N is the total number of fragments without considering their mass distribution. The average hit rate (λ) is calculated using the following equation:

$$\lambda = q\, S_b \qquad (31)$$

Where S_b is the body area that would be present by an average person (0.58 m^2). According to the Poisson distribution, the probability of the number of hits to be n is equal to the following:

$$\Pr[hits = n] = \frac{e^{-\lambda}\lambda^n}{n!} \qquad (32)$$

The hit probability, which implies at least one hit, is calculated as follows:

$$\Pr[H] = 1 - \exp\left(-\frac{N}{2\pi R_{so}^2}\, S_b\right) \qquad (33)$$

In the event of a silo explosion, projectiles could originate from the silo wall or from the silo roof area. The hit probabilities for projectiles originating from these areas are estimated in the following sections.

8.4.1 Silo wall projectiles

With respect to projectiles originating from the silo wall, it is expected that only the exterior halves of the silos facing west will present a projectile hazard to the public as shown in Figure 8.6. Additionally, it is expected that only the top 50% of the silo wall will rupture in the event of an explosion and contribute to the total number of projectiles.

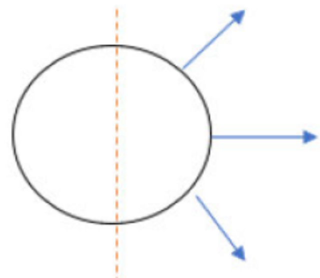


Figure 8.6: Diagram of expected silo wall contribution to projectiles.

Based on the information outlined above, the total wall areas that are expected to contribute to projectiles were calculated and are summarized in Table 8.13. It was assumed that the silo wall would break into equally sized fragments that are circular in dimension with an average diameter of 1 m. Based on this assumption, the total number of fragments generated by destruction of the silo wall (above the midpoint) was estimated.

Table 8.13: Estimated number of fragments from the silo walls (per silo).

Equipment	Contributing wall area (m^2)	Avg. diameter of fragments (m)	Number of fragments, N (m)
Annex 1-3 silos	285	1.0	362
Annex 4 silos	535	1.0	681

To estimate the maximum range of the projectiles, a simplified projectile motion calculation was performed using the following equation:

$$Range = V_o * \cos(\alpha) * \frac{\left[V_o * \sin(\alpha) + \sqrt{(V_o * \sin^2(\alpha) + 2 * g * h)}\right]}{g} \quad (34)$$

Where V_o is the initial velocity of the projectile which was assumed to be 25 m/s, α is the launch angle, g is the gravitational force (9.81 m/s^2), and h is the initial height that the projectile is launched from. The calculation was performed for initial heights of 33 m (top of the silo wall), 16.5 m (midpoint of the silo), and 24.8 m (halfway between the midpoint and top). To determine the maximum range, the calculations were performed for all launch angles between 0 and 90 degrees. The calculation results are summarized in Table 8.14.

Table 8.14: Maximum projectile range from the silo walls.

Equipment	Initial velocity (m/s)	Initial height (m)	Maximum range (m)
Annex 1-4 silos	25	16.5	79
	25	24.8	85
	25	33.0	91

As shown in Table 8.14, the maximum projectile range was estimated to be 91 m. The estimated projectile distances are similar to the findings from the SEMABLA dust explosion in Blaye, France in 1997 [21] where pieces of concrete about a meter in size were found 50 meters from the structure while projectiles of significant size were found at distances of up to 100 m. To be conservative, it was assumed that projectiles could cause harm at distances up to 120 meters from the exterior walls of Annexes 1-4.

8.4.1.1 Consequences associated with silo wall projectiles

Using Equation 33 and the estimated number of fragments (*N*) outlined in Table 8.13, the hit probability, *P[H]*, was calculated at distances ranging from 0 to 120 meters from the silos. Due to the difficulty of determining the probability of fatality associated with projectile hitting a person, it is conservatively assumed that the probability of fatality will be 100% for a person struck with a projectile inside 120 m. As such, the hit probability can be used to represent the probability of fatality associated with projectiles. The calculation results are summarized in Figure 8.7.

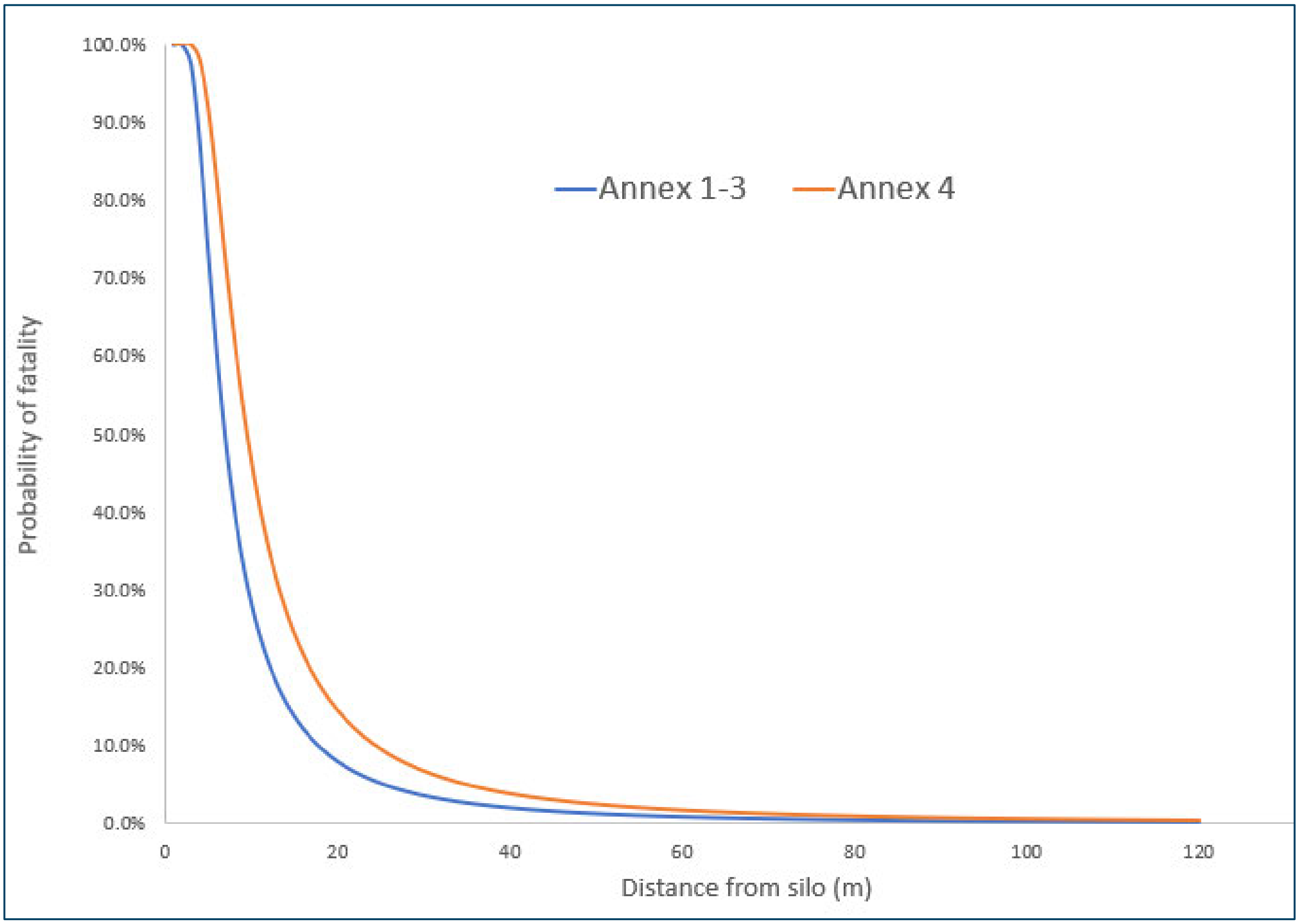


Figure 8.7: Probability of fatality associated with projectiles originating from the silo walls.

It is important to note that the maximum range of a given projectile is dependent upon the launch angle and initial velocity. For example, the maximum projectile distances that were calculated occurred at launch angles from 33 – 40 degrees. As such, a correction factor was applied to the calculated probabilities based on the percentage of launch angles that allowed for a projectile to travel a specific distance. The correction factors are summarized in Table 8.15.

Table 8.15: Correction factors for the probability of fatality associated with wall projectiles.

Distance from silo (m)	Correction factor based on launch angles (%)
0 – 29	100
30 – 39	86
40 – 49	81
50 – 59	76
60 – 69	65
70 – 79	50
80 – 120	26

Based on the correction factors outlined in Table 8.15, the corrected probabilities of fatality associated with projectiles originating from the silo walls were estimated and the results are summarized in Figure 8.8.

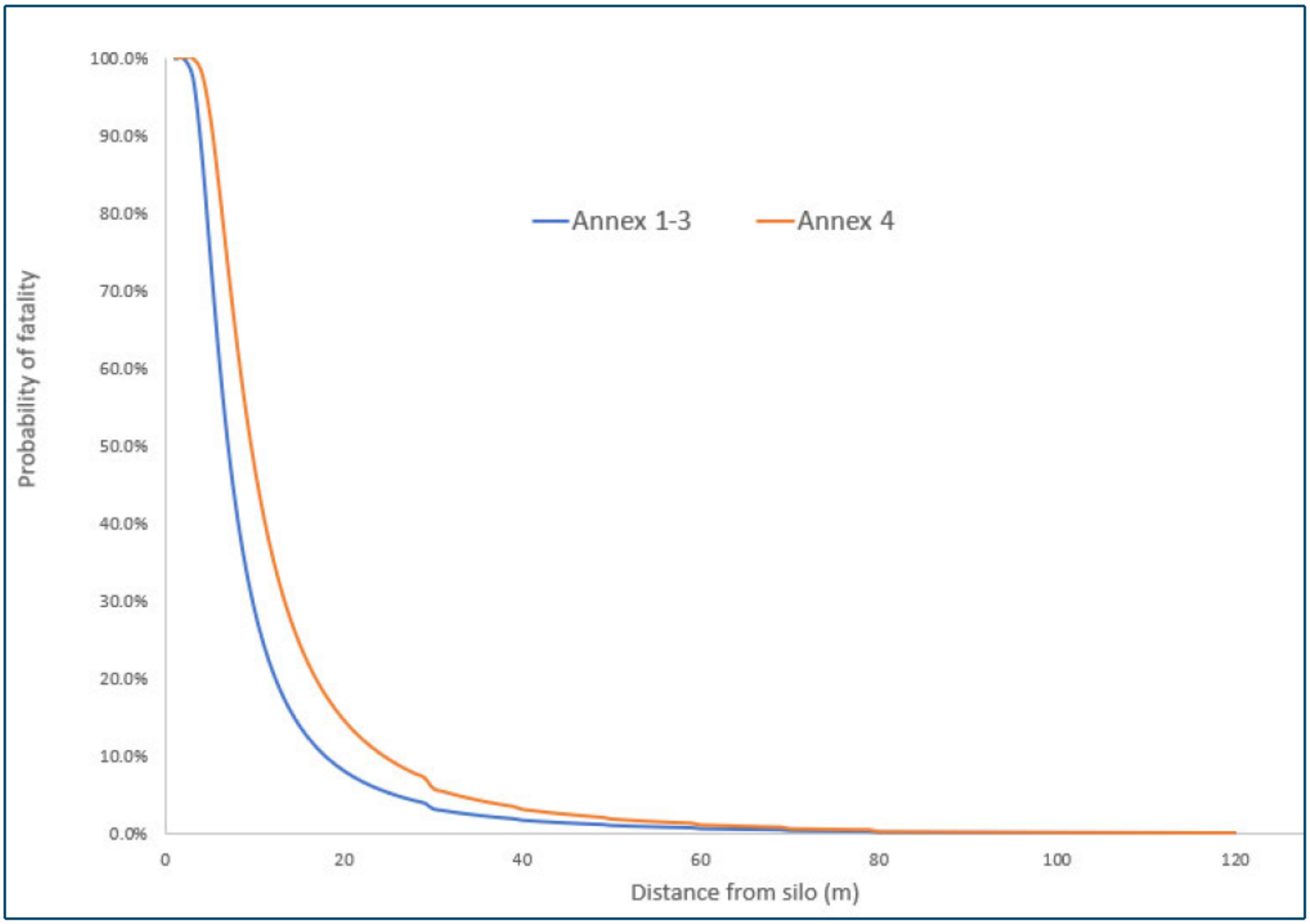


Figure 8.8: Corrected probability of fatality associated with projectiles originating from the silo walls.

8.4.1.2 Risk associated with silo wall projectiles

The risk associated with wall projectiles in the event of a silo explosion is estimated based on the frequency and probability of fatality. The calculated risk associated with the projectiles at various distances from the silos is communicated in fatalities per year and is summarized in Figure 8.9.

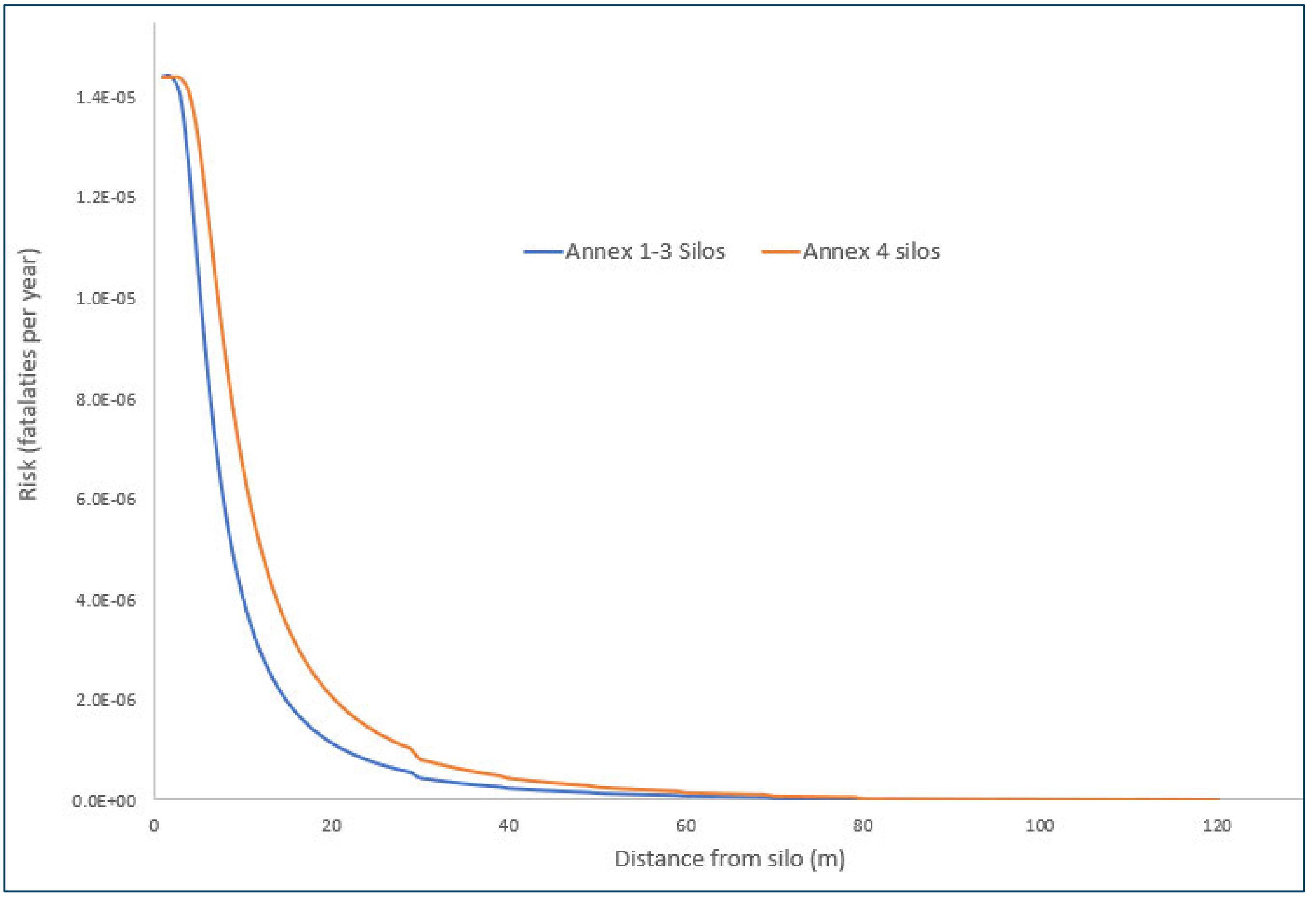


Figure 8.9: Risk associated with wall projectiles for each silo.

8.4.1.3 Assumptions and limitations

The following assumptions were made to estimate the probability of fatality and risk associated with projectiles originating from the silo walls:

1. It was assumed that the projectiles would be launched at an initial velocity of 25 m/s.
2. It was assumed that only the top 50% of the exterior wall would contribute to projectiles and would break into equal size fragments.
3. The hit probability was determined based on the average target area that would be presented by a human (0.58 m^2). It is important to note that buildings with a large surface area would have a higher probability of being hit by projectiles and would most likely receive multiple hits depending on their distance from the silo wall.
4. To be conservative, it was assumed that projectiles could cause harm within a range of 120 meters. However, given the estimated projectile range and information from the SEMABLA explosion incident, it is expected that significant size projectiles would not exceed 100 meters.

5. To satisfy the requirement for equations 30 – 33, the following assumptions were made:
   - Hemispherical burst conditions exist.
   - The angular distribution of launched fragments is uniform.
   - In the vicinity of the detonation source the fragment trajectories are approximated by straight lines.
6. The effects of obstructions (existing buildings, etc.) were not taken into account when determining the projectile range. As such, it was assumed that wall projectiles generated from all silos have the potential to travel up to 120 meters regardless of their location.

8.4.2 Silo roof projectiles

In the event of a silo explosion, projectiles can also originate from the silo roof and over-cell gallery. The number of projectiles (*N*) was estimated based on the surface areas of the silo roofs. As the bin level galleries are located above the silos, it was assumed that materials from the gallery (concrete, steel, glass, etc.) could also break into fragments in the event of an explosion and contribute to the total number of projectiles. As such, the number of fragments expected from the roof was multiplied by a factor of five to account for the additional concrete and building structures that could contribute to projectiles. It was assumed that the roof and gallery would break into equal sized fragments with a circular cross-section. The estimated number of projectiles is summarized in Table 8.16.

Table 8.16: Estimated number of fragments from the silo roofs (per silo).

Equipment	Roof area (m^2)	Avg. diameter of fragments (m)	Number of fragments, N	Number of fragments, N, Corrected
Annex 1-3 silos	23.8	1.0	31	155
Annex 4 silos	84.2	1.0	107	540

The projectile range was estimated using Equation 34 in Section 7.4.1. The initial velocity was assumed to be 25 m/s and the initial height was set to the height of the silos (33 m). In the event of roof failure, it is expected that the blast wave would be projected vertically and as such, it was assumed that projectiles originating from the silo roof and gallery areas would be launched at angles greater than 60 degrees. Therefore, to determine the maximum range, the calculation was performed for all launch angles between 60 and 90 degrees. The calculation results are summarized in Table 8.17.

Table 8.17: : Maximum projectile range from the silo roof.

Equipment	Initial velocity (m/s)	Initial height (m)	Maximum range (m)
Annex 1-4 silos	25	33	70

8.4.2.1 Consequences associated with silo roof projectiles

Using Equation 33 and the number of fragments (*N*) outlined in Table 8.16, the hit probability, *P[H]*, was calculated at distances ranging from 0 to 70 meters from the silos. Due to the difficulty of determining the probability of fatality associated with projectile hitting a person, it is conservatively assumed that the probability of fatality will be 100% for a person struck with a projectile inside 70 m. As such, the hit probability can be used to represent the probability of fatality associated with projectiles. Similar to the roof projectiles, a correction factor was applied to the calculated probabilities based on the percentage of launch angles that allowed for a projectile to travel a specific distance.

The correction factors are summarized in Table 8.18 and the estimated probabilities of fatality are summarized in Figure 8.10.

Table 8.18: Correction factors for the probability of fatality associated with projectiles.

Distance from silo (m)	Correction factor based on launch angle (%)
0 – 9	100
10 – 19	90
20 – 29	77
30 – 39	63
44 – 49	50
50 – 59	37
60 – 70	20

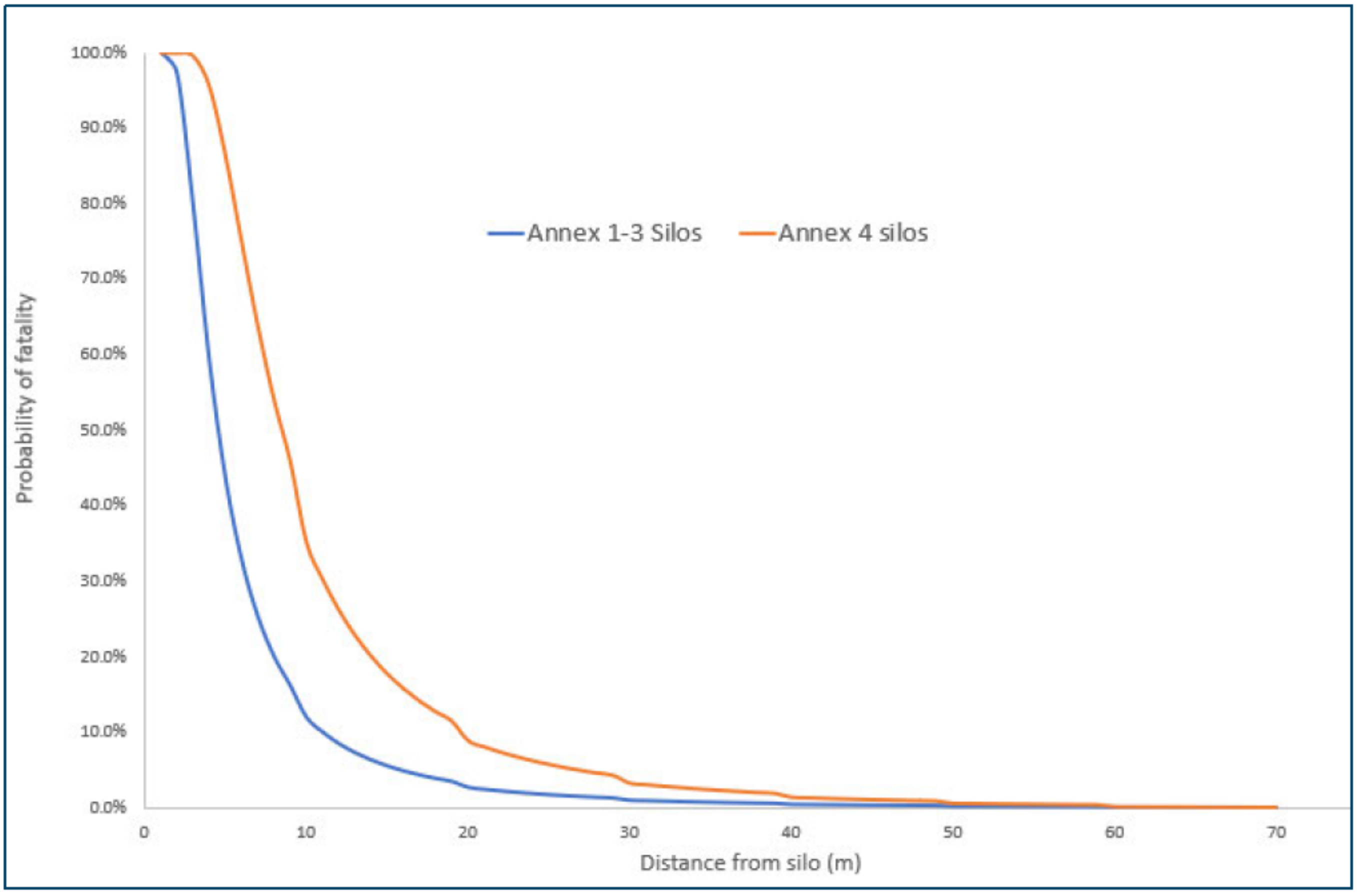


Figure 8.10: Probability of fatality associated with projectiles originating from the silo roofs.

8.4.2.2 Risk associated with silo roof projectiles

The risk associated with roof projectiles in the event of a silo explosion was estimated based on the event frequency and probability of fatality. The calculated risk associated with the projectiles at various distances from the silos is communicated in fatalities per year and is summarized in Figure 8.11.

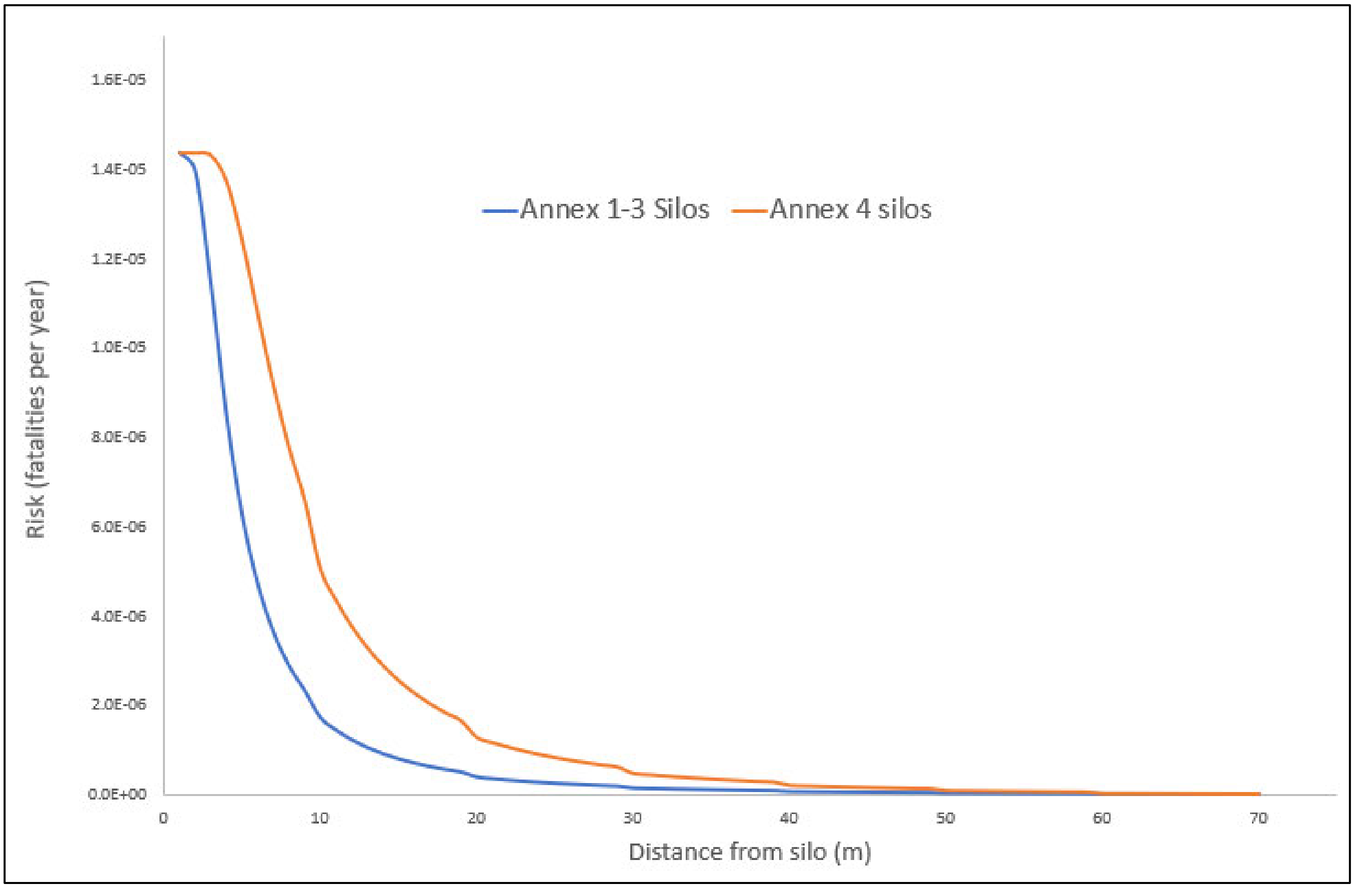


Figure 8.11: Risk associated with roof projectiles for each silo.

8.4.2.3 Assumptions and limitations

The following assumptions were made to estimate the probability of fatality and risk associated with projectiles originating from the silo roof areas:

1. It was assumed that the projectiles would be launched at an initial velocity of approximately 25 m/s.
2. To account for the gallery areas it was assumed that the total area that would contribute to projectiles was approximately five times the surface area of the silo roofs. It was assumed that the contributing area would break into equal sized fragments.
3. The hit probability was determined based on the average target area that would be presented by a human (0.58 m^2). It is important to note that buildings with a large surface area would have a higher probability of being hit by projectiles and would most likely receive multiple hits depending on their distance from the silo.
4. It was assumed that projectiles from the roof and gallery area would be launched at angles greater than 60 degrees.

8.5 COMBINED RISK PER INDIVIDUAL SILO

The estimated risks associated with the individual effects that would be posed to the public in the event of a dust explosion were outlined in Sections 8.1 – 8.4 of this report. The risk presented by each individual silo located within the facility is equivalent to the summation of the risk associated with these individual explosion effects. As such, the combined risk for each individual silo is calculated using Equation 5 as follows:

$$Risk = Risk_{fireball} + Risk_{overpressure} + Risk_{radiation} + Risk_{bulk\ outflow} + Risk_{wall\ debris} + Risk_{roof\ debris}$$

The combined individual risk associated with each individual silo in Annexes 1-3 was estimated at various distance intervals from the exterior silo walls. The results are summarized in Table 8.19 and Figure 8.12.

Table 8.19: Overview of combined risk at select distances for each individual silo in Annexes 1-3.

	Risk (fatalities per year)						
Distance (m)	Overpressure	Fireball	Thermal radiation	Bulk outflow	Wall projectiles	Roof projectiles	Combined risk
0	7.04E-06	1.44E-05	-	1.44E-05	1.44E-05	1.44E-05	**6.45E-05**
5	7.04E-06	1.44E-05	-	1.44E-05	1.06E-05	6.28E-06	**5.26E-05**
10	1.72E-06	1.44E-05	-	0	4.08E-06	1.73E-06	**2.19E-05**
15	4.67E-07	1.44E-05	-	0	1.98E-06	7.98E-07	**1.76E-05**
20	1.44E-07	1.44E-05	-	0	1.15E-06	3.90E-07	**1.61E-05**
21	1.08E-07	1.44E-05	-	0	1.05E-06	3.52E-07	**1.59E-05**
22	7.18E-08	1.44E-05	-	0	9.59E-07	3.22E-07	**1.57E-05**
23	0	1.44E-05	-	0	8.80E-07	2.95E-07	**1.55E-05**
24	0	0	1.44E-05	0	8.10E-07	2.71E-07	**1.54E-05**
25	0	0	1.43E-05	0	7.49E-07	2.50E-07	**1.53E-05**
26	0	0	4.31E-06	0	6.94E-07	2.31E-07	**5.23E-06**
27	0	0	0	0	6.44E-07	2.15E-07	**8.59E-07**
30	0	0	0	0	4.51E-07	1.43E-07	**5.94E-07**
35	0	0	0	0	3.34E-07	1.06E-07	**4.40E-07**
40	0	0	0	0	2.41E-07	6.41E-08	**3.05E-07**
45	0	0	0	0	1.92E-07	5.07E-08	**2.42E-07**
50	0	0	0	0	1.45E-07	3.04E-08	**1.76E-07**
55	0	0	0	0	1.19E-07	2.49E-08	**1.44E-07**
60	0	0	0	0	8.64E-08	1.14E-08	**9.78E-08**
65	0	0	0	0	7.38E-08	9.74E-09	**8.36E-08**
70	0	0	0	0	4.89E-08	8.40E-09	**5.73E-08**
75	0	0	0	0	4.23E-08	0	**4.23E-08**
80	0	0	0	0	1.95E-08	0	**1.95E-08**
85	0	0	0	0	1.72E-08	0	**1.72E-08**
90	0	0	0	0	1.53E-08	0	**1.53E-08**
95	0	0	0	0	1.38E-08	0	**1.38E-08**
100	0	0	0	0	1.24E-08	0	**1.24E-08**
110	0	0	0	0	1.03E-08	0	**1.03E-08**
120	0	0	0	0	8.63E-09	0	**8.63E-09**

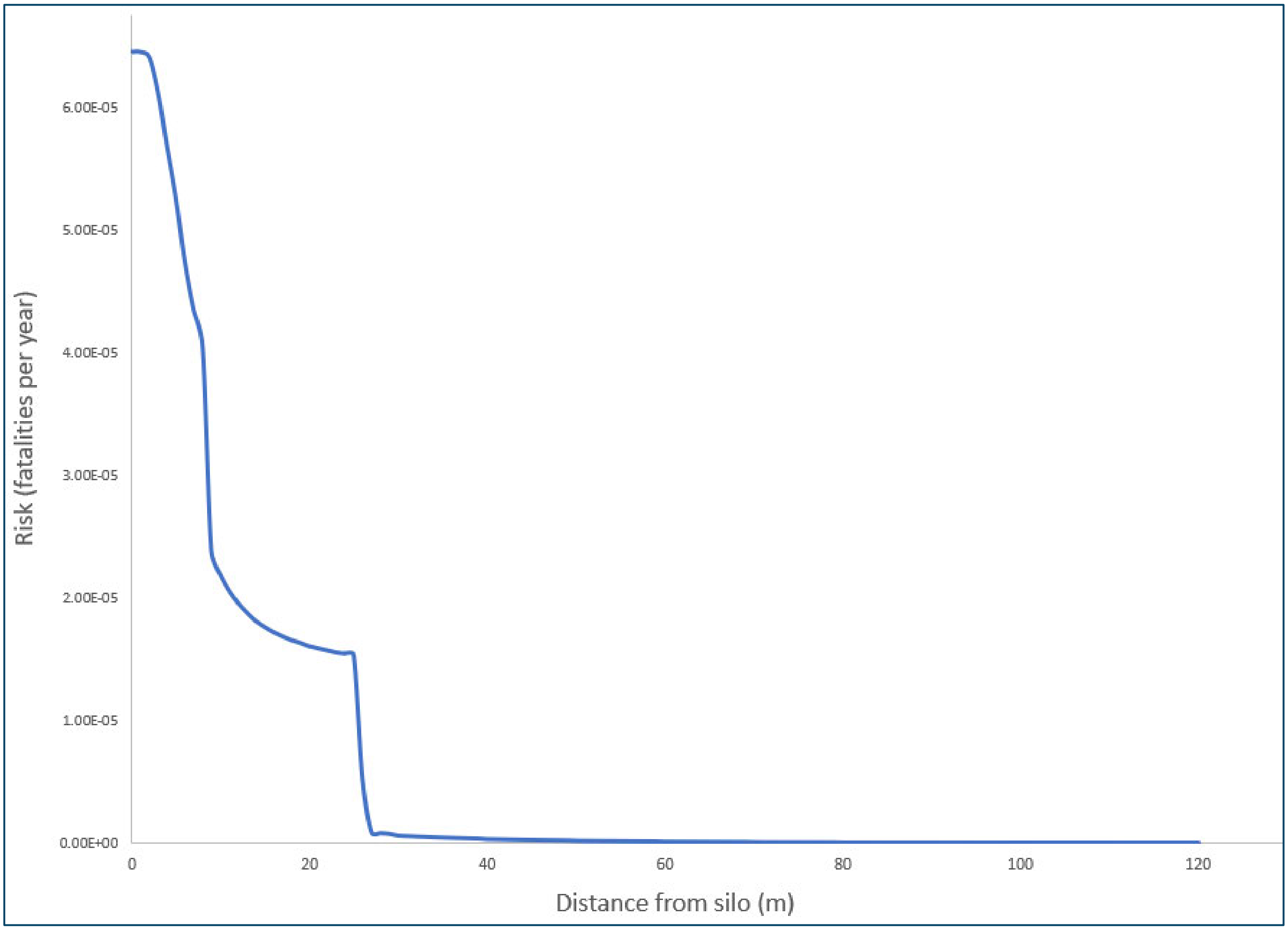


Figure 8.12: Combined risk for each individual silo in Annexes 1-3. The risk decreases as the distance from the silo is increased.

Figure 8.13 shows a schematic of the risk contours surrounding each silo in Annexes 1-3 at 10 meter intervals up to a distance of 100 meters.

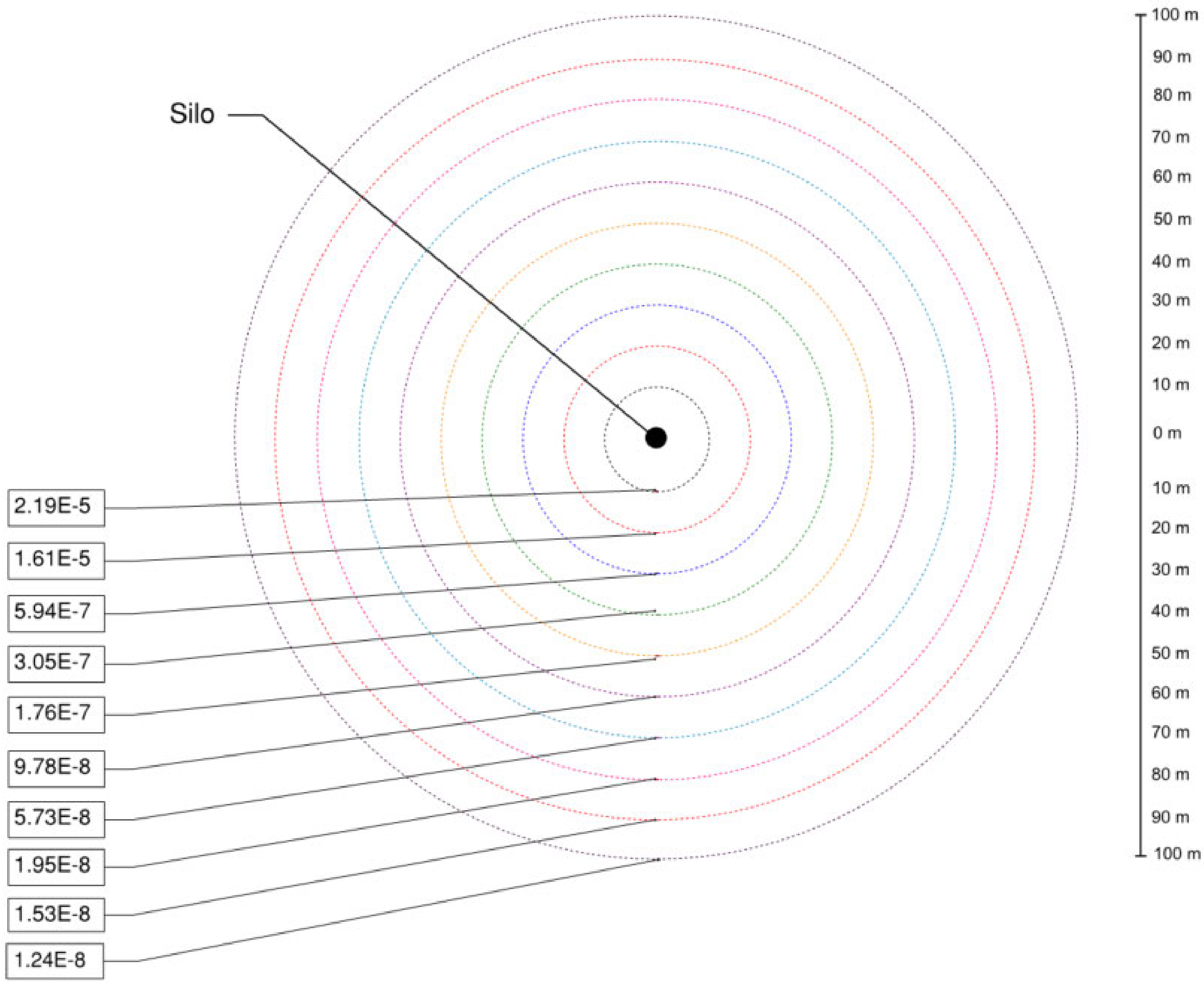


Figure 8.13: Risk contours associated with each individual silo in Annexes 1-3 at 10 meter distance intervals up to 100 meters.

The combined individual risk associated with each individual silo in Annex 4 was estimated at various distance intervals from the exterior silo walls. The results are summarized in Table 8.20 and Figure 8.14.

Table 8.20: Overview of combined risk at select distances for each individual silo in Annex 4.

Distance (m)	Risk (fatalities per year)						
	Overpressure	Fireball	Thermal radiation	Bulk outflow	Wall projectiles	Roof projectiles	Combined risk
0	1.37E-05	1.44E-05	-	1.44E-05	1.44E-05	1.44E-05	**7.12E-05**
5	1.37E-05	1.44E-05	-	1.44E-05	1.32E-05	1.24E-05	**6.81E-05**
10	7.90E-06	1.44E-05	-	1.44E-05	6.71E-06	5.09E-06	**4.84E-05**
15	3.88E-06	1.44E-05	-	0	3.50E-06	2.58E-06	**2.43E-05**
20	2.01E-06	1.44E-05	-	0	2.09E-06	1.30E-06	**1.98E-05**
25	1.01E-06	1.44E-05	-	0	1.38E-06	8.46E-07	**1.76E-05**
30	5.75E-07	1.44E-05	-	0	8.34E-07	4.89E-07	**1.63E-05**
35	3.09E-07	1.44E-05	-	0	6.21E-07	3.64E-07	**1.57E-05**
36	2.87E-07	1.44E-05	-	0	5.87E-07	3.44E-07	**1.56E-05**
37	2.51E-07	0	1.44E-05	0	5.57E-07	3.26E-07	**1.55E-05**
38	2.37E-07	0	1.43E-05	0	5.29E-07	3.09E-07	**1.54E-05**
39	2.30E-07	0	4.31E-06	0	5.02E-07	2.94E-07	**5.34E-06**
40	2.16E-07	0	0	0	4.49E-07	2.21E-07	**8.85E-07**
45	7.18E-08	0	0	0	3.58E-07	1.75E-07	**6.05E-07**
50	0	0	0	0	2.71E-07	1.05E-07	**3.76E-07**
55	0	0	0	0	2.23E-07	8.63E-08	**3.10E-07**
60	0	0	0	0	1.62E-07	3.96E-08	**2.01E-07**
65	0	0	0	0	1.38E-07	3.38E-08	**1.72E-07**
70	0	0	0	0	9.16E-08	2.91E-08	**1.21E-07**
75	0	0	0	0	7.93E-08	0	**7.93E-08**
80	0	0	0	0	3.65E-08	0	**3.65E-08**
85	0	0	0	0	3.22E-08	0	**3.22E-08**
90	0	0	0	0	2.88E-08	0	**2.88E-08**
95	0	0	0	0	2.58E-08	0	**2.58E-08**
100	0	0	0	0	2.33E-08	0	**2.33E-08**
110	0	0	0	0	1.93E-08	0	**1.93E-08**
120	0	0	0	0	1.62E-08	0	**1.62E-08**

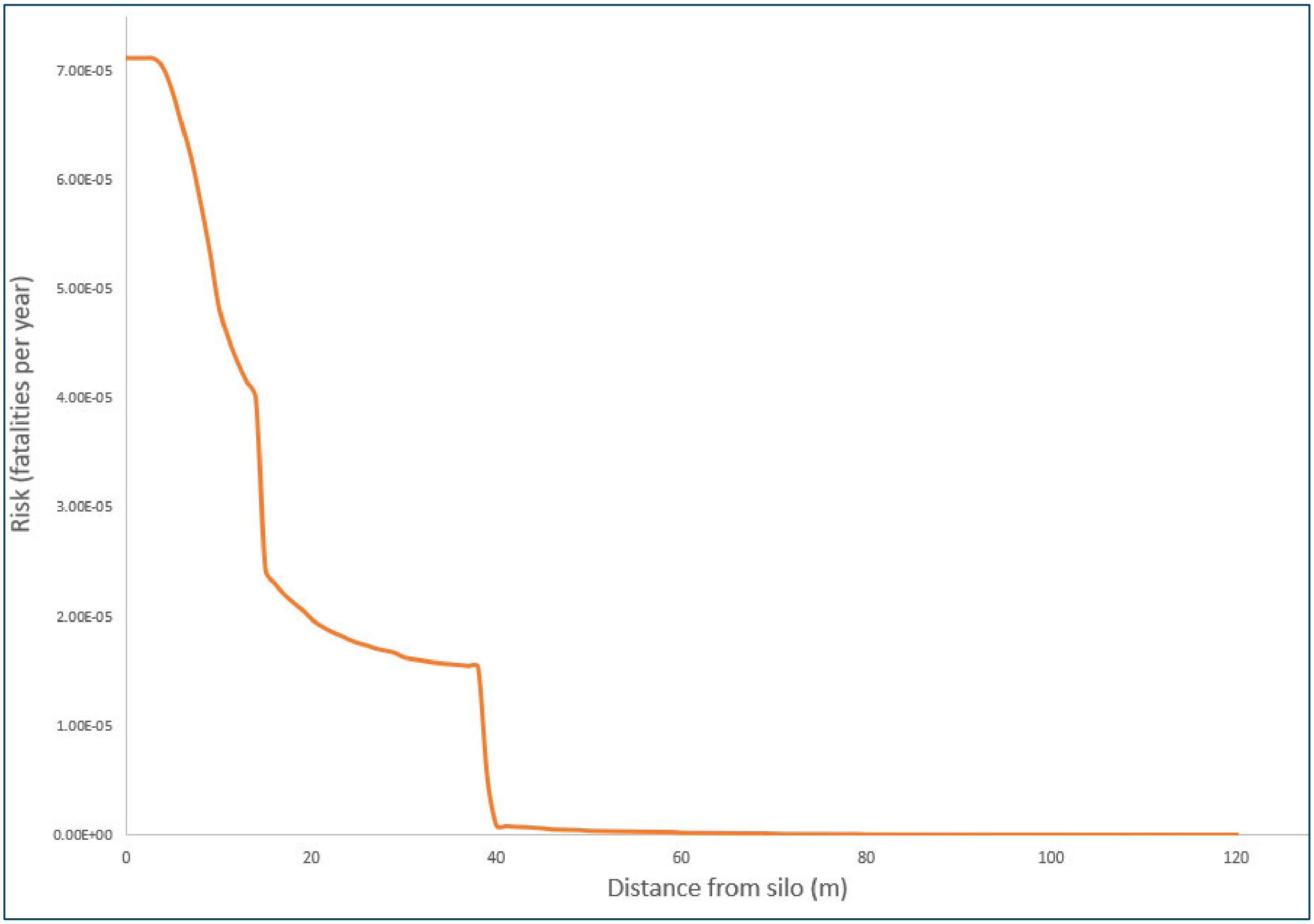


Figure 8.14: Combined risk for each individual silo in Annex 4. The risk decreases as the distance from the silo is increased.

Figure 8.15 shows a schematic of the risk contours surrounding each silo in Annex 4 at 10 meter intervals up to a distance of 100 meters.

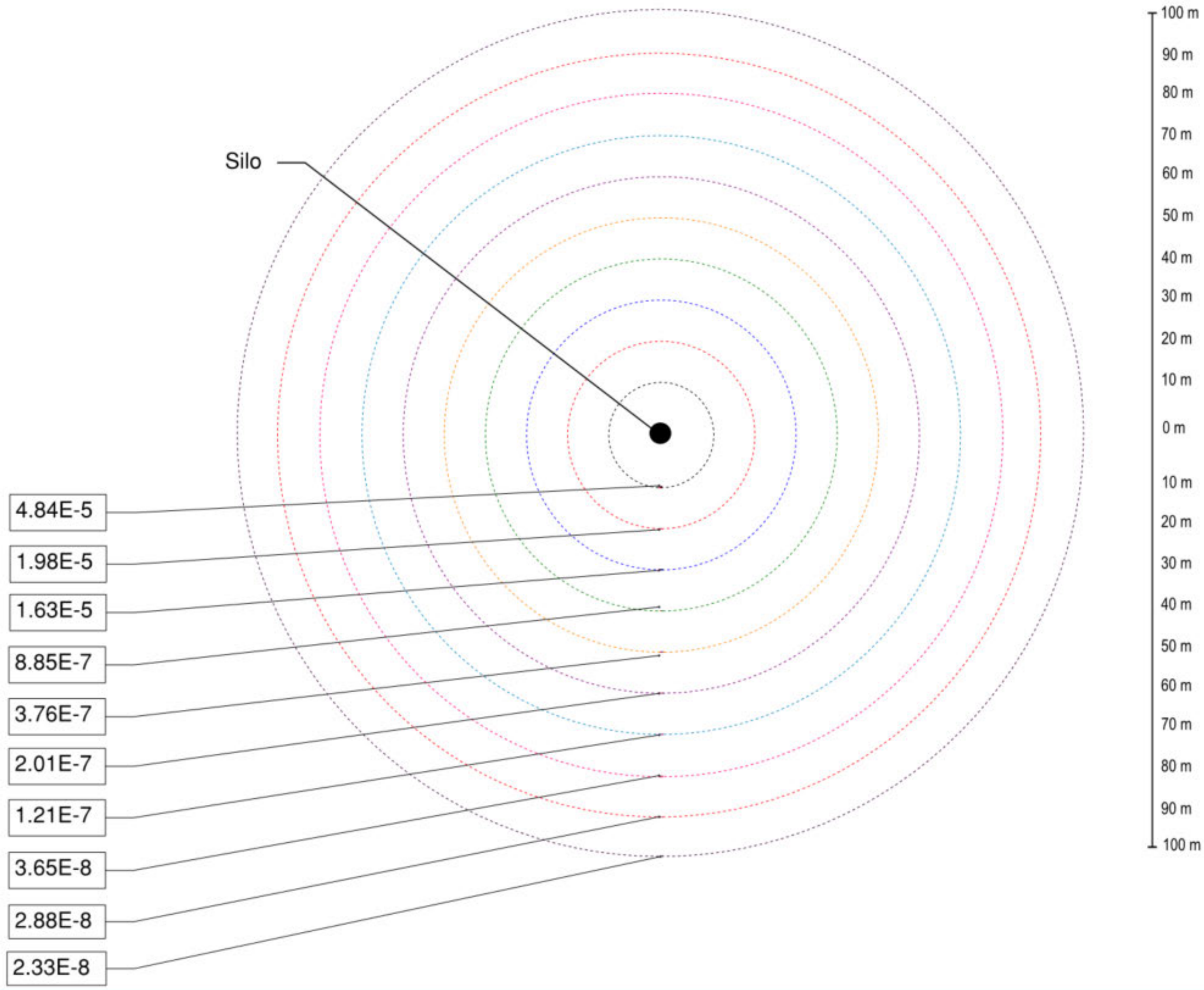


Figure 8.15: Risk contours associated with each individual silo in Annex 4 at 10 meter distance intervals up to 100 meters.

8.6 CUMULATIVE RISK SURROUNDING THE GRAIN ELEVATOR

This estimated risk outlined in Section 8.5 is representative of the risk presented by each individual silo at various distance intervals from the exterior silo walls in each annex. Each individual silo is a point source of risk as there is the potential for an explosion to occur within or propagate to each silo. As such, the individual risk at various distances from the silos is equivalent to the cumulative risk of all silos whose explosion effects have the potential to cause harm to an individual at that distance. Further explanation is provided in Figure 8.16.

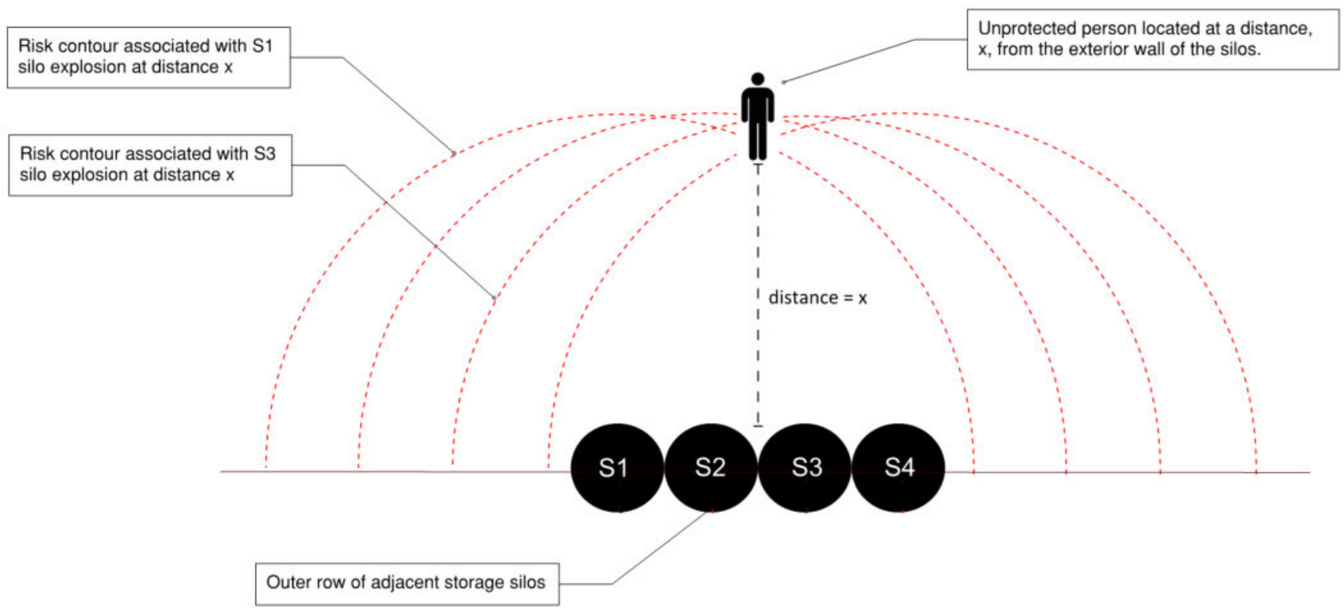


Figure 8.16: Example of cumulative individual risk posed to an unprotected person by multiple silos at a specific distance, x.

As shown in Figure 8.16, the individual risk posed to an unprotected person at distance, x, is the summation of the risk contours associated with the four silos (S1 – S4) at the given distance. To determine the allowable land uses surrounding the grain elevator facility, it was necessary to determine the cumulative individual risk that is presented by all silos at various distance intervals from the exterior annex walls. It is important to note that the cumulative individual risk will increase as the number of adjacent silos increases as this will result in a larger number of silos having the potential to cause harm to an individual.

With respect to Annexes 1-3, the largest number of adjacent silos is found in Annex 3, where 23 adjacent silos are positioned at the exterior on the western side of the annex. A total of 23 silos was used to determine the cumulative individual risk that would be presented by a worst-case dust explosion in all external areas surrounding Annexes 1-3. With respect to Annex 4, the largest number of adjacent silos located on the exterior wall is six and as such, a total of 6 silos was used to determine the cumulative individual risk in all external areas surrounding Annex 4.

The cumulative individual risk that would be presented by the worst-case dust explosion event was estimated at five meter intervals from the exterior silo walls in each annex. The cumulative individual risk was determined by summating the risk contours from all adjacent silos that intersect an imaginary zone placed central to the adjacent silos at each distance interval. The cumulative individual risk to the external area presented by an explosion event surrounding Annexes 1-3 at various distance intervals is summarized in Table 8.21 and Figure 8.17.

Table 8.21: Cumulative individual risk to the public in the external areas surrounding Annexes 1-3.

Distance from grain elevator exterior wall (m)	Individual silo risk (fatalities/year)	Cumulative risk (fatalities/year)
5	5.26E-05	**3.03E-04**
10	2.19E-05	**1.68E-04**
15	1.76E-05	**1.52E-04**
20	1.61E-05	**1.46E-04**
25	1.53E-05	**8.20E-05**
30	5.94E-07	**6.94E-06**
35	4.40E-07	**5.51E-06**
40	3.05E-07	**4.05E-06**
45	2.42E-07	**3.25E-06**
50	1.76E-07	**2.42E-06**
55	1.44E-07	**1.83E-06**
60	9.78E-08	**1.33E-06**
65	8.36E-08	**1.06E-06**
70	5.73E-08	**7.45E-07**
75	4.23E-08	**5.10E-07**
80	1.95E-08	**3.75E-07**
85	1.72E-08	**3.29E-07**
90	1.53E-08	**2.96E-07**
95	1.38E-08	**2.68E-07**
100	1.24E-08	**2.44E-07**
105	1.13E-08	**2.23E-07**
110	1.03E-08	**2.04E-07**
115	9.39E-09	**1.88E-07**
120	8.63E-09	**1.73E-07**

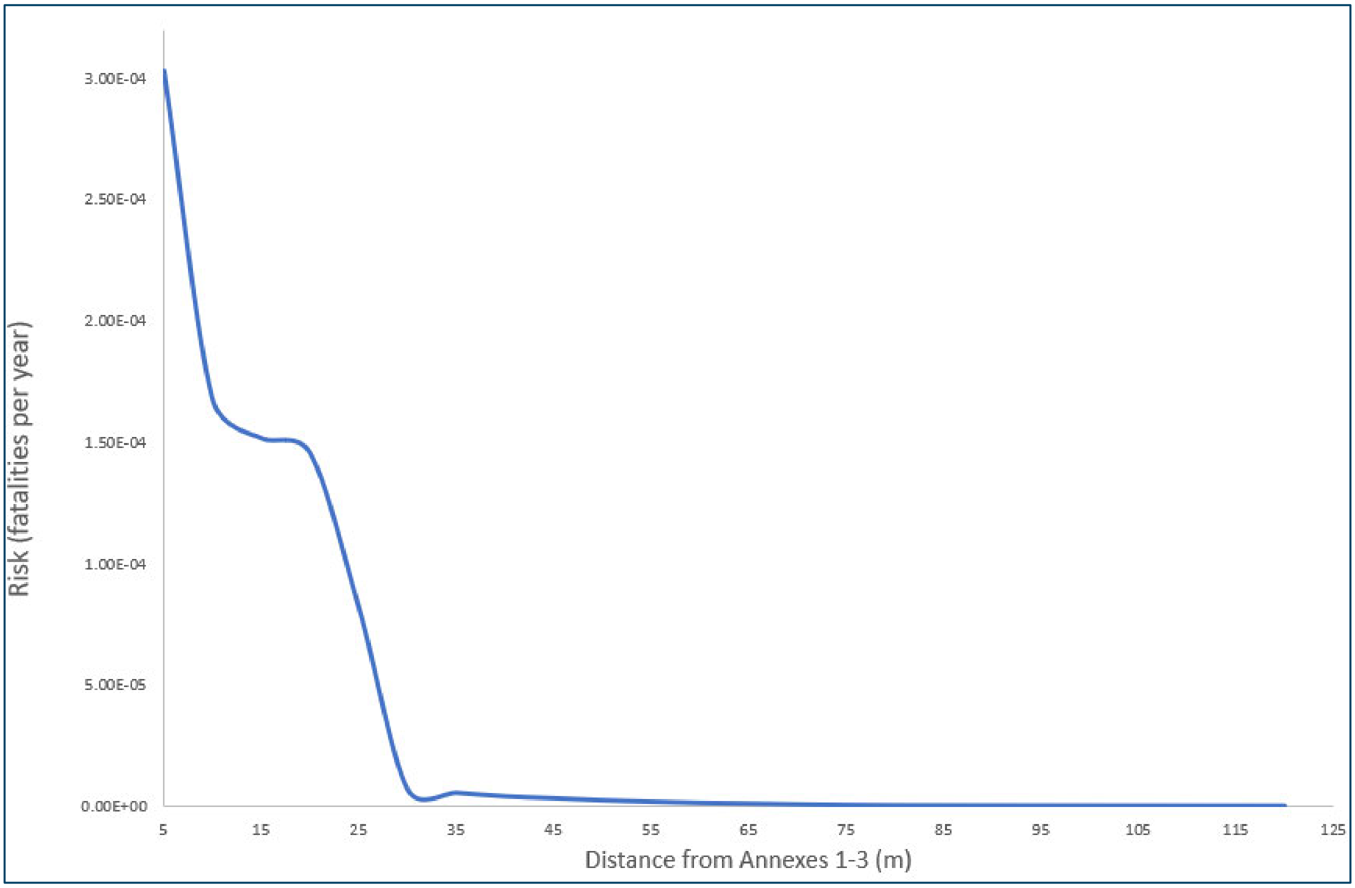


Figure 8.17: Cumulative individual risk posed by the worst-case explosion event at various distance intervals surrounding Annexes 1-3.

The cumulative individual risk to the external area presented by an explosion event surrounding Annexes 1-3 at various distance intervals is summarized in Table 8.22 and Figure 8.18.

Table 8.22: Cumulative risk at various distances surrounding Annex 4.

Distance from grain elevator exterior wall (m)	Individual silo risk (fatalities/year)	Cumulative risk (fatalities/year)
5	6.81E-05	**2.73E-04**
10	4.84E-05	**1.81E-04**
15	2.43E-05	**1.23E-04**
20	1.98E-05	**1.07E-04**
25	1.76E-05	**9.90E-05**
30	1.63E-05	**6.56E-05**
35	1.57E-05	**3.43E-05**
40	8.85E-07	**3.73E-06**
45	6.05E-07	**2.58E-06**
50	3.76E-07	**1.78E-06**
55	3.10E-07	**1.37E-06**
60	2.01E-07	**9.89E-07**
65	1.72E-07	**7.45E-07**
70	1.21E-07	**4.73E-07**
75	7.93E-08	**2.96E-07**
80	3.65E-08	**1.95E-07**
85	3.22E-08	**1.74E-07**
90	2.88E-08	**1.56E-07**
95	2.58E-08	**1.41E-07**
100	2.33E-08	**1.27E-07**
105	2.12E-08	**1.16E-07**
110	1.93E-08	**1.06E-07**
115	1.76E-08	**9.76E-08**
120	1.62E-08	**8.99E-08**

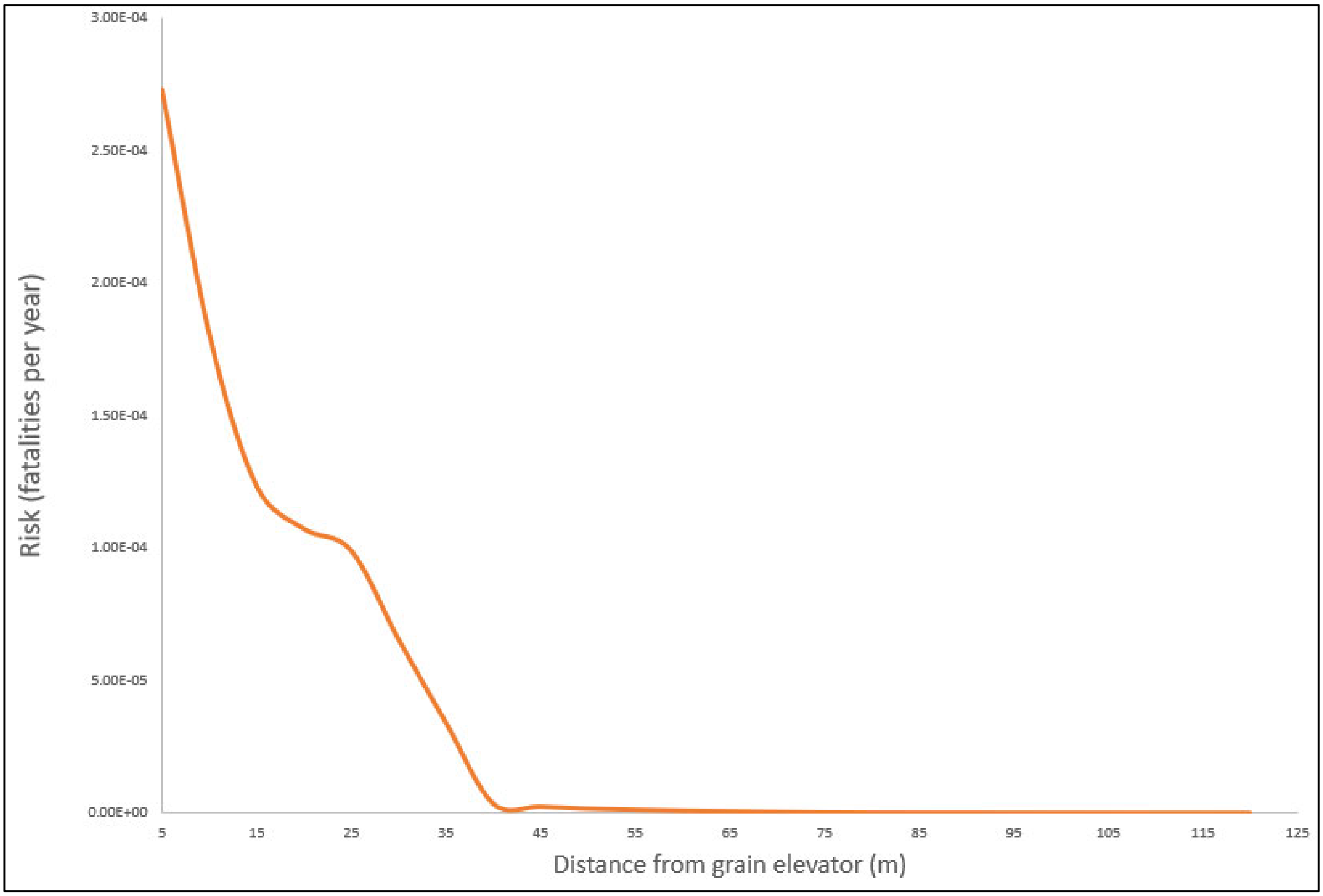


Figure 8.18: Cumulative individual risk posed by the worst-case explosion event at various distance intervals surrounding Annex 4.

Based on the cumulative individual risk that would be presented to the public in the event of a large scale dust explosion event, risk contours were developed for the area surrounding the Halifax Grain Elevator. A simplified diagram showing the risk contour surrounding the grain elevator is shown in Figure 8.19. In the diagram, risk contours that demonstrate individual risks of 1.0×10^{-4} fatalities per year (green), 1.0×10^{-5} fatalities per year (red), 1.0×10^{-6} fatalities per year (blue), and 0.3×10^{-6} fatalities per year (pink) are shown.

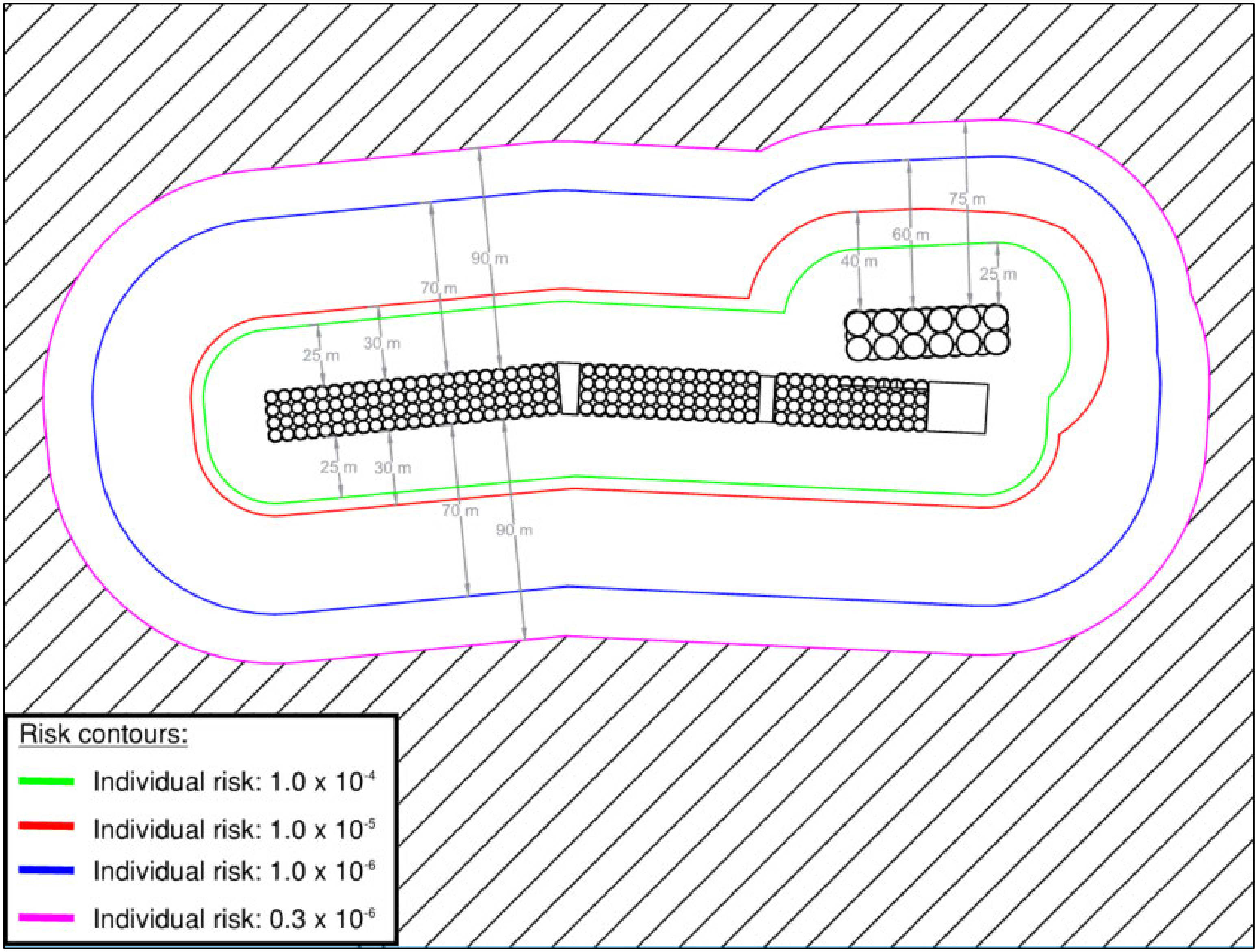


Figure 8.19: Diagram of risk contours surrounding the Halifax grain elevator based on the individual risk associated with the worst-case dust explosion event.

9.0 Land use planning

As outlined in Section 5 of this report, the risk acceptability criteria provided in the MIACC Guidelines forms the basis for determining the allowable land uses surrounding the Halifax Grain Elevator. The MIACC provides the following land use guidelines:

+ All other land uses are prohibited in areas surrounding industrial facilities where the individual risk posed by an industrial facility exceeds 1 x 10^{-4} fatalities per year.
+ Manufacturing, warehouse, and parkland uses are permitted in areas where the individual risk posed by an industrial facility is less than 1 x 10^{-4} fatalities per year.
+ Low-density residential and commercial land uses are permitted in areas where the individual risk posed by an industrial facility is less than 1 x 10^{-5} fatalities per year.
+ High-density residential and commercial land uses are permitted in areas where the individual risk posed by an industrial facility is less than 1 x 10^{-6} fatalities per year.
+ Sensitive land uses such as hospitals and care facilities are permitted in areas where the individual risk posed by an industrial facility is less than 0.3 x 10^{-6} fatalities per year.

Based on the findings of the risk assessment and the risk contours outlined in Section 8.6, the allowable land uses surrounding the Halifax Grain Elevator were identified based on the MIACC risk acceptance criteria. An overview of the allowable land uses are outlined in Table 9.1.

Table 9.1: Summary of allowable land uses surrounding the grain elevator based on MIACC guidelines.

Location	Allowable land use (MIACC)	Acceptable risk associated with land use (fatalities/year)	Applicable distance (m)
Annexes 1-3	Restricted – no land use	> 1.0 x 10^{-4}	0 – 25
	Manufacturing, warehouse, & parkland	< 1.0 x 10^{-4}	>25
	Low-density residential & commercial	< 1.0 x 10^{-5}	>30
	High-density residential & commercial	< 1.0 x 10^{-6}	>70
	Sensitive developments (hospitals, etc.)	< 0.3 x 10^{-6}	>90
Annex 4	Restricted – no land use	> 1.0 x 10^{-4}	0 – 25
	Manufacturing, warehouse, & parkland	< 1.0 x 10^{-4}	>25
	Low-density residential & commercial	< 1.0 x 10^{-5}	>40
	High-density residential & commercial	< 1.0 x 10^{-6}	>60
	Sensitive developments (hospitals, etc.)	< 0.3 x 10^{-6}	>75

A risk contour map was developed to demonstrate the required separation distances between the Halifax Grain Elevator and adjacent low-density residential, high-density residential, and sensitive land uses based on the individual risk to the public. The risk contour map is shown in Figure 9.1 and outlines the zones where the individual risk exceeds 1.0 x 10^{-4} fatalities per year (green), 1.0 x 10^{-5} fatalities per year (red), 1.0 x 10^{-6} fatalities per year (blue), and 0.3 x 10^{-6} fatalities per year (pink). It is important to note that the contours shown on the map may not be to scale and are subject to a site survey.

It is important to note that the individual risk was estimated on the basis of fatalities per year in the event of an explosion. Non-fatality risk (i.e., property damage) is difficult to estimate based on the uncertainty of the condition of adjacent and nearby properties. It is important to note that explosion effects associated with projectiles will have a greater impact with respect to property damage as buildings present a large target area and as such the probability of impact at increased distance would be higher. However, it is difficult to estimate the level of damage that would be sustained to the buildings. In an effort to account for the risk of building and property damage, it was conservatively assumed that significant property damage has the potential to occur within 100 meters of the grain elevator facility. This contour is shown in Figure 9.1 where the 100 meter boundary for property damage is shown by the yellow zone. It is important to note that all areas located between the grain elevator and outer boundary of the yellow zone (100 meters) have the potential to experience property damage.

Figure 9.1: Risk contour map for the area surrounding the Halifax Grain Elevator.

As previously mentioned, established low and high-density land uses are present on the western side of the facility and interest in residential development is expected to continue in the surrounding area. This is discussed in the following sections.

9.1 EXISTING DEVELOPMENTS

Established low density and high density developments are located on the western side of the Halifax Grain Elevator. Select low and high-density residential uses are located in areas where the risk was deemed to be nonacceptable for these land uses. This is shown in Figure 9.2. It is important to note that the risk contour may not be to scale and acceptable land uses are subject to a site survey.

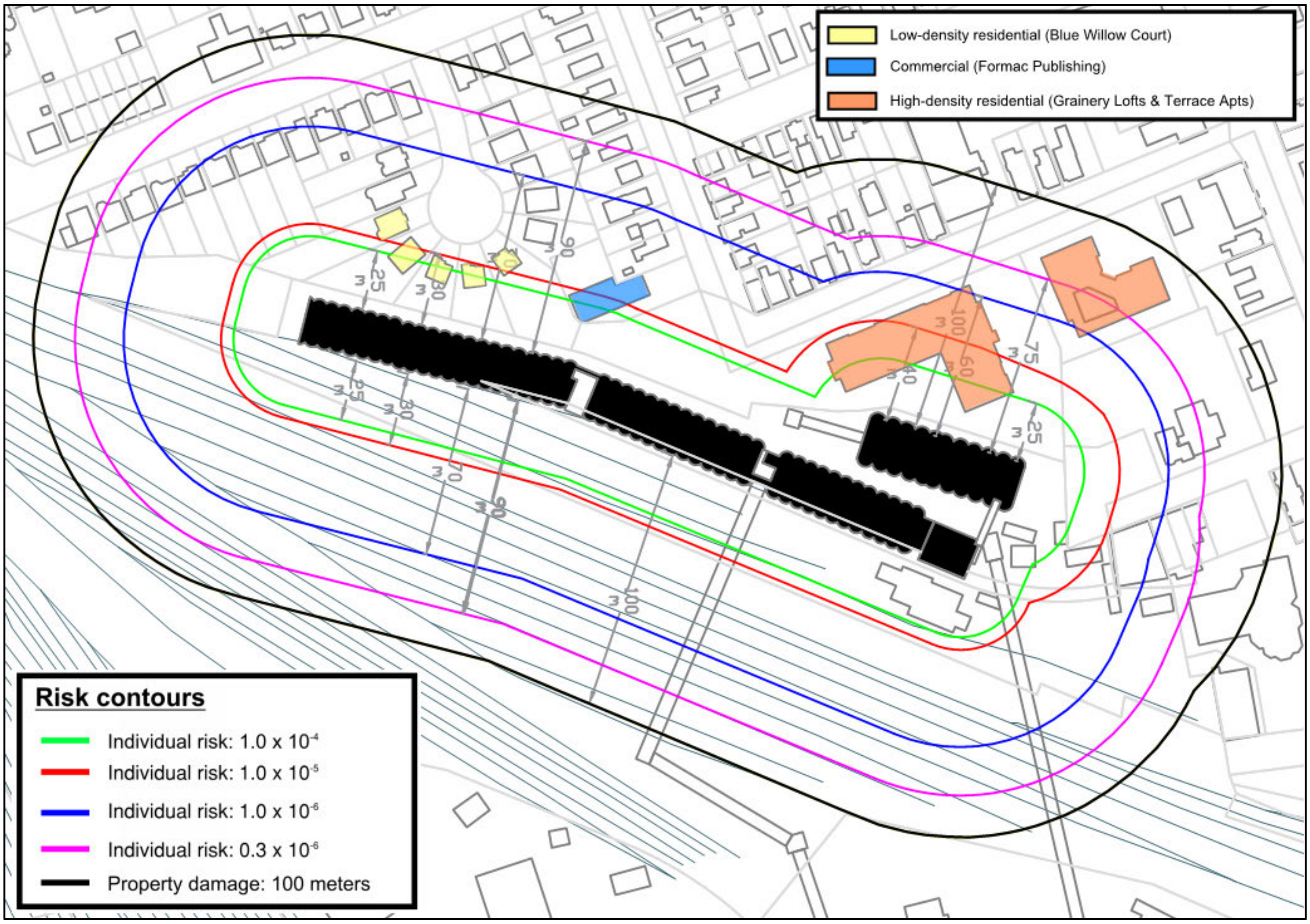


Figure 9.2: Low and high-density residential and commercial developments located in nonacceptable areas based on the MIACC risk acceptance criteria and risk contours.

As outlined in Section 2.1, the Grainery Lofts is a six-story multi-unit apartment building and is a high-density land use. The building directly abuts Annex 4 and is as close as 10 meters at select points. Based on the risk contours developed through completion of the risk assessment, there should be a buffer of at least 60 meters between the Halifax Grain Elevator and high-density residential land uses. The entire Grainery Lofts structure is located inside the buffer zone for high-density residential land uses with a portion of the building being located inside the restricted zone. Based on the drawing, a small portion of the Terrace Apartment building (South Bland Street) is located in close proximity to the buffer zone for high-density residential uses. A commercial use (Formac Publishing) is also located partially within the restricted buffer zone. It is important to note that there is a risk for property damage to occur within 100 meters of the grain elevator in the event of an explosion as outlined in Figure 9.2. Figure 9.3 shows the close proximity of the Grainery Lofts to Annex 4.

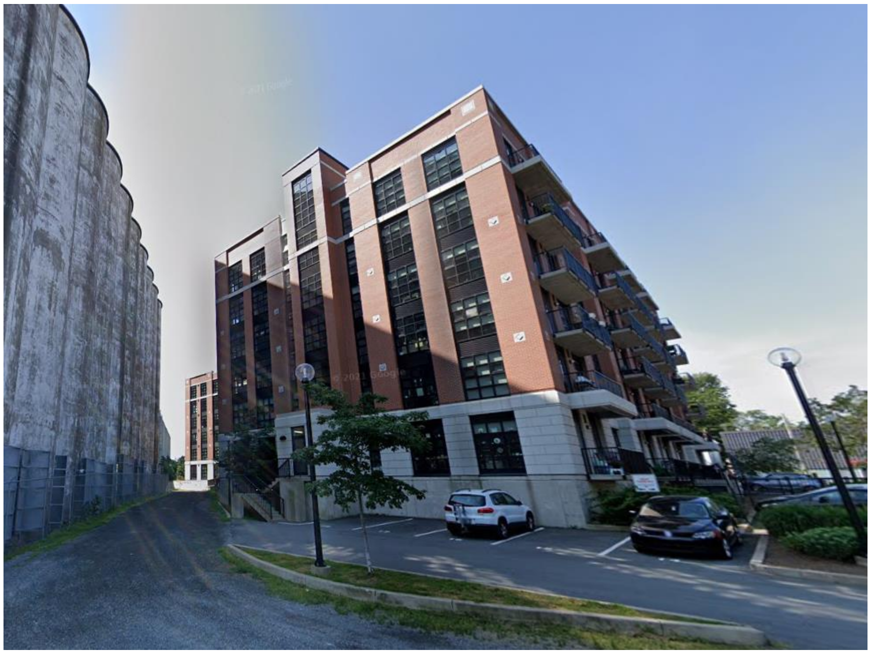


Figure 9.3: Close proximity of the Grainery Lofts to Annex 4.

With respect to existing low-density residential developments, several houses located on Blue Willow Court are located within the restricted buffer zone for low-density residential uses. Figure 9.4 includes a Google Earth image that shows the close proximity of select houses on Blue Willow Court to Annex 3.

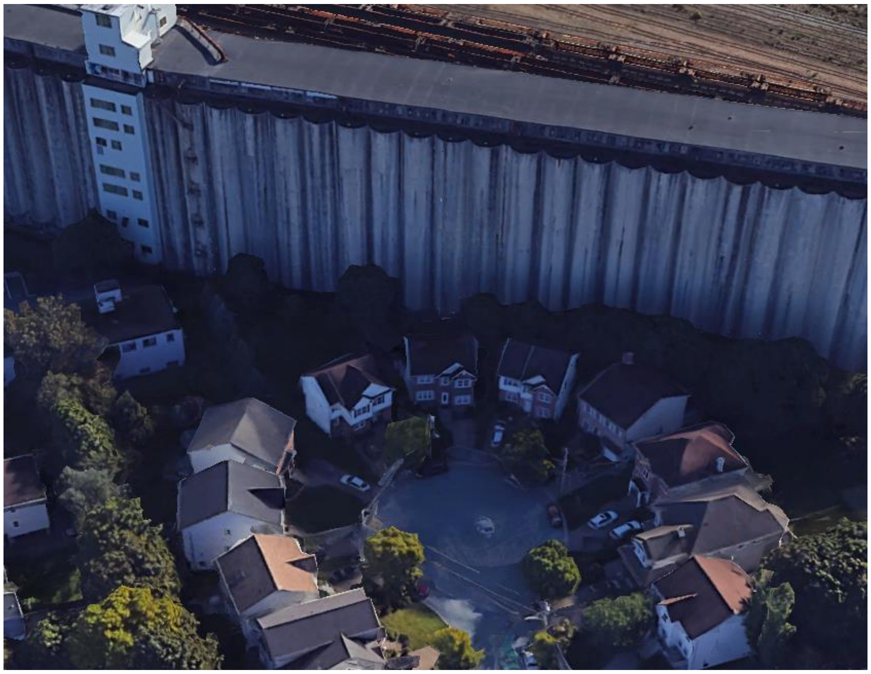


Figure 9.4: Close proximity of low-density residential uses to Annex 3.

9.2 NEW DEVELOPMENTS

This information outlined in this section should apply to new land uses in the areas surrounding the Halifax Grain Elevator. Based on the information provided in Table 9.1 (MIACC risk acceptance criteria), the following restrictions should be applied with respect to land use planning for new developments.

+ All land uses within 25 meters of Annexes 1-4 should be prohibited.
+ Buffer zones of 30 meters surrounding Annexes 1-3 and 40 meters surrounding Annex 4 should be established between the grain elevator and any new low-density residential land uses.
+ Buffer zones of 70 meters surrounding Annexes 1-3 and 60 meters surrounding Annex 4 should be established between the grain elevator and any new high-density residential land uses.
+ Buffer zones of 90 meters surrounding Annexes 1-3 and 75 meters surrounding Annex 4 should be established between the grain elevator and any new sensitive land uses.

The locations of new developments should comply with the buffer zones outlined in Figure 9.1 for adjacent land uses.

9.3 SUMMARY

In most cases, buffer zones are determined for the purpose of siting new industrial or hazardous land uses in proximity to existing non-industrial uses, and not vice versa. Locating sensitive land uses nearby existing hazardous uses is not something that is considered by most provincial or municipal planning departments. In the case of the grain elevator, there are conflicts between existing land uses and the buffer zones or risk contours that were identified through the risk assessment. The main development of concern is the Grainery Lofts building which is located in close proximity to the facility. Recommendations related to hazard mitigation at the facility level and through land use planning have been offered and are outlined in Section 10 of this report. Any new residential, commercial, or sensitive land uses should be located in accordance with the buffer zones outlined in Table 9.1 and the risk contour drawing shown in Figure 9.3. It is important to note that the risk assessment focused on the individual risk of fatality per year to develop the risk contours as outlined in the MIACC Guidelines. It was conservatively assumed that all developments within 100 meters of the grain elevator have the potential to experience property damage in the event of an explosion. Building located closer to the grain elevator will be at a higher risk to experience damage. However, the potential severity of the property damage is unknown.

As outlined in Section 4, Ontario uses a general separation distance approach and recommends a minimum separation distance of 70 meters between the existing use and new sensitive land uses. One of the main findings outlined in the summary report for the SEMABLA dust explosion in Blaye, France was to locate buildings occupied by other parties a distance of at least 1.5 times the height of the facility. The silos have heights of approximately 33 meters. If the height of the facility is conservatively estimated as 50 meters, this would result in a recommended separation distance of 75 meters. The buffer zones of 70 meters (Annexes 1-3) and 60 meters (Annex 4) between the grain elevator and high-density residential uses align with these recommended separation distances.

10.0 Recommendations

This section present recommendations with respect to combustible dust hazard mitigation and land use planning. Implementation of the recommendations is intended to reduce the likelihood of an explosion within the facility and reduce the risk to the public in the surrounding areas.

10.1 RECOMMENDATIONS FOR MITIGATING COMBUSTIBLE DUST HAZARDS

With respect to the Halifax Grain Elevator, the hazard is presented by the potential for a large scale dust explosion event that could cause harm to the public in the surrounding area. As such, reducing the potential for a dust explosion event to occur at the facility is of high importance. With respect to combustible dust hazard management, the goal is to ensure that the risk posed by combustible dust hazards is as low as reasonably practicable (ALARP). This is achieved through implementing controls, safeguards, management systems, and procedures to mitigate potential equipment and building explosion hazards.

As outlined in Section 6 of this report, grain elevator dust explosions have occurred relatively frequently over the years and have resulted in significant losses. It is important to note that no grain elevator explosion event has a singular cause. Based on loss history, common factors have typically lead to dust explosion events at grain handling facilities. These factors include lack of explosion protection and control systems, neglected maintenance, and insufficient housekeeping. With respect to mitigation of combustible dust hazards, the following recommendations have been offered to reduce the dust explosion risk presented by operation of the facility.

Recommendation 1: Implement the DHA recommendations.	
Rec:	The recommendations outlined in the Jensen Hughes DHA Report No. 4H2102690.000 – HGE DHA – FINAL – R0 should be implemented site wide to ensure that the facility and process equipment are operated in accordance with good engineering practice to mitigate potential combustible dust hazards.
Comments:	The key step in lowering the risk to the public in the area surrounding the grain elevator is reducing the likelihood of a dust explosion occurring within the facility. The DHA report has identified and documented deficiencies between the existing conditions at the Halifax Grain Elevator and the good engineering practice guidelines outlined in the applicable codes and standards. The recommendations outlined in the DHA focus on equipment-specific safeguards and controls, design requirements, building hazard management, and management systems. The recommendations outlined in the DHA are summarized in Table B.2 in Appendix B of this report.

Recommendation 2: Maintain fugitive dust below hazardous levels.	
Rec:	Formalized housekeeping procedures should be implemented and maintained at all times through the grain elevator. This is highlighted in Recommendation Gen-5 in Table B.2 (Appendix B). The housekeeping frequency and cleaning practices should be sufficient to maintain fugitive dust accumulation below hazardous thresholds at all times throughout the facility. Refer to the DHA for additional information
Comments:	Removal of fugitive dust accumulation is essential in mitigation of building deflagration hazards. Fugitive dust accumulation located throughout a facility presents a secondary dust explosion hazard. In the event of a dust explosion in a vessel or building area, the generated blast wave has the potential to disperse fugitive dust located on building surfaces creating a large fuel load that can be ignited by the primary explosion. In many cases, the secondary explosions are often more severe than the primary explosion and can lead to propagation throughout an entire facility. When large amounts of fugitive dust are present within a facility there is the potential for a relatively small-scale event to quickly turn catastrophic. With respect to the explosion at the DeBruce grain elevator described in Section 6, secondary dust explosions resulting from dispersion of fugitive dust throughout the facility was one of the primary causes that lead to the significance of the event. Maintaining dust accumulation below hazardous levels at the grain elevator is a key component in preventing explosion propagation through the facility that could lead to a large-scale dust explosion that would affect employees and members of the public

Recommendation 3: Ensure that the dust collection systems provide sufficient remove of suspended dust.	
Rec:	The design and operation of the dust collection systems located throughout the facility should be sufficient to remove suspended dust particulate from equipment and building areas.
Comments:	In addition to Recommendation #2, a key component of eliminating fugitive dust accumulation is ensuring proper operation of dust collection systems. The dust collection systems should provide an air transport velocity that is sufficient to remove suspended dust particulate and prevent material accumulation within the ductwork. Dust collection systems should also be properly inspected and maintained such that they do not introduce potential ignition sources into the process. Improper function of dust collection systems was another key factor in the DeBruce dust explosion event. As outlined in Recommendation A.5.6 of the DHA (Table B.2), dust collection systems should provide air transport velocities of at least 4000 ft/minute in all areas of the system. The air transport velocities in the dust collection systems are unknown. HGEL has indicated that the velocities are sufficient but this was not able to be confirmed by Jensen Hughes. Given the process operations of grain elevators, the potential for dust cloud generation is imminent. As such, it is critical for dust collection systems to operate properly to prevent generation of fugitive dust clouds and dust accumulation.

Recommendation 4: Perform regular inspection, testing, and maintenance to prevent equipment failure or upset conditions.	
Rec:	Implement a formalized inspection, testing, and maintenance program throughout the entire facility as outlined in Recommendation Gen-14 in the DHA (Table B.2).
Comments:	Preventative maintenance is critical in preventing equipment failure that could lead to introduction of ignition sources in the process. Given the size of the grain elevator it is of high importance to keep up with preventative maintenance and inspection of equipment to ensure proper operation of the facility. Lack of adequate maintenance was another key contributor to the DeBruce grain elevator explosion event as described in Section 6.

Recommendation 5: Ensure that damage limiting construction and explosion partitions are appropriate.	
Rec:	To reduce to potential for explosion propagation throughout the facility damage limiting construction and explosion partitions should be utilized. The damage limiting construction should operate as a form of deflagration venting to reduce the overpressure that would be experienced in an explosion and partitions should be used to prevent explosion communication between connected annexes.
Comments:	Based on loss-history for grain elevators, catastrophic explosion events typically involve scenarios where the primary dust explosion event propagated throughout the facility resulting in multiple secondary explosions. This is evident based on the SEMABLA and DeBruce explosion incidents. With respect to the Halifax Grain Elevators, the headhouse and workhouse towers are provided with explosion release cladding. It is important to note that documentation was not provided to detail the design specification of the cladding but HGEL has indicated that the cladding is designed to release at overpressures of approximately 1 psi (0.07 bar). The effectiveness of the explosion release cladding should be evaluated. The facility is provided with partitions in the bin level and basement galleries. Based on information provided by HGEL, these partitions are intended to prevent propagation of an explosion between the annexes. However, based on observation of these partitions they do not appear appropriate as they possess relatively large openings that would allow for communication of flame and overpressure between these areas. All openings that allow for communication between floor levels (not necessary for operation or egress) should be properly sealed to help prevent propagation of flame and pressure to connected building areas in the event of an explosion.

Recommendation 6: Evaluate the existing design of the galleries with respect to overpressure relief.	
Rec:	Perform an assessment of the bin level and basement galleries to determine if the existing design would be sufficient to relieve overpressure.
Comments:	The bin level and basement galleries are constructed primarily of concrete and have some windows located along the exterior walls. There is the potential that the windows and opening would be sufficient to act as vents in the event of an explosion within the galleries. However, an assessment should be performed and adequate venting should be provided in the galleries if possible. It is important to note that lack of adequate venting was a key contributor to the severity of the SEMABLA and DeBruce explosion events.

10.2 LAND USE PLANNING RECOMMENDATIONS

Land use planning recommendations should consider both the annualized level of risk of an event as well as the worst-case scenario outcome from that event. The first task is to evaluate the level of risk associated with an industrial hazard and then assess the tolerability of risk. In assessing the tolerability of risk from potentially hazardous development, both qualitative and quantitative aspects need to be considered. The main quantitative criteria considered are fatality, injury, and property and environmental damage.

The next task is to ensure that the appropriate controls are exercised on new developments of a type that could cause risk intensification, such as new residential or sensitive use development and recreational areas involving large numbers of people. The final task is to establish procedures which ensure that the above controls are exercised when dealing with new developments in the vicinity of existing facilities.

Based on the findings of the risk assessment and the development of the risk contours, recommendations for land use planning were developed by ZZAP Architecture + Planning. Three categories of recommendations were provided which include:

1. Establishing risk precincts
2. Implementing build form guidelines for risk mitigation
3. Addressing non-conforming uses and structures

While the first two categories of recommendations can be implemented relatively easily through existing municipal procedures, the third category will require coordination and cooperation from the Nova Scotia Provincial Government. These recommendations are based upon the best practices for acceptable levels of risk. However, individual communities may have different acceptable levels of risk depending on demographic, economic, and sociological criteria, and therefore, final decision making pertaining to regulations within the Halifax Grain Elevator area should be developed in consultation with landowners and community members.

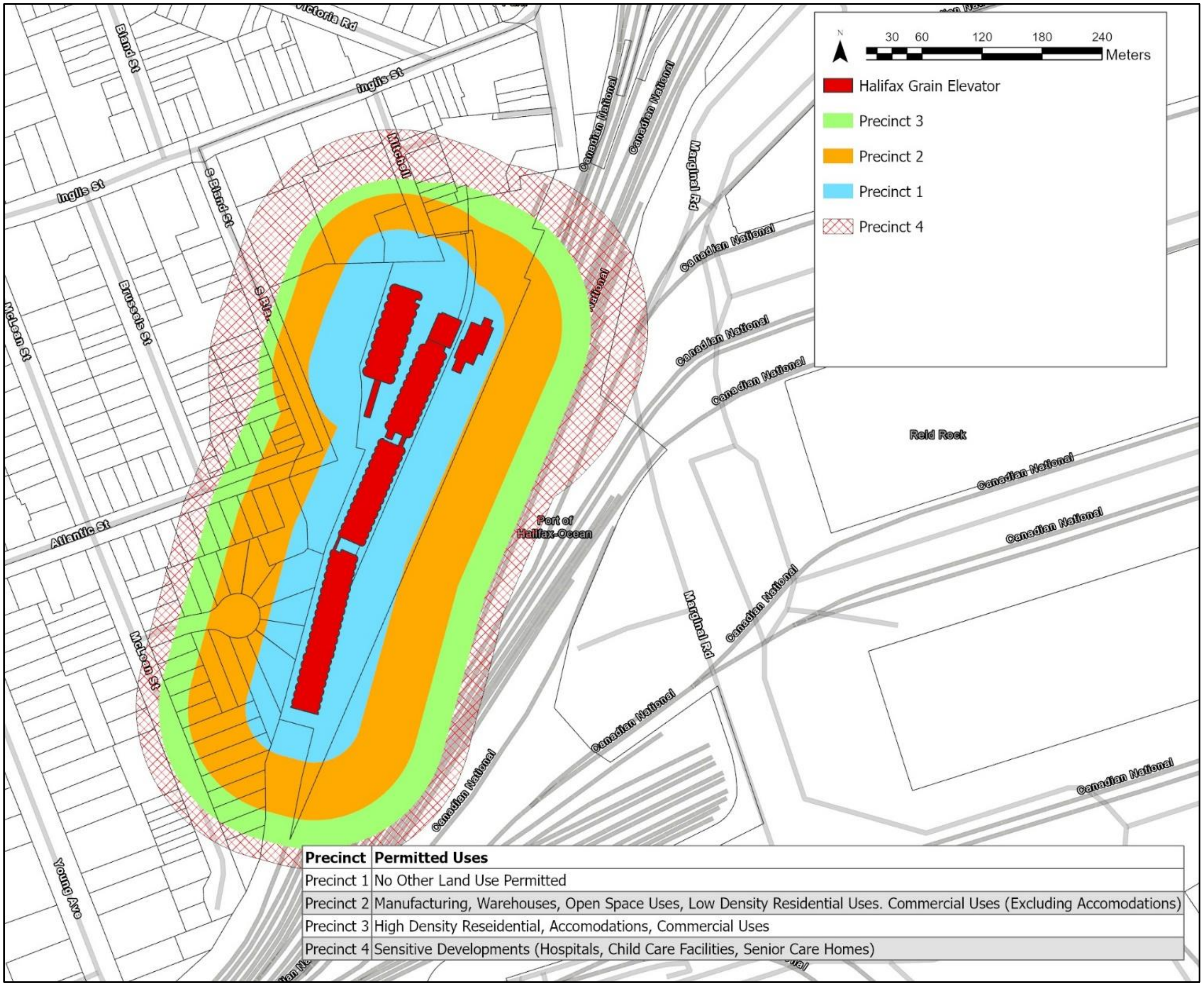
10.2.1 Establish risk precincts

Separation of incompatible land uses remains the most effective risk mitigation strategy. Therefore, the primary recommendation is to adopt appropriate land use controls to exclude incompatible land uses in proximity to the Halifax Grain Elevator. Table 10.1 outlines the four recommended land use precincts and the appropriate permitted land uses based on best practices for acceptable levels of risk.

Table 10.1: Land use precincts.

Precinct	MIACC recommended land use
Precinct 1	No other land use permitted.
Precinct 2	Manufacturing, warehouse, open space uses, low-density residential, commercial (excluding accommodations).
Precinct 3	High-density residential, hotels.
Precinct 4	Hospitals, care homes, etc.

Figure 10.1 demonstrates how the described land use precincts may be applied to lands in proximity to the Halifax Grain Elevator based on the risk contour drawings shown in Section 9.



Precinct	Permitted Uses
Precinct 1	No Other Land Use Permitted
Precinct 2	Manufacturing, Warehouses, Open Space Uses, Low Density Residential Uses. Commercial Uses (Excluding Accomodations)
Precinct 3	High Density Reseidential, Accomodations, Commercial Uses
Precinct 4	Sensitive Developments (Hospitals, Child Care Facilities, Senior Care Homes)

Figure 10.1: Halifax Grain Elevator risk precincts.

The purpose of the precincts is to provide adequate separation distances between incompatible land uses and the above land use categories can help to guide what land uses are appropriate within certain proximities.

To implement these precincts, the Municipality can establish new designations or a special area designation under the Regional Centre SMPS and new zones in the Regional Centre Land Use Bylaw that limits permitted uses and intensities within the land use precincts shown on Figure 10.1. This could include amending the boundary of the Halifax Grain Elevator Special Area in Schedule 3F in the Regional Centre Land Use Bylaw and amending Policy ED-6 in the Regional Centre SMPS to limit the type of development permitted in each risk precinct through a development agreement process.

Alternatively, the Municipality could consider adopting a new Land Use Designation under the Regional Centre SMPS, and new Land Use Zones under the Regional Centre Land Use Bylaw, that correspond to the Risk Precincts to regulate development on lands in proximity to the Halifax Grain Elevator.

Any new or amended policy should also contemplate directing Council to consider the incorporation of Risk Mitigation Built Form Guidelines when reviewing applications for development agreements in the Halifax Grain Elevator Special Area. Alternatively, Risk Mitigation Built Form Requirements could be developed and administered through an as of right process or through a Site Plan Approval mechanism. These Risk Mitigation Built Form Guidelines are discussed in more detail in the next section.

10.2.2 Risk mitigation build form guidelines

While the separation of incompatible uses is the most effective method of mitigating risk in the event of an explosion at the Halifax Grain Elevator, additional built form guidelines can further reduce risk. These include:

- New buildings and additions/alterations to existing buildings should minimize openings (e.g. windows, doors, etc.) facing the Grain Elevator;
- Require primary facades of buildings to be oriented away from the Grain Elevator;
- Orient the inside corner of L-shaped buildings away from the Grain Elevator;
- Prohibit building projections or overhangs facing the Halifax Grain Elevator; and
- Consider design guidelines which encourage the use of blast and fire resistant external cladding materials and windows.

While outside the jurisdiction of the Municipality, consideration should be given to regulating the standards and methods of construction for new buildings and alterations to existing buildings in proximity to the Halifax Grain Elevator.

The Municipality could request that the Province amend Section 235 of the Halifax Charter to permit a Land Use Bylaw to regulate the construction of buildings in proximity to the Halifax Grain Elevator.

In tandem with this request, the Municipality could request that the Provincial to take into consideration requiring building methodologies which are rated for blast resistance, (for example, the American Society of Civil Engineers Blast Protection of Buildings) by amending the Building Code Act. Further exploration is recommended to determine the regulations which would be suitable within the Building Code.

It is important to note that applying Risk Mitigation Built form guidelines to properties within the risk precincts are not sufficient without implementing the recommended land use restrictions as well. The purpose of the Risk Mitigation Built Form Guidelines is to provide an additional risk mitigation measure. However, further research is required to determine the extent that these built form mitigation measures would assist in reducing risk for specific land uses.

The built form recommendation should be implemented for new developments in addition to the established risk precincts. It is important to note that built form guidelines are considered an additional protection measure and do not allow new developments to be located inside higher risk contours (i.e. a new high density residential development should not be located inside the 1.0×10^{-6} risk contour even if it is designed and constructed in accordance with the outlined built-form guidelines).

10.2.3 Existing and potential nonconforming uses and structures

While the previous recommendations deal specifically with land uses and new structures in proximity to the Halifax Grain Elevator, there are many existing structures and land uses whose proximity to the Halifax Grain Elevator exceed the distance for best practices of acceptable risk tolerance. A concerted effort to limit the continued operation of, and expansion of, incompatible uses will be required to achieve acceptable risk tolerances. Therefore, the municipality should consider limiting the expansion of all existing low-density residential uses in Precinct 1 and limit the expansion of existing high-density residential uses in Precincts 1 & 2.

This can partially be achieved by amending Policy IM-18 and Policy IM-19 (policies governing non-conforming structures and uses), to exclude properties within Precincts 1 & 2. However, the expansion of non-conforming uses and structures would still be permitted, to a lesser extent, through Section 254 of the Halifax Charter. Therefore, the Municipality should consider requesting amendments to the Halifax Charter, Section 254, to exclude properties within Precincts 1 & 2.

11.0 Assumptions and limitations

Given the age of the Halifax Grain Elevator and the limited design information and documentation that was available at the time of this report, assumptions were made to complete the land use risk assessment study. It is important to note that various assumptions are stated throughout Section 8 of this report. This section outlines high-level assumptions and limitations as follows:

1. The risk acceptance criteria outlined in the MIACC Risk-Based Land Use Planning Guidelines were used to determine the appropriate buffer zones. This is described in Section 5 of this report.

2. It was assumed that the highest risk to the public would be presented in the event of a dust explosion that occurred within or propagated to one or more of the silos located on the western side of the facility. The worst-case dust explosion event was assessed based on loss-history for similar facilities as described in Section 6 of this report.

3. For the purpose of evaluating the explosion effects, a K_{st} of 170 bar m/s and a P_{max} of 9.0 bar-g were utilized as outlined in Section 3 of this report. These explosion severity parameters were obtained from literature resources and were used in estimated the consequences associated with overpressure effects.

4. The frequency of operations at the Halifax Grain Elevators were estimated based on information provided by HGEL and HPA. This information was used in estimating the event frequency of a dust explosion.

5. The design strength of the silos was estimated based on construction drawings provided by HPA. These drawings are provided in Appendix C of this report. It is important to note that reinforcement details for the Annex 4 silos could not be obtained from the drawings. As such, it was assumed that the design strength would be equivalent to the silos in Annex 3. The effects of corrosion and other factors that may have weakened the silo structure over time were not accounted for in the estimation of the design strength.

6. The risk assessment was conducted on the basis of individual fatality risk for the purpose of identifying appropriate buffer zones between adjacent land uses. As such, the assessment does not account for the effects of building and property damage. To be conservative, it was assumed that property damage could occur in all areas within 100 meters of the grain elevator in the event of an explosion.

7. The risk contour drawings provided in Section 9 of this report may not be to scale. As such, all buffer zones should be verified by a site survey.

12.0 Conclusion

This report documents the findings of the land use risk assessment study conducted for the land area surrounding the Halifax Grain Elevator. Given the inherent dust explosion hazards and loss-history associated with grain handling facilities, the grain elevator is considered to present a risk to the public in the surrounding residential areas on the western side of the facility. For the purpose of the study, the worst-case explosion event was identified based on a review of historical dust explosions at similar facilities. The worst-case event is represented by a large-scale dust explosion that occurs within or propagates to the silos located on the western side of the facility.

A risk based approach was employed to estimate the individual risk to the public in the event of the described explosion scenario. The risk based approach accounted for the frequency of ignition resulting in a dust explosion and accounted for the consequences of various explosion effects including fireball and thermal radiation, overpressure, bulk outflow, and projectiles. The consequences of each explosion effect were evaluated in terms of probability of fatality and were used along with the estimated explosion frequency to determine the individual risk to the public. Risk contours were developed to outline the cumulative risk to the public at various distances from the grain elevator.

With respect to land use planning, the MIACC Guidelines were used to identify risk acceptance criteria for adjacent land uses. Based on the findings of the risk analysis and the MIACC risk acceptance criteria, required buffer zones between the grain elevator and adjacent land uses were identified. The risk assessment resulted in the following findings:

+ Any new land uses within 25 meters of the facility should be prohibited.
+ Buffer zones of 30 meters surrounding Annexes 1-3 and 40 meters surrounding Annex 4 should be established between the grain elevator and any new low-density residential land uses.
+ Buffer zones of 70 meters surrounding Annexes 1-3 and 60 meters surrounding Annex 4 should be established between the grain elevator and any new high-density residential land uses.
+ Buffer zones of 90 meters surrounding Annexes 1-3 and 75 meters surrounding Annex 4 should be established between the grain elevator and any new sensitive land uses.

Based on the findings outlined above, recommendations related to combustible dust hazard management and land use planning were offered and are outlined in Section 10 of this report. The recommendations are intended to reduce the risk to the public presented by the grain elevator.

13.0 References

[1] Major Industrial Accidents Council of Canada (MIACC), Risk-based Land Use Planning Guidelines, 1995.

[2] NFPA 652, "Standard on Fundamentals of Combustible Dusts," 2019.

[3] NFPA 61, "Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities." 2020.

[4] NFPA 51B, "Standard for Fire Prevention During Welding, Cutting, and Other Hot Work," 2019.

[5] NFPA 68, "Standard on Explosion Protection by Deflagration Venting," 2018.

[6] NFPA 69, "Standard on Explosion Prevention Systems," 2019.

[7] NFPA 77, "Recommended Practice on Static Electricity," 2017.

[8] NFPA 91, "Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists, and Particulate Solids," 2020.

[9] NFPA 499, "Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas," 2017.

[10] NFPA 654, "Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids," 2020.

[11] Canadian Commission on Building and Fire Codes, "National Building Code of Canada," 2015.

[12] Canadian Commission on Building and Fire Codes, "National Fire Code of Canada," 2015.

[13] OSHA 29 CFR 1910.272, "Grain Handling Facilities."

[14] SOR/86-304, Canada Occupational Health and Safety Regulations (COHSR), Government of Canada.

[15] NFPA 664, "Standard for the Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities," 2020.

[16] Canadian Society for Chemical Engineering, "Risk Assessment – Recommended Practices for Municipalities and Industry," 2004.

[17] Cremante & Demontis, "Frequency of Dust Explosion in Grain Storage," 2012.

[18] Klein et Al, "A quantitative risk assessment tool for the external safety of industrial plants with a dust explosion hazard," 2006.

[19] Health and Safety Executive (HSE), "Methods of approximation and determination of human vulnerability for offshore major accident hazard assessment."

[20] European Commission's Joint Research Center (JRC), "A survey of computational models for blast induced human injuries for security and defence applications," 2020.

[21] F. Masson, "Explosion of a grain Silo – Summary Report," Ministry for National and Regional Development and the Environment, 1998.

[22] Full Report: Explosion of DeBruce Grain Elevator, Wichita, Kansas; June 8,1998. Graine Elevator Explosion Investigation Team (GEEIT). Obtained from OSHA.

[23] Center for Chemical Process Safety (CCPS), “Guidelines for Developing Quantitative Safety Risk Criteria,” 2009.

Appendix A. Sample calculations

This appendix provides sample calculations with respect to the risk assessment that was completed and documented in Sections 7 and 8 of this report.

A.1 EVENT FREQUENCY

This section provides sample calculations for the expected frequency of a dust explosion event as described in Section 7.2 of this report. The ignition frequency was estimated based on the methodology outlined in Klein et Al (2006) [18]. Given the silo and bin configurations in Annexes 1-3 at the grain elevator, the explosion frequency was calculated based on a group of nine modules (i = 9) as follows:

i = 1: over-silo gallery
i = 2, 3, 4, 5, 6, 7: silo cells
i = 8, 9: intermediate bins

The calculation was based on the following ignition frequencies and probabilities of propagation:

- Ignition frequency in a cell gallery of handling tower: 1 x 10^{-4} events per year
- Ignition frequency in a silo cell: 1 x 10^{-5} events per year
- Probability of propagation to a direct neighbor module (e.g., gallery to silo or vice versa): 10%
- Probability of propagation to a remote neighbor module (e.g. silo to silo): 1%

Using nine modules and accounting for the frequency of operation, the following vector was obtained, where the values represent the frequency of ignition in the given module (i).

$$P_i = \begin{pmatrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \end{pmatrix} = \begin{pmatrix} 1 \times 10^{-4} \\ 1 \times 10^{-5} \\ 1 \times 10^{-5} \\ 1 \times 10^{-5} \\ 1 \times 10^{-5} \\ 1 \times 10^{-5} \\ 1 \times 10^{-5} \\ 1 \times 10^{-5} \\ 1 \times 10^{-5} \end{pmatrix}$$

Accounting for the frequency of operation of the silos and over-cell gallery as estimated in Section 3.2, the vector is modified as follows:

$$P_i = \begin{pmatrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \end{pmatrix} = \begin{pmatrix} 0.25 \times 1 \times 10^{-4} \\ 0.01 \times 1 \times 10^{-5} \\ 0.01 \times 1 \times 10^{-5} \\ 0.01 \times 1 \times 10^{-5} \\ 0.01 \times 1 \times 10^{-5} \\ 0.01 \times 1 \times 10^{-5} \\ 0.01 \times 1 \times 10^{-5} \\ 0.01 \times 1 \times 10^{-5} \\ 0.01 \times 1 \times 10^{-5} \end{pmatrix} = \begin{pmatrix} 2.5 \times 10^{-5} \\ 1 \times 10^{-7} \\ 1 \times 10^{-7} \\ 1 \times 10^{-7} \\ 1 \times 10^{-7} \\ 1 \times 10^{-7} \\ 1 \times 10^{-7} \\ 1 \times 10^{-7} \\ 1 \times 10^{-7} \end{pmatrix}$$

Given the probabilities of propagation between modules, the following correlation matrix was obtained. Within the matrix, each element represents the potential for propagation between modules. For example, element 1,2 represent the potential for propagation between module i=1 (gallery) and i=2 (silo cell) which is 10% as they are direct neighboring modules.

$$P_{cor,ij} = \begin{pmatrix} 1,1 & 1,2 & 1,3 & 1,4 & 1,5 & 1,6 & 1,7 & 1,8 & 1,9 \\ 2,1 & 2,2 & 2,3 & 2,4 & 2,5 & 2,6 & 2,7 & 2,8 & 2,9 \\ 3,1 & 3,2 & 3,3 & 3,4 & 3,5 & 3,6 & 3,7 & 3,8 & 3,9 \\ 4,1 & 4,2 & 4,3 & 4,4 & 4,5 & 4,6 & 4,7 & 4,8 & 4,9 \\ 5,1 & 5,2 & 5,3 & 5,4 & 5,5 & 5,6 & 5,7 & 5,8 & 5,9 \\ 6,1 & 6,2 & 6,3 & 6,4 & 6,5 & 6,6 & 6,7 & 6,8 & 6,9 \\ 7,1 & 7,2 & 7,3 & 7,4 & 7,5 & 7,6 & 7,7 & 7,8 & 7,9 \\ 8,1 & 8,2 & 8,3 & 8,4 & 8,5 & 8,6 & 8,7 & 8,8 & 8,9 \\ 9,1 & 9,2 & 9,3 & 9,4 & 9,5 & 9,6 & 9,7 & 9,8 & 9,9 \end{pmatrix} = \begin{pmatrix} 0 & 0.1 & 0.1 & 0.1 & 0.1 & 0.1 & 0.1 & 0.1 & 0.1 \\ 0.1 & 0 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 \\ 0.1 & 0.01 & 0 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 \\ 0.1 & 0.01 & 0.01 & 0 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 \\ 0.1 & 0.01 & 0.01 & 0.01 & 0 & 0.01 & 0.01 & 0.01 & 0.01 \\ 0.1 & 0.01 & 0.01 & 0.01 & 0.01 & 0 & 0.01 & 0.01 & 0.01 \\ 0.1 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0 & 0.01 & 0.01 \\ 0.1 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0 & 0.01 \\ 0.1 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0 \end{pmatrix}$$

The frequency of ignition in a module, not followed by propagation to any of the other modules (a mono scenario) was calculated as follows:

$$P_{mono,i} = P_i \prod_j (1 - P_{cor,ij})$$

$$P_{mono,1} = 2.5\,x\,10^{-5} \cdot (1-0) \cdot (1-0.1) \cdot (1-0.1) \cdot (1-0.1) \cdot (1-0.1) \cdot (1-0.1) \cdot (1-0.1) \cdot (1-0.1) \cdot (1-0.1) = 1.1\,x\,10^{-5}$$

$$P_{mono,2} = 1\,x\,10^{-7} \cdot (1-0.1) \cdot (1-0) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) = 8.39\,x\,10^{-8}$$

$$P_{mono,3} = 1\,x\,10^{-7} \cdot (1-0.1) \cdot (1-0.01) \cdot (1-0) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) = 8.39\,x\,10^{-8}$$

$$P_{mono,4} = 1\,x\,10^{-7} \cdot (1-0.1) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) = 8.39\,x\,10^{-8}$$

$$P_{mono,5} = 1\,x\,10^{-7} \cdot (1-0.1) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) = 8.39\,x\,10^{-8}$$

$$P_{mono,6} = 1\,x\,10^{-7} \cdot (1-0.1) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) = 8.39\,x\,10^{-8}$$

$$P_{mono,7} = 1\,x\,10^{-7} \cdot (1-0.1) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0) \cdot (1-0.01) \cdot (1-0.01) = 8.39\,x\,10^{-8}$$

$$P_{mono,8} = 1\,x\,10^{-7} \cdot (1-0.1) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0) \cdot (1-0.01) = 8.39\,x\,10^{-8}$$

$$P_{mono,9} = 1\,x\,10^{-7} \cdot (1-0.1) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0.01) \cdot (1-0) = 8.39\,x\,10^{-8}$$

The summed frequency of all domino scenarios was then calculated as follows:

$$P_{domino,total} = \sum_i (P_i - P_{mono,i})$$

$$P_{Total} = (2.5\,x\,10^{-5} - 1.1\,x\,10^{-5}) + (9) \cdot (1.07\,x\,10^{-7} - 8.39\,x\,10^{-8}) = \mathbf{1.44\,x\,10^{-5}}$$

A.2 ESTIMATED RUPTURE AREA

This section provides sample calculations for the estimated rupture or failure area that would be created in one of the silos in the event of an explosion was estimated by performing deflagration vent size calculations in accordance with NFPA 68 [X]. For the purpose of the sample calculations, the dimensions of the silos in Annexes 1-3 were used as outlined in Table A.1.1.

Table A.1.1: Silo design parameters and material parameters.

Equipment	Volume (m^3)	Inner diameter (m)	Height (m)	P_{max} (bar-g)	K_{st} (bar m/s)
Silos Annex 1-3	672	5.1	33	9.0	170

The maximum flame length along which the flame can travel, *H*, is equal to the height of the silo, 33 m. The effective volume, V_{eff}, is equivalent to the total silo volume, 672 m^3.

The effective area, A_{eff}, was calculated as follows:

$$A_{eff} = \frac{V_{eff}}{H} = \frac{672\ m^3}{33\ m} = 20.4\ m^2$$

The hydraulic diameter, D_{he}, is calculated based on the geometry of the vessel using the following equation. However, given a circular cross-section, D_{he}, is equal to the diameter of the vessel, 5.1 m.

$$D_{he} = \frac{A_{eff}}{H}$$

The *L/D* ratio was calculated using the following equation:

$$L/_{D} = H/_{D_{he}} = \frac{33\ m}{5.1\ m} = 6.45$$

The minimum required vent area was calculated using the following equation. P_{red} is equivalent to the reduced pressure that is developed in a vented deflagration and P_{stat} is the vent release pressure. However, in this case as the silos are not vented, P_{red} and P_{stat} are set equal to the estimated failure or rupture pressure for the silo (0.40 bar-g).

$$A_{v0} = 1 \cdot 10^{-4} \cdot (1 + 1.54 \cdot P_{stat}{}^{4/3}) \cdot K_{St} \cdot V^{3/4} \cdot \sqrt{\frac{P_{max}}{P_{red}} - 1}$$

$$A_{v0} = 1 \cdot 10^{-4} \cdot \left(1 + 1.54 \cdot (0.40)^{4/3}\right) \cdot 170 \cdot (672)^{3/4} \cdot \sqrt{\frac{9.0}{0.40} - 1} = \mathbf{15.1\ m^2}$$

For L/D values greater than 2 and less than or equal to 6 (or 8 for silos), the required vent area, A_{v1}, is calculated as follows, where $P_{initial}$ is the pressure inside the vessel prior to the explosion event.

$$A_{v1} = A_{v0}\left[1 + 0.6 \cdot \left(\frac{L}{D} - 2\right)^{0.75} \cdot exp\left(-0.95 \cdot \left(\frac{P_{red}}{1 + P_{initial}}\right)^{2}\right)\right]$$

$$A_{v1} = 15.1 \cdot \left[1 + 0.6 \cdot (6.45 - 2)^{0.75} \cdot exp\left(-0.95 \cdot \left(\frac{0.40}{1 + 0}\right)^{2}\right)\right] = \mathbf{39\ m^2}$$

When air flow velocities through the equipment (v_{axial} & $v_{tangential}$) exceed 20 m/s, a correction factor is required and A_{v2} is calculated as follows:

$$A_{v2} = \left[1 + \frac{\max(v_{axial}, v_{tang}) - 20}{36} \cdot 0.7\right] \cdot A_{v1}$$

The effects of air velocity do not apply to the silos and as such, A_{v2} is equal to A_{v1}. Where the vent panel mass is greater than 40 kg/m^2, the following equations are used to determine if a correction factor is required:

$$M_T = \left[6.67 \cdot (P_{red}^{0.2}) \cdot (n^{0.3}) * \left(\frac{V}{K_{st}^{0.5}}\right)\right]^{1.67}$$

As the silos are not vented, the effects of vent panel inertia were not considered in the analysis and A_{v3} is equal to A_{v1}. When the volume fill fraction, X_r, can be determined for a worst-case explosion scenario, the minimum required vent area shall be permitted to be calculated from the following equation:

$$A_{v4} = A_{v3} \cdot X_r^{-\frac{1}{3}} * \sqrt{\frac{X_r - \left(\frac{P_{red}}{P_{max}}\right)}{1 - \left(\frac{P_{red}}{P_{max}}\right)}}$$

The effects of partial volume were not considered as it was assumed that the explosion event would occur in the entire volume of the silo. As such, A_{v4} is equal to A_{v1}. The effects of vent ducts are not applicable as the silos are not vented. As such, the required vent area was calculated to be 39 m^2.

A.3 EXTERNAL OVERPRESSURE AND CONSEQUENCE

This section provides sample calculations based on the effects of overpressure as outlined in Section 8.1 of this report. For the purpose of the calculations, the silos in Annexes 1-3 were used.

The external peak overpressure was estimated as follows:

$$P_{max,a} = 0.2 \cdot P_{red} \cdot A_v^{0.1} * V^{0.18}$$

$$P_{max,a} = 0.2 \cdot 0.40\ bar \cdot 39\ m^2 * (672\ m^3)^{0.18} = 0.37 \text{ bar}$$

The horizontal and vertical distances at which the maximum external overpressure will be experienced were calculated as follows where *α* is a constant and L_f is the maximum calculated fireball length.

$$R_{s-vertical} = \alpha \cdot L_f = 0.25 * 23\ m = 5.75\ m$$

$$R_{s-horizontal} = \alpha \cdot L_f = 0.20 * 23\ m = 4.60\ m$$

At further distances, the overpressure was estimated using the following equation, where R_s is the distance where the maximum overpressure was experienced and *r* is the distance from the silo.

$$P_{max,r} = P_{max,a} \cdot \left(\frac{R_s}{r}\right)$$

For example, at a distance of 10 meters from the silo, the overpressure is calculated as follows:

$$P_{max} = 0.37\ bar \cdot \left(\frac{4.60}{10}\right) = 0.17\ bar$$

The following probability of fatality data outlined by the Australian Petroleum Production and Exploration Association Limited was used to determine the consequences associated with overpressure.

- 20% probability of fatality to a person located indoors at an overpressure of 0.210 bar-g.
- 50% probability of fatality to a person located indoors at an overpressure of 0.350 bar-g.
- 100% probability of fatality to a person located indoors at an overpressure of 0.700 bar-g.

Based on these values, the following probit functions were developed through linear interpolation:

$$For\ P \leq 0.35\ bar: \quad Y = 6.727 + 1.645 \cdot \ln(P)$$

$$For\ P > 0.35\ bar: \quad Y = 6.727 + 1.645 \cdot \ln(P)$$

Using these equations the overpressure values obtained at various distances were converted to probability units. A probit transformation table as shown below in Figure A.1.1, was used to convert the probability units to probability of fatality. A summary of the calculation results are shown in Table A.1.2.

Probit Table

Percentage affected - probit transformation (taken from Finney, D.J., 1971. probit analysis, p25).

%	0	1	2	3	4	5	6	7	8	9
0	-	2.67	2.95	3.12	3.25	3.36	3.45	3.52	3.59	3.66
10	3.72	3.77	3.82	3.87	3.92	3.96	4.01	4.05	4.08	4.12
20	4.16	4.19	4.23	4.26	4.29	4.33	4.36	4.39	4.42	4.45
30	4.48	4.50	4.53	4.56	4.59	4.61	4.64	4.67	4.69	4.72
40	4.75	4.77	4.80	4.82	4.85	4.87	4.90	4.92	4.95	4.97
50	5.00	5.03	5.05	5.08	5.10	5.13	5.15	5.18	5.20	5.23
60	5.25	5.28	5.31	5.33	5.36	5.39	5.41	5.44	5.47	5.50
70	5.52	5.55	5.58	5.61	5.64	5.67	5.71	5.74	5.77	5.81
80	5.84	5.88	5.92	5.95	5.99	6.04	6.08	6.13	6.18	6.23
90	6.28	6.34	6.41	6.48	6.55	6.64	6.75	6.88	7.05	7.33
%	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
99	7.33	7.37	7.41	7.46	7.51	7.58	7.65	7.75	7.88	8.09

Figure A.1.1: Probit transformation table.

Table A.1.2: Probit and probability of fatality data related to overpressure for the silos in Annexes 1-3.

Distance from silo (m)	Pressure (bar-g)	Probability unit	Probability of fatality (%)
5	0.34	4.97	49.0
6	0.29	4.67	37.0
7	0.24	4.41	28.0
8	0.21	4.19	21.0
9	0.19	4.00	16.0
10	0.17	3.83	12.0
12	0.14	3.53	7.0
15	0.11	3.16	3.3
20	0.09	2.69	1.0

With respect to the consequences associated with thermal radiation, the same methodology was used to obtain values for probability units and probability of fatality from the thermal dose.

A.4 PROJECTILES

This section provides sample calculations based on the effects of projectiles as outlined in Section 8.4 of this report. For the purpose of the calculations, the silos in Annexes 1-3 were used.

Based on the dimensions of the silos in Annexes 1-3 (height – 33 m & outside diameter =5.51 m) the lateral surface are of the silo was calculated as follows:

$$Lateral\ surface\ area = 2 \cdot \pi \cdot h * d_o = 2 \cdot \pi \cdot 33m \cdot 5.51m = 1138\ m^2$$

It was assumed that only the top 50% of the exterior face of each silo would contribute to wall projectiles. As such the total area of material expected to contribute to projectiles was estimated as follows:

$$Area = 1138\ m^2 \cdot 0.25 = 285\ m^2$$

It was assumed that the wall would break into fragments of equal size and a circular dimension with average diameters of 1 m. As such, it was estimated that each projectile would have a face area of approximately 0.79 m^2. The total number of fragments generated from the silo wall in the event of an explosion was estimated as follows:

$$Number\ of\ fragments\ (N) = \frac{Contributing\ face\ area\ of\ silo\ wall}{Face\ area\ of\ fragments} = \frac{285\ m^2}{0.79\ m^2} = 362$$

Based on the number of fragments (N) the hit probability (Pr[H]) was calculated using the following equation:

$$\Pr[H] = 1 - \exp\left(-\frac{N}{2\pi R_{so}^2}\ S_b\right)$$

Where:
S_b = the surface area presented by the target which in this case is an average sized human (0.58 m^2).
R_{so} = the distance from the source of the projectile

For example, at a distance of 40 meters from the wall of the silo, the hit probability is calculated as follows:

$$\Pr[H] = 1 - \exp\left(-\frac{N}{2\pi R_{so}^2}\ S_b\right) = 1 - \exp\left(-\frac{362}{2 \cdot \pi \cdot (40m)^2} \cdot 0.58\ m^2\right) = 2.1\%$$

Correction factors were applied based on the potential launch angles of the projectiles. With respect to projectiles from the silo walls, it was expected that projectiles could be launched from initial heights ranging from 16.5 m (midpoint of silo) to 33 m (top of silo). Based on an estimated initial velocity of 25 m/s and accounting for launch angles from 0 – 90 degrees, the maximum projectile ranges were calculated using the following equation:

$$Range = V_o * \cos(\alpha) * \frac{\left[V_o * \sin(\alpha) + \sqrt{(V_o * \sin^2(\alpha) + 2 * g * h)}\right]}{g}$$

For example, based on an initial height of 33 meters and a launch angle of 33 degrees, the projectile range was estimated as follows:

$$Range = 25\frac{m}{s} * \cos(33°) * \frac{\left[25\frac{m}{s} * \sin(33°) + \sqrt{\left(25\frac{m}{s} * \sin^2(33°) + 2 * 9.81\frac{m}{s^2} * 33\ m\right)}\right]}{9.81\frac{m}{s^2}} = 91\ m$$

From initial heights of 16.5 m, 24.75 m, and 33 m, the percentages of launch angles that contribute to various launch distances were analyzed as shown in Table A.1.3. To be conservative all launch angles were assumed to result in projectile launch distances of at least 30 meters.

Table A.1.3: Projectile launch angle corrections.

	Percentage of launch angles that exceed the specified distance based on initial height			
Launch distance (m)	33 m	24.75 m	16.5 m	Average
>0	100	100	100	100
>10	100	100	100	100
>20	100	100	100	100
>30	86	86	85	86
>40	82	81	81	81
>50	79	77	72	76
>60	72	68	56	65
>70	62	50	37	50
>80	49	29	0	26

The values outlined in Table A.1.3 were used to apply correction factors to the hit probability. For example, the corrected hit probability at a distance of 40 meters was calculated as follows:

$$\Pr[H] = 2.1\% \cdot 0.81 = 1.7\%$$

The sample methodology was used for projectiles originating from the silo roofs with the following changes:

- The number of projectiles was estimated based on the face areas of the silo roofs. The roof area was multiplied by a factor of 5 to account for additional fragments that could result from the gallery areas.
- It was assumed that projectiles from the roof would be launched at angles greater than 60 degrees.

Appendix B. Summary of DHA evaluations and recommendations

This appendix includes all recommendations related to the process equipment and facility that were identified as part of the DHA conducted by Jensen Hughes. The equipment evaluations are summarized in Table B.1 and the recommendations are summarized in Table B.2. The recommendations are prioritized based on a qualitative assessment of the hazards. The following definitions describe the three-tiered prioritization scheme:

+ **High Priority Recommendations (red):** Recommendations identified as "high priority" are those that address hazards judged to present an immediate threat to life safety and/or have the potential for a severe impact to the building, equipment, or business continuity. These hazards could represent severe consequences or high likelihood, but in either case, realization of the hazard would present a significant impact to Halifax Grain Elevator operations and assets due to exposures to employees and/or damage to equipment and the facility. Accordingly, it is recommended to consider implementing these recommendations as soon as possible to reduce the risks associated with combustible dust hazards throughout the Halifax Grain Elevator facility.
+ **Medium Priority Recommendations (orange):** Recommendations identified as "medium priority" are those that are judged to present a moderate threat to life safety and/or have the potential to impact building, equipment, or business continuity – less so than high priority items but more substantial than low priority items. These hazards could represent moderate consequences or likelihood, but in either case realization of the hazard would present a moderate impact to Halifax Grain Elevator operations and assets due to exposures to employees and/or damage to equipment and the facility. Accordingly, it is recommended to consider implementing these recommendations as part of a short-term strategy for reducing the risks associated with combustible dust hazards throughout the Halifax Grain Elevator facility.
+ **Low Priority Recommendations (green):** Recommendations identified as "low priority" are those that are judged to present a relatively low threat to life safety and/or building, equipment, or business continuity. These hazards could present an impact to Halifax Grain Elevator operations and assets but are not perceived to be significant due to a relatively low possibility of exposures to employees and/or damage to equipment and the facility. Although these recommendations are not perceived to present an immediate threat to life safety and property protection, they should be implemented to reduce the overall hazard levels within the facility. Accordingly, it is recommended to consider implementing these recommendations as part of a long-term strategy for reducing the risks associated with combustible dust hazards throughout the Halifax Grain Elevator facility.

Detailed evaluations that were used to identify the recommendations can be found in the DHA (Report No. 4H2102690.000 – HGE DHA – FINAL – R0).

Table B.1: Summary of equipment hazard evaluations conducted as part of the DHA.

Equipment type	Equipment name	Explosible dust	Dispersion	Concentration	Confinement	Credible ignition sources	Explosion hazard	Fire hazard
Bucket Elevators	S1, S2, R1, R2, S7, S8	Yes	Yes	Possible	Yes	Possible	Yes	Yes
	Marine leg	Yes	Yes	Possible	Yes	Possible	Yes	Yes
	Fines collection	Yes	Yes	Possible	Yes	Possible	Yes	Yes
Upper garners,	S1, S2, R1, R2, S7, S8	Yes	Yes	Unlikely	Yes	Possible	Unlikely	Yes
Weigh hoppers	S1, S2, R1, R2, S7, S8	Yes	Yes	Unlikely	Yes	Possible	Unlikely	Yes
Shipping garners	S5, S7, S8	Yes	Yes	Unlikely	Yes	Possible	Unlikely	Yes
Conveyors	Bin level and basement belts	Yes	Possible	Unlikely	No	Possible	No	Yes
	Shipping gallery belts	Yes	Possible	Unlikely	No	Possible	No	Yes
	Receiving gallery belts and tunnel belts	Yes	Unlikely	Unlikely	No	Possible	No	Yes
	Drag chain conveyors (fines)	Yes	Unlikely	Possible	Yes	Possible	Unlikely	Yes
Silos & intermediate bins	Silos & intermediate bins (Annexes 1–4)	Yes	Yes	Unlikely	Yes	Possible	Unlikely	Yes
Dust tanks	Main & auxiliary dust tanks	Yes	Yes	Yes	Yes	Possible	Yes	Yes
Dust collection systems	Baghouse #1	Yes	Yes	Yes	Yes	Possible	Yes	Yes
	Baghouses #2 – #14	Yes	Yes	Yes	Yes	Possible	Yes	Yes
	Baghouses #15 – #18	Yes	Yes	Yes	Yes	Possible	Yes	Yes
	Marine leg baghouse	Yes	Yes	Yes	Yes	Possible	Yes	Yes
	Beehives (cyclones)	Yes	Yes	Unlikely	Yes	Possible	Unlikely	Yes
Receiving/loading hoppers	Receiving hoppers (100 ton/50 ton)	Yes	Yes	Unlikely	Yes	Possible	Unlikely	Yes
	Truck/railcar loading scales/hoppers	Yes	Yes	Unlikely	Yes	Possible	Unlikely	Yes
	Ship unloading hopper	Yes	Yes	Unlikely	No	Possible	Unlikely	Yes

Table B.2: Summary of recommendations identified as part of the DHA.

Recommendation Type	Rec No.	Recommendation	Comments	Priority
Process equipment	A.1.1	The marine leg bucket elevator should be equipped with adequate deflagration isolation located upstream and downstream to prevent propagation to connected equipment in the event of an explosion.	It should be noted that the potential for explosion propagation to connected equipment is considered low based on the presence of explosion protection, the equipment configuration, operating conditions, and frequency of use. However, the potential for propagation to connected equipment cannot be discounted based on the limited information available. If an evaluation is conducted that demonstrates that explosion propagation will not occur, the need for deflagration isolation can be eliminated. Given the infrequent use of this bucket elevator and the presence of explosion protection, this is considered a medium priority recommendation.	Medium
	A.1.2	The fines collection bucket elevator should be provided with explosion protection designed and installed in accordance with NFPA 68 or NFPA 69.	Prior to the 2013 edition of NFPA 61, bucket elevators that operated at speeds of less than 500 ft/s (2.5 m/s) were exempt from requiring explosion protection. The National Fire Code of Canada (NFC 2015) recommends that bucket elevators are provided with explosion protection and references the 2017 Edition of NFPA 61 which no longer includes the exemption. As the fines bucket elevator is considered to present a credible explosion hazard, adequate explosion protection is required in accordance with NFPA 68 or NFPA 69.	High
	A.1.3	The fines collection bucket elevator should be equipped with adequate deflagration isolation in accordance with NFPA 69 to prevent explosion propagation to connected equipment.	In the event of an explosion in the bucket elevator, flame and overpressure could propagate upstream to the drag conveyor or downstream to the dust tanks. As the bucket elevator and drag conveyor are located outdoors, the consequence of an explosion is expected to be limited to equipment damage and potential business interruption. However, the potential for propagation upstream cannot be discounted based on the limited information available. The dust tanks located downstream are expected to contain a large amount of fine dust particulate. As such, if an explosion were to propagate from the bucket elevator to the dust tanks, it could result in a significant explosion event. Priority should be given to providing explosion isolation between the bucket elevator and dust tanks. As the bucket elevator is located outdoors and is not directly connected to any equipment located inside the facility, this is considered a medium priority recommendation.	Medium
	A.1.4	Provide belt alignment and bearing temperature monitoring for the fines collection bucket elevator.	Prior to the 2013 Edition of NFPA 61, there was an exemption from monitoring for bucket elevators that operate at speeds below 500 ft/s (2.5 m/s). However, this exemption has been removed from the newer editions of NFPA 61. Based on the limited information and documentation for the system, frictional heating resulting from belt or bearing failure is considered a credible ignition source.	Low
	A.1.5	A formalized inspection, testing, and maintenance is required for the bucket elevator explosion suppression systems to ensure they are properly maintained. Regular inspection, testing, and maintenance is required to be performed in accordance with Chapter 15 of NFPA 69. Explosion protection systems are required to be inspected at a minimum frequency of 3-month intervals and maintenance records must be retained.	Documentation provided for the explosion suppression systems was limited to an equipment proposal from 2007. HGEL does not have any formal documentation related to the equipment design or records of maintenance and testing. Proper maintenance, inspection, and testing is critical to ensure the reliability of the system in the event of an explosion. Without testing and maintenance records, it is unknown if the systems will operate properly to mitigate the effects of an explosion. Inspections should be periodically performed by personnel trained by the system manufacturer and maintenance records should be retained. All inspection and maintenance procedures should be conducted in accordance with the manufacturer's instructions and any changes to the system or operating conditions should be discussed with the manufacturer. Disarming and lockout/tagout procedures should be followed during maintenance and inspection procedures. The inspection and maintenance of the explosion suppression systems should be included in the formalized ITM program described in Recommendation Gen-14. Quarterly inspection forms can be found in Appendix A of NFPA 69.	Low

Recommendation Type	Rec No.	Recommendation	Comments	Priority
			Based on information provided by HGEL, the suppression systems are inspected by trained personnel. A formalized program for ITM and record retention is required but is considered low priority.	
	A.1.6	Vent size calculations should be conducted in accordance with NFPA 68 to determine if the deflagration venting is sufficient to provide explosion protection for the marine leg bucket elevator. Refer to Recommendation Gen-4.	Vent size calculations were not provided for the bucket elevator. Given the age of the equipment, it is unknown if the provided vent area is sufficient to provide explosion protection.	Low
	A.2.1	Evaluate the need for deflagration isolation between the upper garners and weigh scales.	The S1, S2, R1, and R2 upper garners receive material from the bucket elevators. The upper garners and weigh scales are separated by iris valves and there is a small window of time when the upper garner is empty during material transfer. The upper garners are not considered to present credible explosion hazards under normal operation. However, due to the close coupling of the bucket elevators and upper garners, there is the potential that an explosion could propagate into the upper garner and to connected equipment (weigh scales). The bucket elevators are provided with explosion protection and isolation (chemical suppression) and the upper garners are provided with explosion vents. However, vent size calculations were not provided for the upper garners and the effectiveness of the venting is unknown. It is unknown if HGEL had an evaluation performed to determine if a deflagration could propagate from the upper garners to the weigh scales as no formal documentation was provided. Propagation to the weigh scales could result in secondary explosions under certain conditions.	Medium
	A.2.2	Deflagration vent size calculations should be provided for the S1, S2, R1, and R2 upper garners. Refer to Recommendation Gen-4.	Vent size calculations were not provided for the upper garners and it is unknown if the provided vent area is sufficient to provide explosion protection in the event of propagation from the bucket elevators.	Low
	A.3.1	Given the level of dust accumulation observed in the shipping gallery, the need for an effective ignition source control program and inspection, testing, and maintenance is considered high.	The shipping gallery conveyors are provided with anti-friction bearings and under speed monitoring devices. To further mitigate potential fire hazards in the shipping gallery, ITM and ignition source control programs should be implemented as outlined in Recommendation Gen-14 and Gen-15. Priority should be given to this area based on the level of dust accumulation. The capture velocity provided by the dust collection systems should be evaluated to determine if it is sufficient to remove suspended dust and prevent accumulation of fine dust particulate in the shipping gallery.	Medium
	A.4.1	Formalized procedures should be implemented to ensure that oxygen is prevented from entering the silos during normal operation to prevent the potential for fires. Consideration should be given to providing devices to monitor the oxygen level within the silos.	HGEL has indicated that the silos present an oxygen limiting environment. However, it should be noted that oxygen monitoring is not provided and a formal evaluation of the oxygen concentration within the silos and bins was not conducted. When the chutes above the silos are not covered, it is expected that there would be sufficient oxygen to support combustion in the headspace above the grain bed.	Low
	A.4.2	Heat detectors (thermocouples) should be installed in all silos and storage bins used for long term storage of grains and wood pellets. The heat detectors should be monitored from the control room.	Thermocouples are installed in the Annex 3 silos and are monitored from the control room. However, the silos in Annexes 1, 2, and 4 do not have thermocouples. The need for thermocouples should be prioritized for silos that are used for wood pellet storage as there has been issues with the wood pellets heating in the past. FM Data Sheet 7-75 outlines that heat detectors should be installed in silos and bins to monitor the temperature of the grain bed for early detection of conditions that could lead to a fire. Temperature monitoring devices should be designed for use with combustible dust (Class II, Division 1).	Low

Recommendation Type	Rec No.	Recommendation	Comments	Priority
	A.4.3	A fire response plan should be developed for the silos in the event that a fire was to occur. Refer to Section 7 of this report and Recommendation Gen-11 for additional information on emergency response.	As the bins are not provided with automatic fire protection, a fire response plan should be developed to isolate and extinguish any fires. The hazards associated with extinguishing fires in oxygen limiting silos should be addressed.	Low
	A.5.1	The baghouse filter cages should be bonded and grounded with a resistance to ground of less than 10 Ω.	Baghouse filter cages should be engineered so that a positive ground connection is always maintained. Continuity and resistance should be regularly checked as part of maintenance activities as outlined in Recommendation Gen-2. It is important to note that pulse-jet filter cleaning operations and maintenance activities can result in loss of filter cage grounding.	Medium
	A.5.2	Explosion isolation should be provided on the inlet ducts to Baghouse #1, the Marine Leg Baghouse, and Baghouses #15 – #18, to prevent deflagration propagation to indoor building areas and process equipment located upstream. This could be achieved using a passive flap valve or another isolation device designed and installed in accordance with NFPA 69.	The ductwork upstream of Baghouses Nos. 2–14 is equipped with deflagration vent panels designed to release at an overpressure of 0.5 – 1 psi. Explosion propagation to equipment located upstream of the No. 2–14 baghouse units is considered unlikely based on the following: • The dust collectors are provided with explosion protection and the ductwork has vent panels. • The length of duct between the baghouses and upstream equipment is relatively long. • The direction of airflow in the system.	High
	A.5.3	The baghouse rotary valves should be replaced with rotary valves designed in accordance with NFPA 69 for use as deflagration isolation devices. Their design should comply with the requirements included in Section 12.2.4 of NFPA 69 for explosion isolation. NFPA 69 details requirements for vane clearance, number of vanes, position of vanes, metal construction etc.	In the event of an explosions in the baghouses, the explosion could propagate through the rotary valve to connected equipment or building areas. It should be noted that all of the baghouses are provided with deflagration venting that will reduce the overpressure experienced in the event of an explosion. As such, the potential for explosion breakthrough is considered relatively low but cannot be discounted. With respect to Baghouses Nos. 2–14 and the marine leg baghouse, propagation through the rotary valves would result in transfer of flames and overpressure to the drag chain conveyor and could result in equipment damage or propagation to downstream equipment. The rotary valves on Baghouse #1 and Baghouses #15 – #18 are located indoors and as such, an explosion could propagate to surrounding building areas or connected process equipment. The risk associated with propagation through these rotary valves is higher and as such, priority should be given to replacing these rotary valves.	High
	A.5.4	A management strategy should be implemented to manage potential hazards associated with one of the marine leg baghouse vent panels facing the interior of the Marine Tower. Proper signage should be provided to warn facility personnel of the potential hazards associated with vent discharge.	Fireball calculations were not performed for the baghouse. In the event of a deflagration, a considerable fireball, projectiles, and burning debris would be anticipated. Based on the orientation of the vent, vent discharge would likely impinge on the interior of the Marine Tower and the adjacent staircase and could potentially result in building damage or injury to facility personnel. As reconfiguring the deflagration venting may be impractical, a management strategy should be implemented to manage potential hazards resulting from a vented deflagration.	Low
	A.5.5	Vent size calculations should be conducted in accordance with NFPA 68 to determine if the deflagration venting is sufficient to provide explosion protection for the baghouses. Refer to Recommendation Gen-4.	Vent size calculations were not provided for the baghouse systems. Given the age of the equipment, it is unknown if the provided vent area is sufficient to provide explosion protection.	Low

Recommendation Type	Rec No.	Recommendation	Comments	Priority
	A.5.6	An evaluation should be conducted to determine the air transport velocities in the baghouse ductwork systems. The air transport velocities should be measured by HGEL or by an external consultant.	As outlined in NFPA 61, an air transport velocity of 4000 ft/min is recommended for ductwork systems that handle combustible dusts. It should be noted that the air transport velocities in the existing ductwork systems are unknown. HGEL has indicated that the pickup points are inspected every 50-hours for dust accumulation. The air transport velocity should be measured to determine if there is the potential for material accumulation in the ductwork and to ensure that the pickup points have an appropriate capture velocity to remove suspended dust particulate. Maintaining adequate capture velocities will help to minimize fugitive dust accumulation. Inadequate air transport velocities can result in material accumulation within the ductwork that can lead to fire and deflagration hazards within the ducts. Adequate air transport velocities will assist with prevention of fugitive dust accumulation throughout the facility. Personnel from HGEL have indicated that the air transport velocity in the shipping gallery dust collection systems may be inadequate. As such, this recommendation is considered high priority.	High
	A.6.1	The dust tanks should be provided with adequate explosion protection in accordance with NFPA 68 or NFPA 69.	The most effective way to provide explosion protection for the dust tanks would be through the use of deflagration venting in accordance with NFPA 68.	High
	A.6.2	Deflagration isolation should be provided at the inlet and outlet of the dust tanks.	Given the limited information available for the operations, the potential for deflagration propagation cannot be discounted. As the dust tanks are located on the exterior of the facility, the recommendation is considered medium priority.	Medium
	A.6.3	The tank trucks that receive the material from the dust tanks should be bonded to the fill system and all bonding and grounding should be in place prior to starting filling operations.	Bonding and grounding of tank trucks should be conducted in accordance with NFPA 77.	Low
	A.7.1	Ensure that the process equipment and chutes are not equipped with combustible linings as outlined in Recommendation Gen-3.	If insulative linings/coatings are used, it should be verified that the breakdown voltage across the linings/coatings does not exceed 4 kV as outlined in Section 9.4.7.1.2 (4) of NFPA 652.	Low
General	Gen-1	Perform explosion severity testing for representative samples of wood and grain dusts to obtain the material specific explosibility parameters. It is recommended to perform testing for representative samples of wheat and wood dust as these material as expected to be the most hazardous based on the reference data.	Explosibility testing was not performed for material samples from the Grain Elevator. It is important to note that the design of explosion protection systems (deflagration venting, explosion suppression, etc.) is based on the explosion severity parameters (P_{max} and K_{St}). Explosibility parameters are not intrinsic properties and are dependent upon particle size, moisture content, and chemical composition. Testing should be performed to ensure that the reference explosibility parameters are representative of the material handled at the facility.	Low
	Gen-2	A formalized program is required to ensure that bonding and grounding continuity is maintained for all conductive process equipment. Loss of bonding and grounding can result in electrostatic charge accumulation that could ignite a combustible dust cloud. The resistance to ground for all conductive process equipment handling combustible dusts should be less than 1.0 x 10^6 ohms.	Bonding and grounding were observed at the Grain Elevator during the site visit. However, bonding and grounding continuity and resistance to ground were not tested by Jensen Hughes. HGEL does not have any formal documentation related to the provision of bonding and grounding or records of regular checks for bonding and grounding continuity. It should be noted that loss of bonding and grounding can result from equipment vibration or movement, corrosion, and maintenance activities. As such, it is critical to regularly test for bonding and grounding to prevent electrostatic charge accumulation in conductive equipment. Continuity and resistance of bonding and grounding systems throughout the facility should be checked at regular intervals as part of maintenance activities and should be documented. These checks should be conducted immediately after installation, repair, or modification of equipment and at a minimum of annually thereafter. Self-testing bonding clamps and systems can be used to continuously monitor the resistance to ground and verify acceptable levels. The	Medium

Recommendation Type	Rec No.	Recommendation	Comments	Priority
			resistance to ground can also be measured using an ohmmeter. Detailed information related to bonding and grounding is outlined in NFPA 70 and NFPA 77. Bonding and grounding were observed during the site visit. However, as loss of bonding and grounding can result in the presence of potential ignition sources, this recommendation is considered medium priority.	
	Gen-3	UHMW plastic (insulative) linings in chutes and other equipment are required to be replaced with linings that are static dissipative or conductive. The breakdown voltage of linings/coatings must be less than 4 kV as outlined in Section 9.4.7.1.2 (4) of NFPA 652.	HGEL has indicated that UHMW linings are used in select areas of the facility. The use of these linings could result in the generation of propagating brush discharges that could ignite a suspended dust cloud. These linings need to be replaced to prevent electrostatic charge accumulation during bulk material flow.	Low
	Gen-4	Deflagration vent size calculations are required for the baghouse systems, marine tower bucket elevator, and the upper garners to determine if the deflagration venting is appropriate to provide explosion protection.	Documentation related to the design of the deflagration venting systems has not been provided by HGEL. It is unknown if the vent areas are properly sized based on the equipment geometry, enclosure strength, vent panel characteristics, and material handled. As such, the effectiveness of the deflagration vents as explosion protection devices is unknown. If the vents are not properly sized, it could result in destruction of the equipment or propagation to connected equipment and building areas.	Low
	Gen-5	A formalized housekeeping program should be maintained throughout the facility to maintain fugitive dust accumulations below hazardous levels. The housekeeping program should include, at a minimum, the information outlined in Section 5.4.1 of this report. Housekeeping procedures should strive to manage to a quantifiable dust layer thickness or total dust volume based on the threshold layer thickness outlined in NFPA 654 as presented in Section 5.1 of this report. Two thresholds should be defined: “acceptable” which indicates that normal housekeeping procedures can continue to be followed and “excessive” which triggers the need for near-term, increased housekeeping frequency. Procedures should also be put in place to immediate cleaning of dust accumulations experienced during upset conditions. Standardized housekeeping SOPs should be developed for each area. The procedures should identify targeted (problem areas) to clean, the cleaning method(s) that should be used, and hazards associated with the task. The program should be optimized to target areas with heavy dust build-up, areas where dust build-up may present an ignition source (e.g., on / around bearings, hot surfaces, and electrical equipment), and easily-accessible spaces, such as floors, which are easy to access and can substantially reduce the total volume of fugitive dust in a space. Dust accumulations should be removed following the good cleaning practices outlined in Section 8.3 of NFPA 654. Additional information related to housekeeping is outlined in Section 8.4 of NFPA 652 and in Section 1910.272(j) of the OSHA Grain Handling Standard.	A cleaning schedule was provided by HGEL that outlines the housekeeping schedule for the grain elevator. It should be noted that the existing cleaning schedule outlines the areas of the facility that are to be cleaned on a given day of the week and does not outline cleaning practices. The plan should be reviewed to ensure that the cleaning frequency is sufficient to maintain dust accumulation below hazardous levels (~1/6 inches) in all areas of the facility. Fugitive dust accumulation has the potential to present secondary explosion hazards. The primary explosion will shake or suspend other dust that has accumulated. When this dust becomes airborne, it also ignites. This secondary dust explosion is often more destructive than the primary one. Due to the hazards associated with secondary dust explosions, the need for adequate housekeeping is considered a high priority recommendation.	High
	Gen-6	Given the level of dust accumulation observed in the shipping gallery, the conveying and loading systems should be evaluated to determine the cause of the material accumulation. The chute blocks and loading spouts should be redesigned or reconfigured to minimize material accumulation in this area. An evaluation should be performed to ensure that the capture velocity at the collection points is sufficient to remove suspended dust particulate. It should be ensured that potential ignition sources in this area are adequately controlled through the implementation of an ignition source control program and proper maintenance. Dust accumulations should be removed as quickly as possible following completion of the vessel loading operations.	The level of dust accumulation in this area presents credible fire and deflagration hazards. The material accumulation could result in a secondary explosion occurring in the shipping gallery area under certain conditions.	Medium
	Gen-7	Personnel working in the shipping gallery area should be provided with flame resistant garments. Given the significant amount of dust accumulation in the shipping gallery, personnel working in this area should be provided with proper PPE including flame resistant garments as outlined in NFPA 2112 [27] and NFPA 2113 [28].	It is unknown if personnel working in this area are provided with flame resistant garments. Given the level of dust accumulation observed in this area, this recommendation is considered medium priority.	Medium

Recommendation Type	Rec No.	Recommendation	Comments	Priority
	Gen-8	When using compressed air for housekeeping purposes, the compressed air pressure should be below 30 psi as outlined in Section 8.3 of NFPA 654. When cleaning with compressed air, all electrical components in the area not rated for use in combustible dust atmosphere should be powered down.	HGEL has indicated that compressed air pressurized to 100 psi is currently used for housekeeping activities.	Low
	Gen-9	All Class II areas throughout the facility should be identified and documented. It should be confirmed that the electrical components in these areas are designed to be dust ignition proof or are provided with dust tight enclosures as specified in NFPA 70. Priority should be given to the shipping gallery as this area was observed to contain the highest level of fugitive dust accumulation. All electrical components in this area should be designed for use in combustible dust atmospheres or equipped with dust tight enclosures.	During the site visit, classified electrical components were observed throughout most areas of the facility. However, documentation outlining the locations of classified electrical components was not provided.	Low
	Gen-10	All electrical components located inside process equipment (silos, dust collectors, ductwork, etc.), should be designed for use in Class II, Division 1 locations.	During the site visit, select electrical components located inside equipment containment were observed and were found to be classified for use in combustible dust atmospheres. However, all electrical components located inside of process equipment were not observed by Jensen Hughes during the site visit. All electrical components being replaced or installed in the future within process equipment should be properly rated for use with combustible dusts.	Low
	Gen-11	An emergency response plan should be developed for the facility to account for potential fire or explosion scenarios that could occur during operation. The emergency response plan should be readily available in written or electronic format and should include, at a minimum, the following: • A means of notification for occupants in the event of a fire or explosion • A preplanned evacuation assembly area • A person(s) designated to notify emergency responders, including the fire department • A facility layout drawing(s) showing egress routes, hazardous chemical locations, and fire protection equipment. • Location of safety data sheets for hazardous chemicals • An emergency telephone number(s) • Emergency response duties for occupants • A person(s) designated to meet the offsite emergency responder(s) to coordinate the incident The emergency response plan should be reviewed at least annually. As part of the review, training should be provided for employees. The emergency response plan should be developed in accordance with Section 8.10 of NFPA 61. Additional information related to emergency response is outlined in NFPA 1600, "Standard on Continuity, Emergency, and Crisis Management." The emergency response plan should also comply with the National Fire Code of Canada (NFC) and the Canada Occupational Health and Safety Regulations. The Canada OHS Regulations outline Emergency Procedures in Section 17. The OSHA Grain Handling Standard outlines that emergency response plans should meet the requirements outlined in *OSHA 1910.38 Emergency action plans.*	A fire safety plan was provided by HGEL. The response plan includes required information such as contact information, response procedures, etc. This response plan should be reviewed and updated to be compliant with the requirements of the NFC, Canada OHS Regulations, NFPA 61 and NFPA 1600. The existing fire safety plan is included in Appendix F of the DHA report.	Medium
	Gen-12	A program should be implemented to manage the retention of documentation in accordance with Section 8.13 of NFPA 652. This should include, but not be limited to, the following: • Training records • Equipment inspection, testing, and maintenance records • Incident investigation reports • Dust hazard analyses • Process and technology information	A policy for documenting and maintaining the design basis for the process and facility is an important aspect of a broader Process Safety Management program. Up-to-date documentation is required to assess hazards and manage change to ensure that changes to the process or facility do not introduce hazards that are not being managed. The intent of this recommendation is to ensure that the design of new systems or modifications to existing systems are thoroughly documented and maintained on site for the life of the facility / process. Special care should be taken to ensure this policy applies to the design of fire and explosion protection systems for dust-handling equipment. Where designs are prepared by outside contractors,	Low

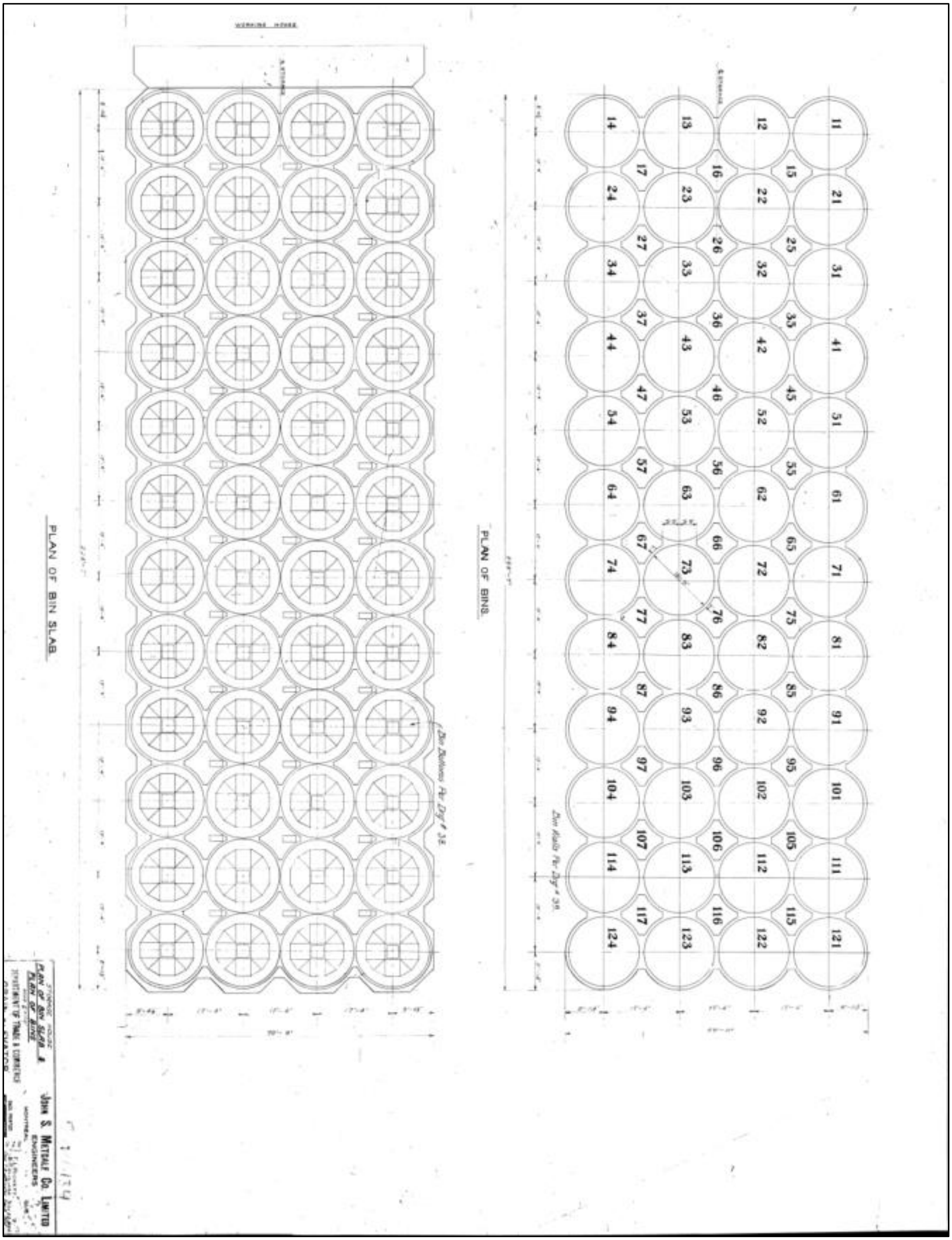
Recommendation Type	Rec No.	Recommendation	Comments	Priority
		• Management of change documents • Emergency response plan documents • Contractor records	consideration should be given to establishing policies that require appropriate design documentation to be prepared and submitted to HGEL. Additional information is outlined in Appendix C.1.3 of the DHA report.	
	Gen-13	Implement a facility-wide program to develop safe work practices for tasks associated with maintenance and servicing operations pertaining to combustible dust handling equipment. The procedures should be standardized with oversight from designated management personnel knowledgeable in combustible dust hazards and plant maintenance and servicing practices. Factors for consideration are as follows: • Safe work procedures should be developed for maintenance and servicing (including cleaning/housekeeping) of systems that handle combustible dusts. • Work tasks should be evaluated with respect to the five conditions required for a combustible dust outlined in this report to determine if a credible hazard exists. The DHA sheets provided in Appendix A of the DHA report should be consulted for input. Special attention should be paid to tasks which involve the entry / opening or cleaning of vessels or other elevated surfaces with fugitive dust accumulations that could be readily dispersed via gravity. • Where conditions which could lead to a fire, deflagration or explosion are identified, safe work practices or eliminating the condition should be developed. The selection of appropriate PPE should be considered as part of this assessment. • To the extent practicable, safe work practices should be tied to work orders such that the appropriate safe work practices are generated with an accompanying work order.	Safe work practices include, but are not limited to, hot work, confined space entry, lockout/tagout, and the use of personal protective equipment (PPE). Entry to silos and bins should be conducted based on the safe practices outlined in NFPA 350, "*Guide for Safe Confined Space Entry and Work,*" and Section 1910.272(g) of the OSHA Grain Handling Standard. Safe work practices including hot work, confined space entry, and equipment isolation should also comply with the Canada Occupational Health and Safety Regulations. Information related to confined spaces and hot work is outlined in Part XI of the Canada OHS Regulations.	Low
	Gen-14	An inspection, testing, and maintenance (ITM) program should be established for the facility in accordance with Section 8.7 of NFPA 652. The ITM program should include the following: • Fire and explosion protection and prevention equipment in accordance with the applicable NFPA standards • Dust control equipment • Housekeeping • Potential ignition sources • Electrical, process, and mechanical equipment, including process interlocks • Process changes • Lubrication of bearings The ITM program should establish procedures and schedules for maintaining safe operating conditions for the facility and equipment. Formal operating and maintenance plans should be documented and retained (including preventive maintenance of dust collection fans, tools which could serve as ignition sources, and other equipment pertinent to the avoidance of combustible dust fire / deflagration / explosion hazards as noted in this report). See Appendix C.1.4.3 of the DHA report for additional discussion on inspection, testing, and maintenance requirements. Additional information related to preventative maintenance is outlined in Section 1910.272(m) of the OSHA Grain Handling Standard. The inspection, testing and maintenance of fire safety equipment should comply with the National Fire Code of Canada. Information related to ITM of fire protection equipment is outlined in Section 6 of the NFC.	If process equipment is not adequately inspected, tested, and maintained, it can result in the presence of ignition sources that could ignite combustible dust within the facility. Inspection and maintenance tasks are carried out within the facility. However, it is unknown if the ITM program is compliant with the applicable codes and standards. As such, this is considered medium priority.	Medium

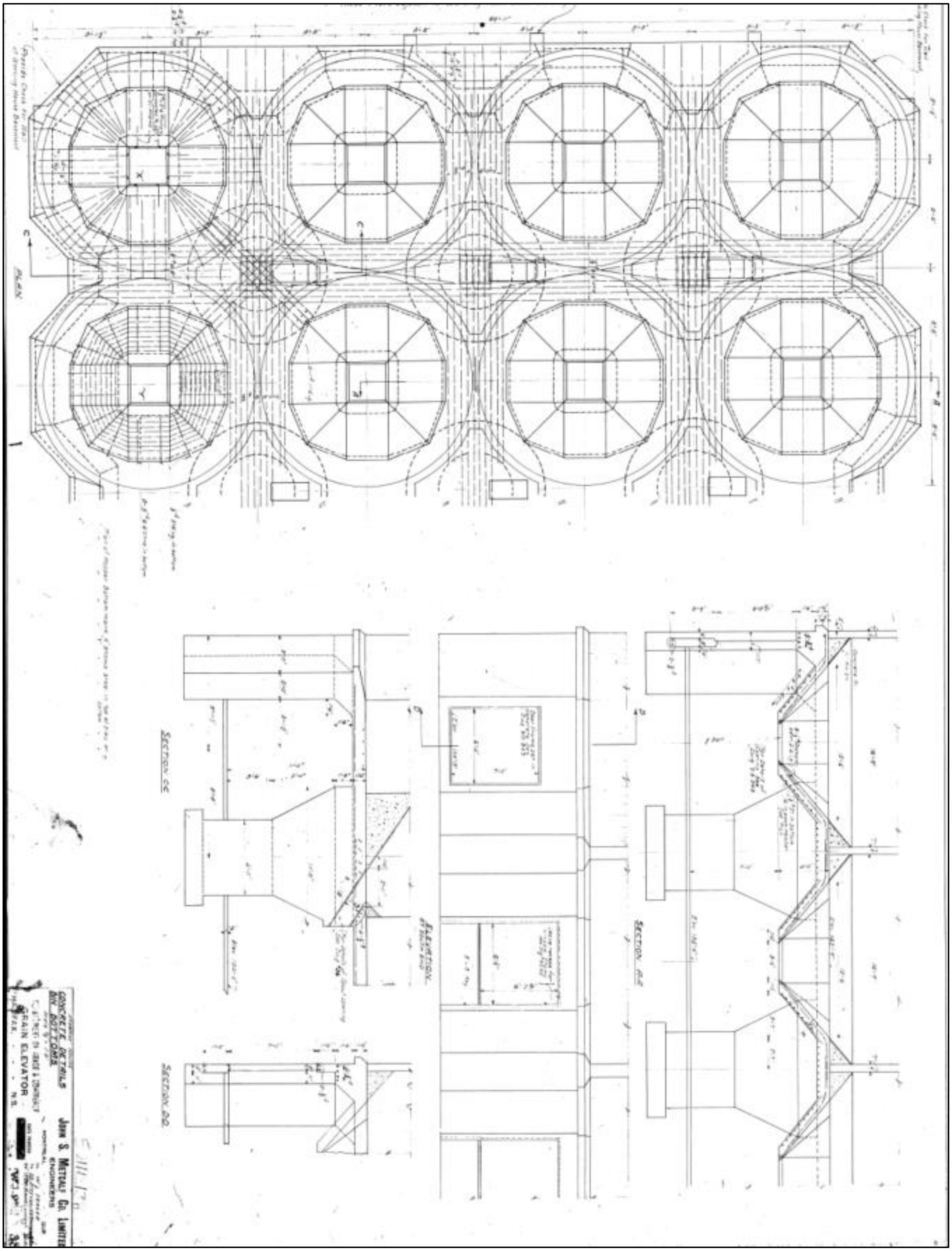
Recommendation Type	Rec No.	Recommendation	Comments	Priority
	Gen-15	An ignition source control program should be established for the facility in accordance with Section 9.4 of NFPA 61 and NFPA 652. The program should be implemented to eliminate potential ignition sources that could ignite combustible dust particulate. The program should include provisions for hot work (open flames, cutting, welding, etc.), smoking, and electrostatic hazards. The ignition source control program should comply with the following: • NFPA 51B, Standard for Fire Prevention During Welding, Cutting, and Other Hot Work. • NFPA 70, National Electrical Code. • NFPA 77, Recommended Practice on Static Electricity. The OSHA Grain Handling Standard provides information related to hot work in Section 1910.272(f). Hot work procedures should also comply with the National Fire Code of Canada and the Canada OHS Regulations.	HGEL has provided documentation related to hot work control. This document should be reviewed and updated to be compliant with the requirements of NFPA 51B. As a lack of proper ignition source control can result in a dust fire or explosion hazard, this recommendation is considered high priority.	High
	Gen-16	Combustible dust awareness training should be provided for all facility personnel in accordance with Section 8.8 of NFPA 652. The training should be customized based on the Grain Elevator facility. With this approach, hazards pertinent to the facility can be highlighted and personalized to employees. It is important to note that there is not a NFPA or OSHA requirement to develop plant-specific training material; however, our experience has shown that this approach is an effective step towards building a culture of combustible dust awareness at plants. The training should ensure that employees are knowledgeable of the following: • Hazards of their workplace • General orientation, including plant safety rules • Process description • Equipment operation, safe startup and shutdown, and response to upset conditions • Fire and explosion protection systems • Equipment maintenance requirements • Housekeeping requirements • Emergency response plans	As part of the training, contractors working on or near processes handling combustible dust should be made aware of the potential hazards from and exposures to fires and explosions in accordance with NFPA 652 9.6.3.3. Contractors should also be trained to comply with the facility's safe work practices. Additional information is provided in Appendix C.1.4.4 of the DHA report. Additional information related to training is outlined in Section 1910.272(e) of the OSHA Grain Handling Standard.	Low
	Gen-17	A MOC structure should be established for the facility in accordance with Section 8.12 of NFPA 652. The program should include specific fields pertaining to combustible dust and should include written procedures to manage proposed changes to process materials, job tasks, technology, equipment, and the facility. Individuals responsible for approving changes should be pre-selected and possess the necessary knowledge to review changes pertaining to dust-handling processes and equipment. The MOC program should address the following: • The technical basis for the change • Safety implications • Whether the change is permanent or temporary • Modifications to operating and maintenance procedures • Employee training requirements • Authorization requirements • Hazard assessment, if conducted	All dust handling equipment that is required to be covered by MOC should be identified. corresponding policy should be developed and training should be administered to ensure the appropriate facility personnel are familiar with the policy. Key items include: • Changes to dust collection systems (including removal of filters or additional inlets to dust collectors) • Changes to housekeeping procedures. • Changes to electrical equipment. Changes to the types of materials handled at the facility.	Low

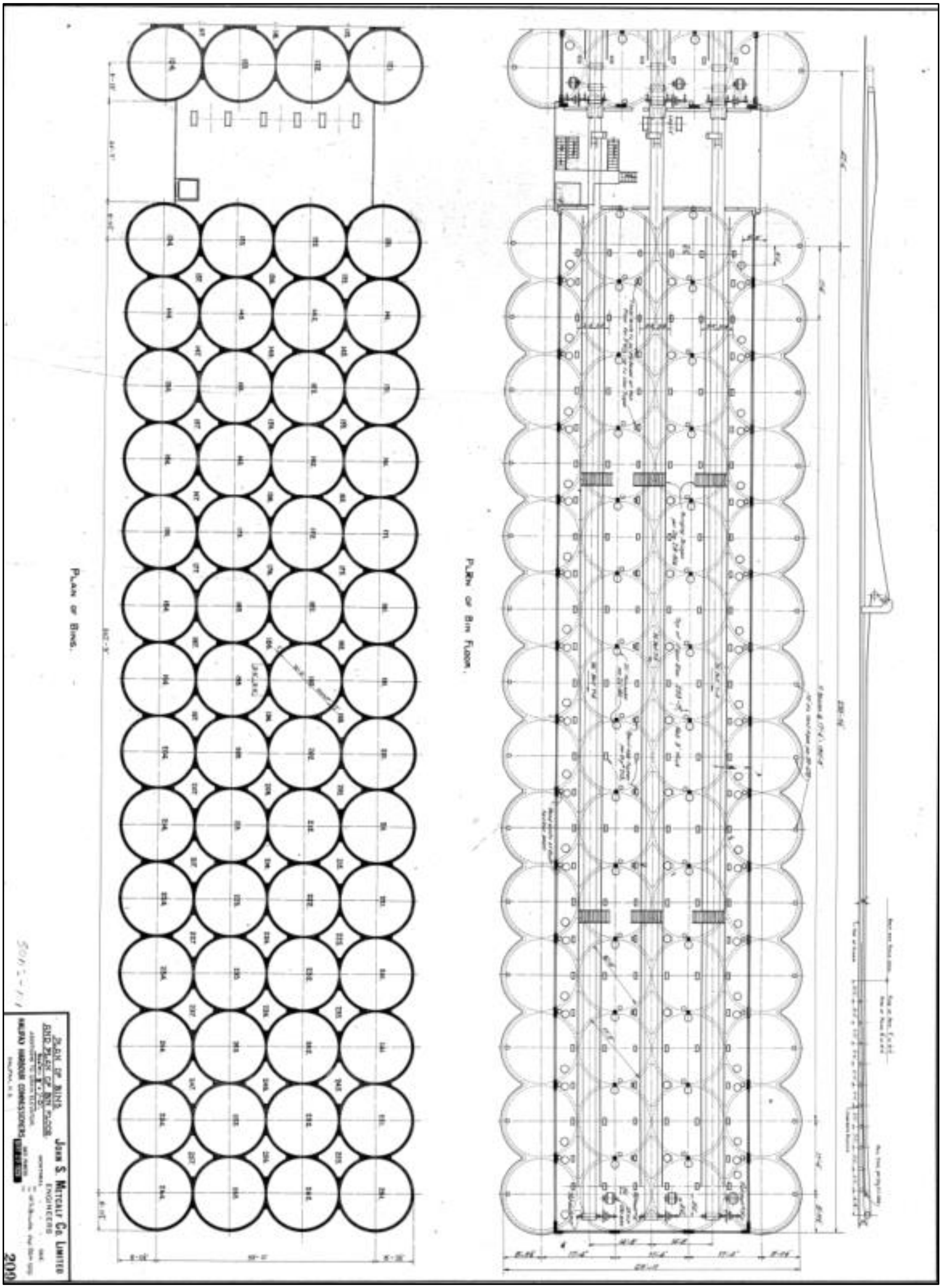
Recommendation Type	Rec No.	Recommendation	Comments	Priority
	Gen-18	Conduct a workplace hazard assessment in accordance with NFPA 2113 to determine PPE requirements for facility personnel. The assessment should be conducted in accordance with Section 4.2 of NFPA 2113. The analysis should consider work tasks that could potentially expose workers to flash fires, characterize potential exposures, and determine appropriate FR and/or thermally protective PPE and implement a policy regarding care, cleaning, and maintenance for flame-resistant garments per Section 8.6.1.6 of NFPA 652. Activities / tasks identified in this analysis which may warrant the use of FR clothing include, but are not limited to: • Tasks involving cleaning or maintenance of interior compartments of dust collection systems (e.g., bag filter replacements). • Tasks involving the clearing of blockages / plugs from elevated equipment containing combustible particulate solids. • Tasks involving housekeeping in areas with heavy dust accumulations.	The assessment and selection of PPE, such as fire-retardant clothing, should comply with the Canada Occupational Health and Safety Regulations. Information related to protection equipment and preventative measures is outlined in Part XII of the Canada OHS Regulations.	Low

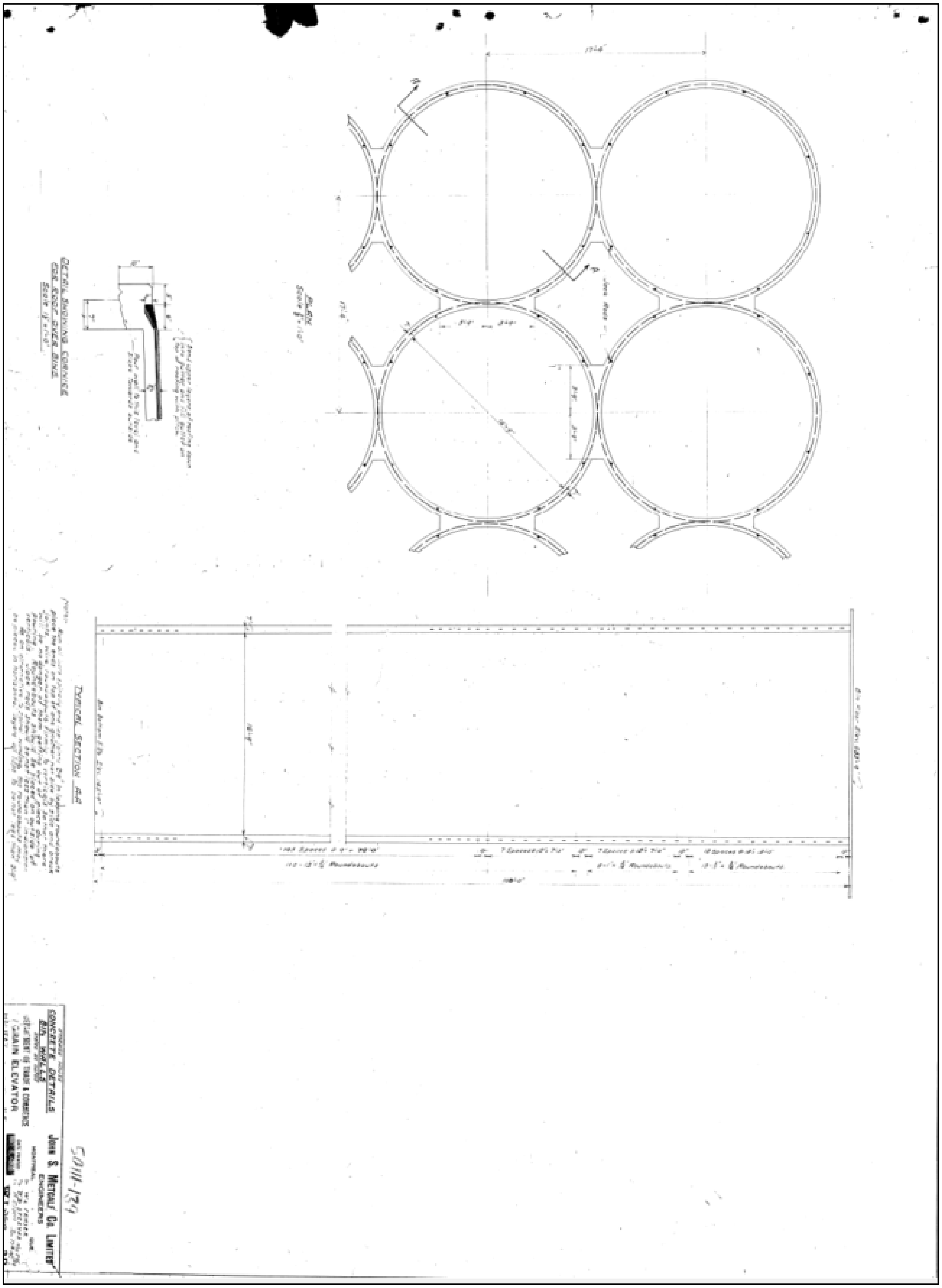
Appendix C. Referenced documentation

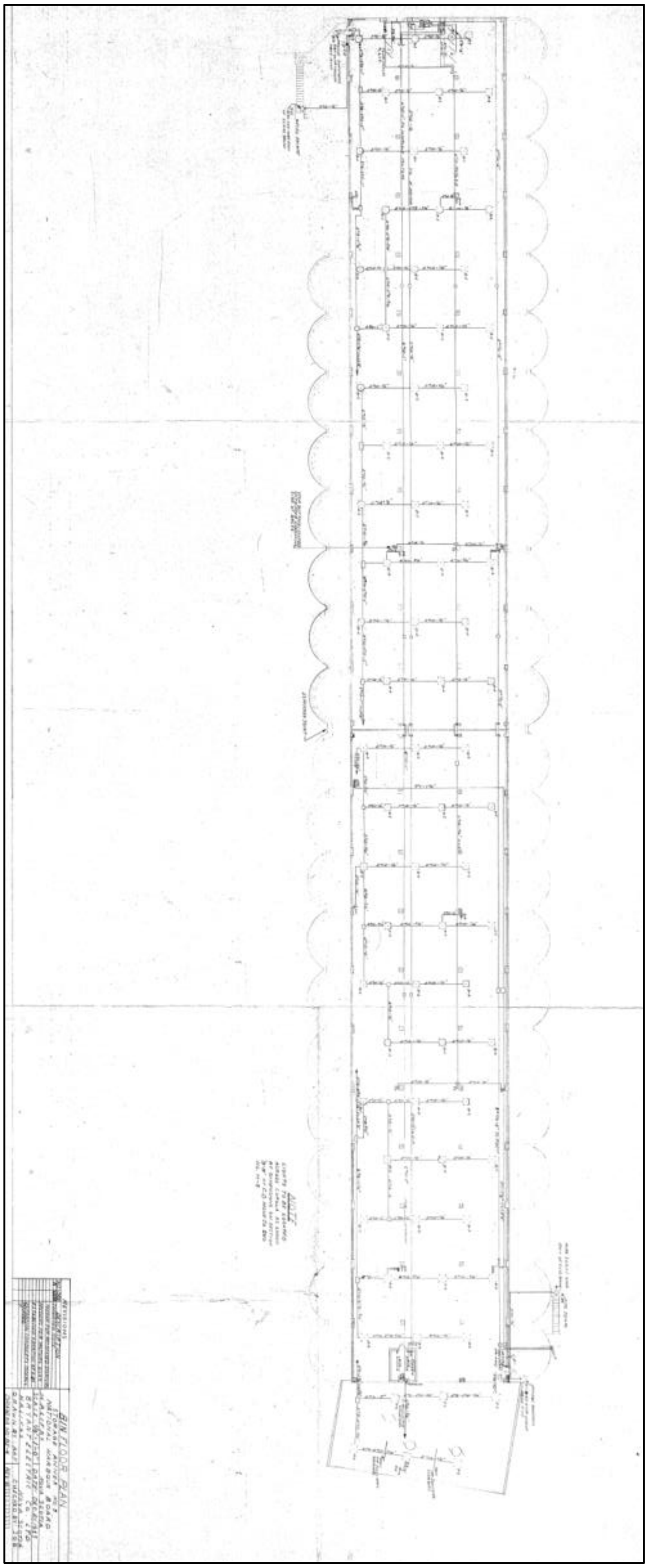
C.1 SILO CONSTRUCTION DRAWINGS

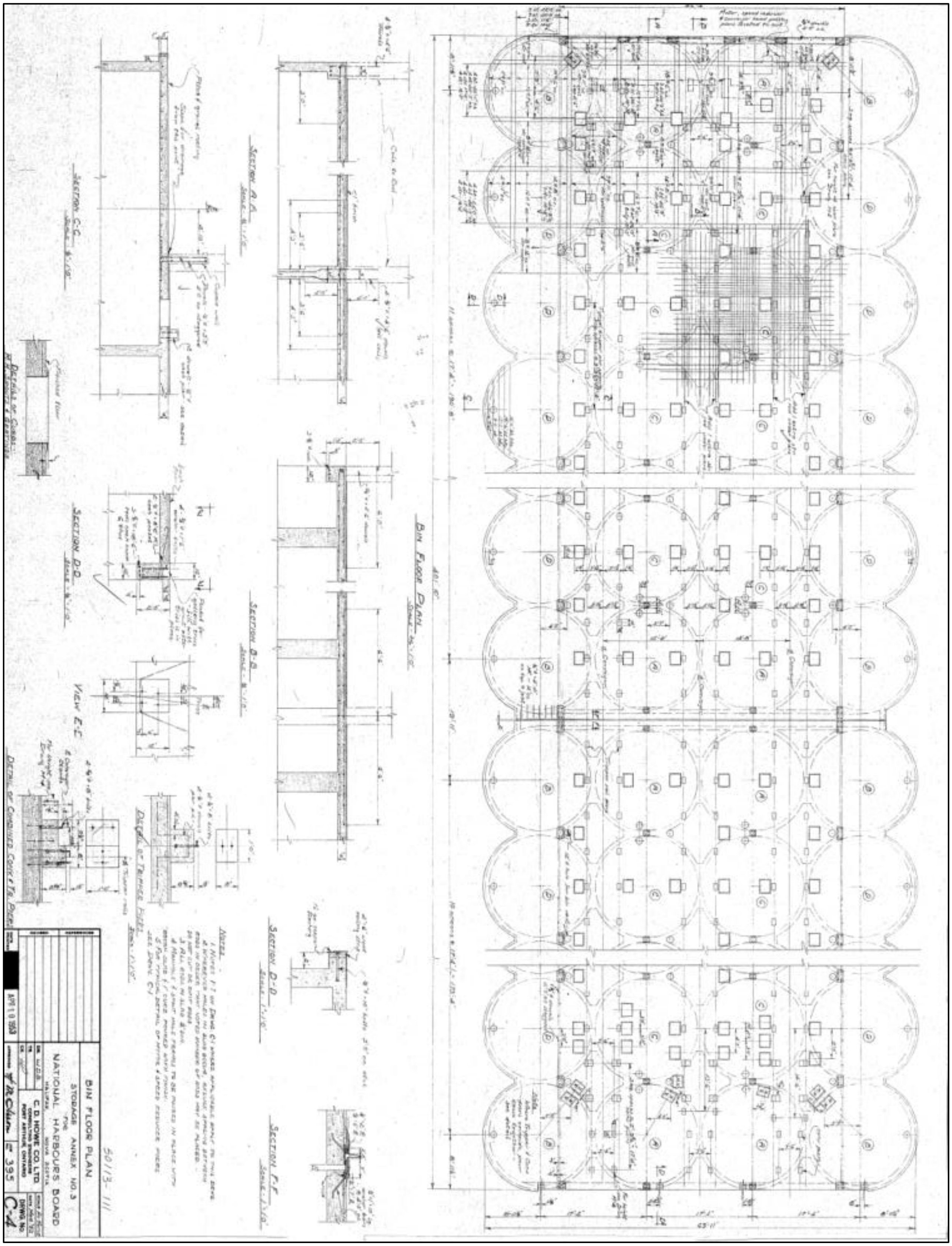

PLAN OF BIN SLAB
PLAN OF BINS
JOHN S. METCALF CO. LIMITED
ENGINEERS

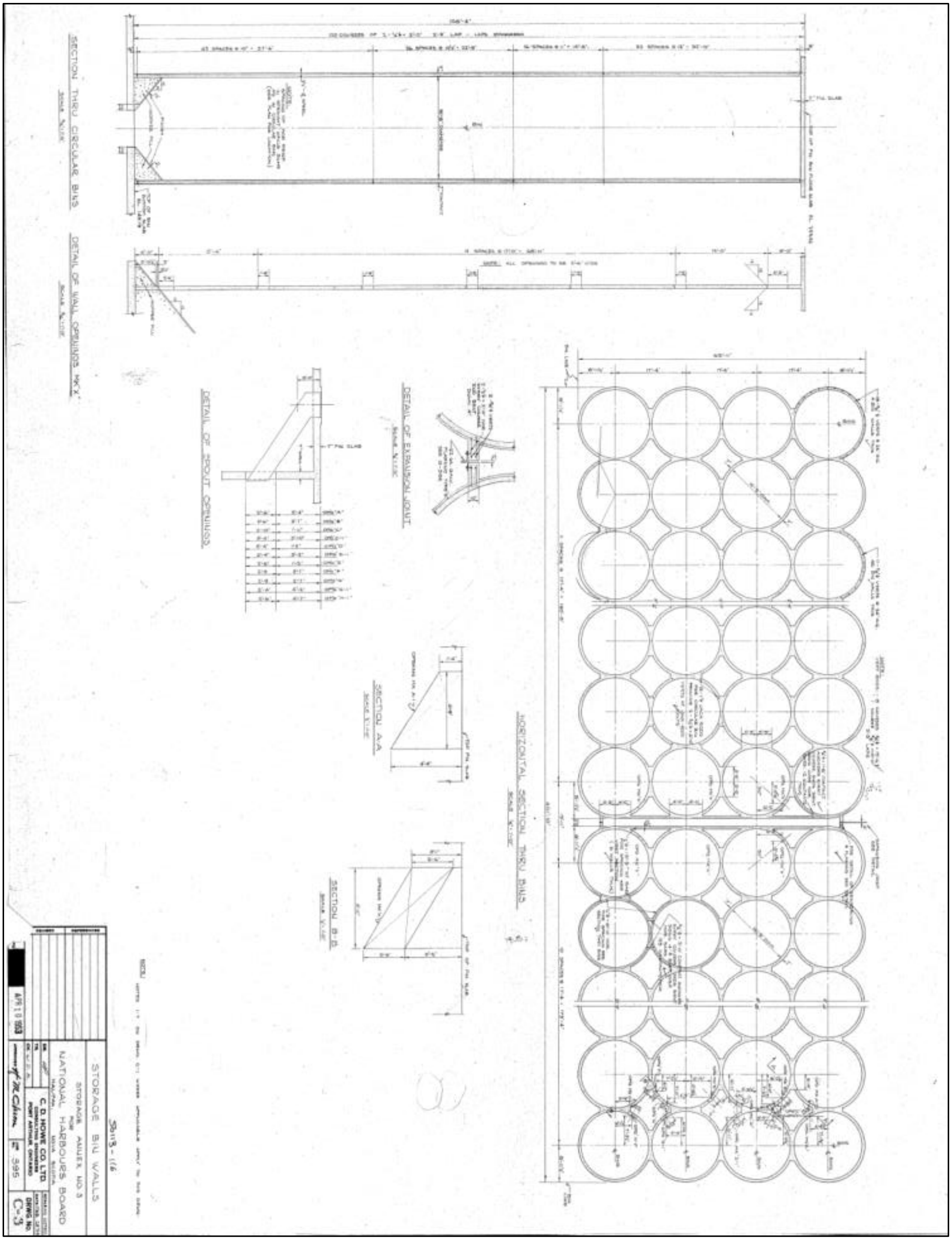

PLAN
SECTION CC
SECTION DD
ELEVATION
SECTION AA
CONCRETE DETAILS
BIN BOTTOMS
JOHN S. METCALF CO. LIMITED
ENGINEERS
GRAIN ELEVATOR

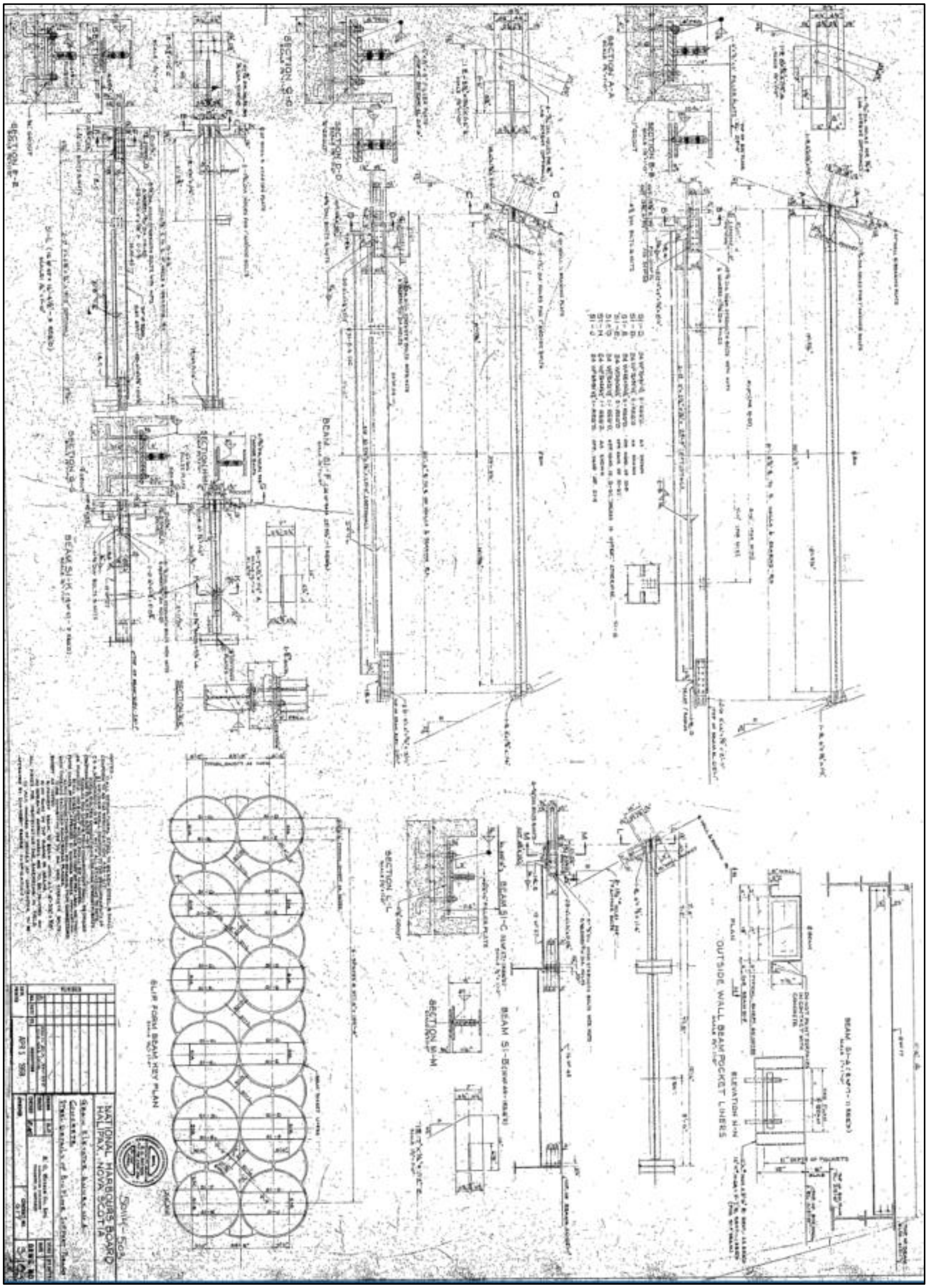

Plan of Bins.
Plan of Bin Floor.
John S. Metcalf Co. Limited
Engineers
Halifax Harbour Commissioners
209

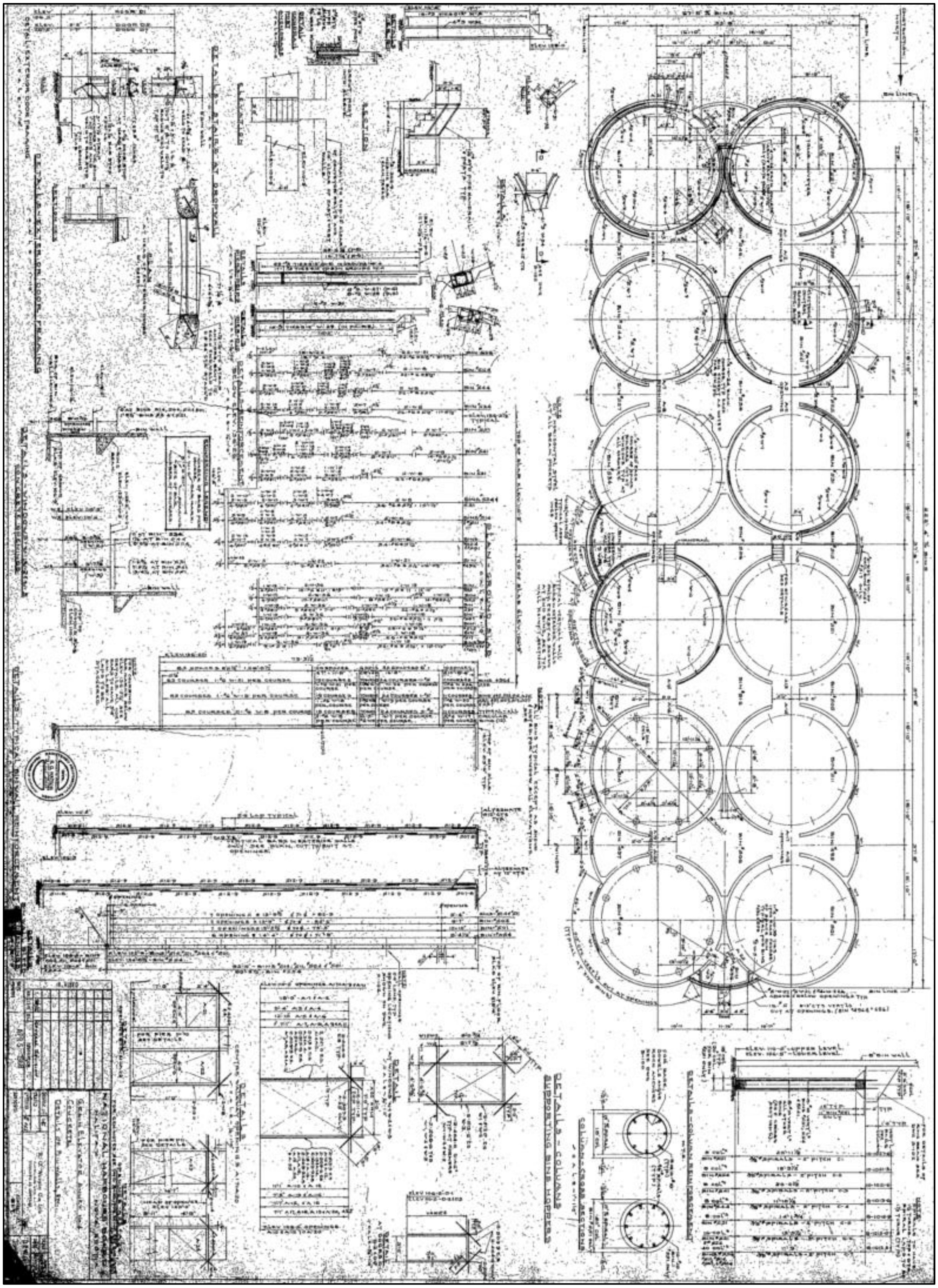

Plan
Typical Section A-A
Detail Showing Cornice for Roof over Bins
Concrete Details
Bin Walls
Grain Elevator
John S. Metcalf Co. Limited
Engineers

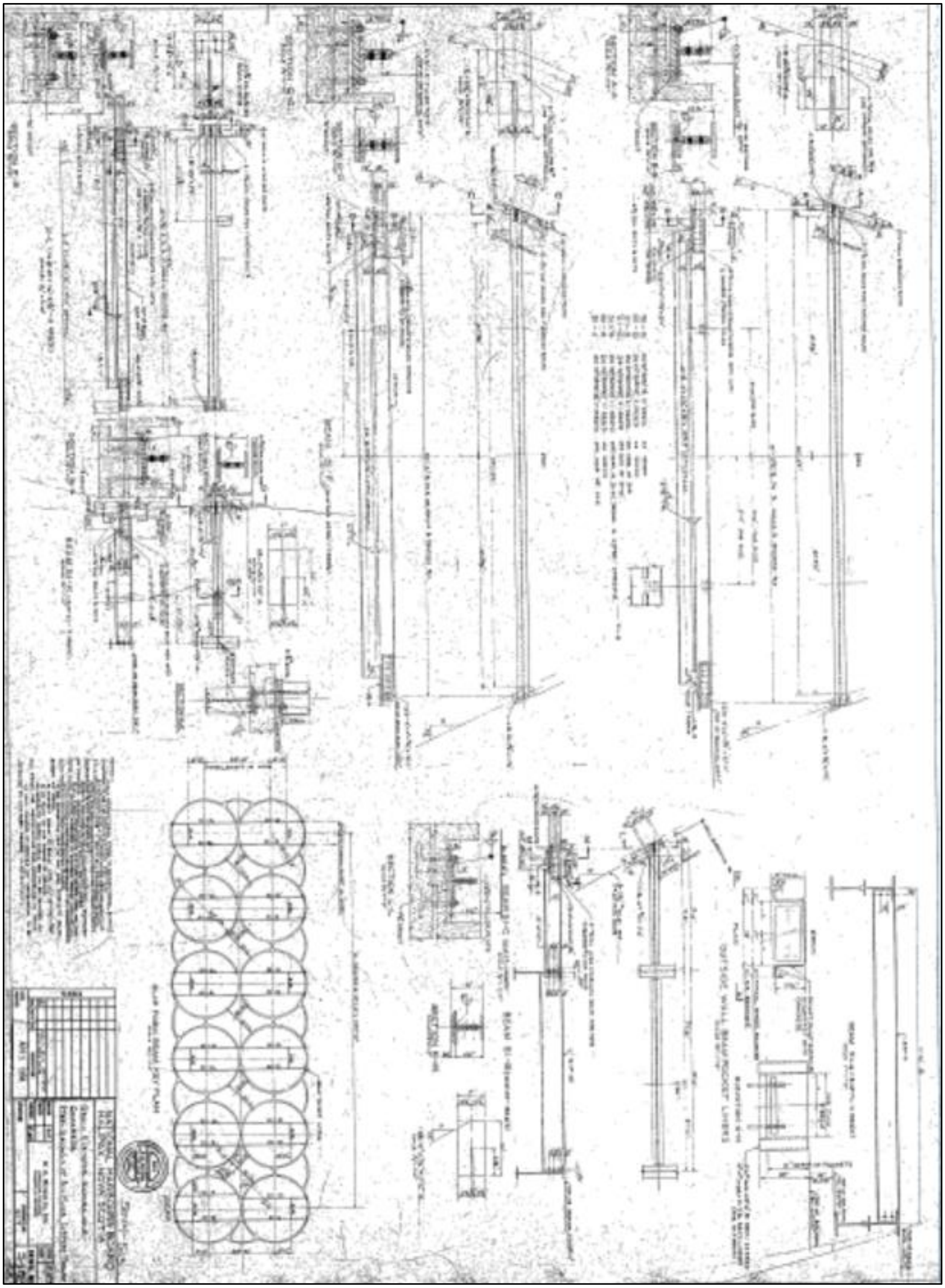



BIN FLOOR PLAN
STORAGE ANNEX NO.3
NATIONAL HARBOURS BOARD
C.D. HOWE CO. LTD.
C-4

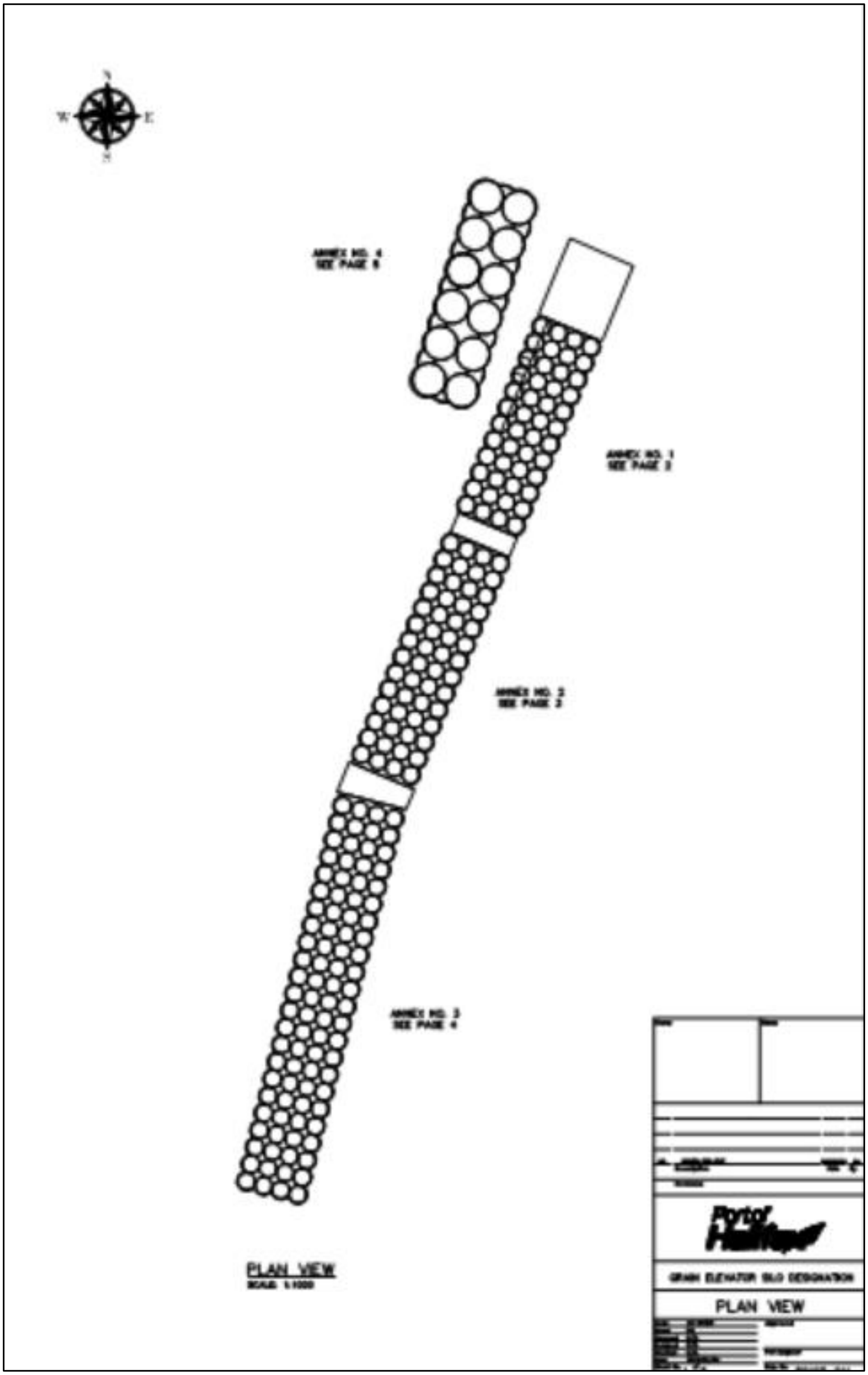

SECTION THRU CIRCULAR BINS
DETAIL OF WALL OPENINGS
DETAIL OF SPOUT OPENINGS
DETAIL OF EXPANSION JOINT
SECTION A-A
SECTION B-B
HORIZONTAL SECTION THRU BINS
STORAGE BIN WALLS
STORAGE ANNEX NO. 3
NATIONAL HARBOURS BOARD
C. D. HOWE CO. LTD
C-3

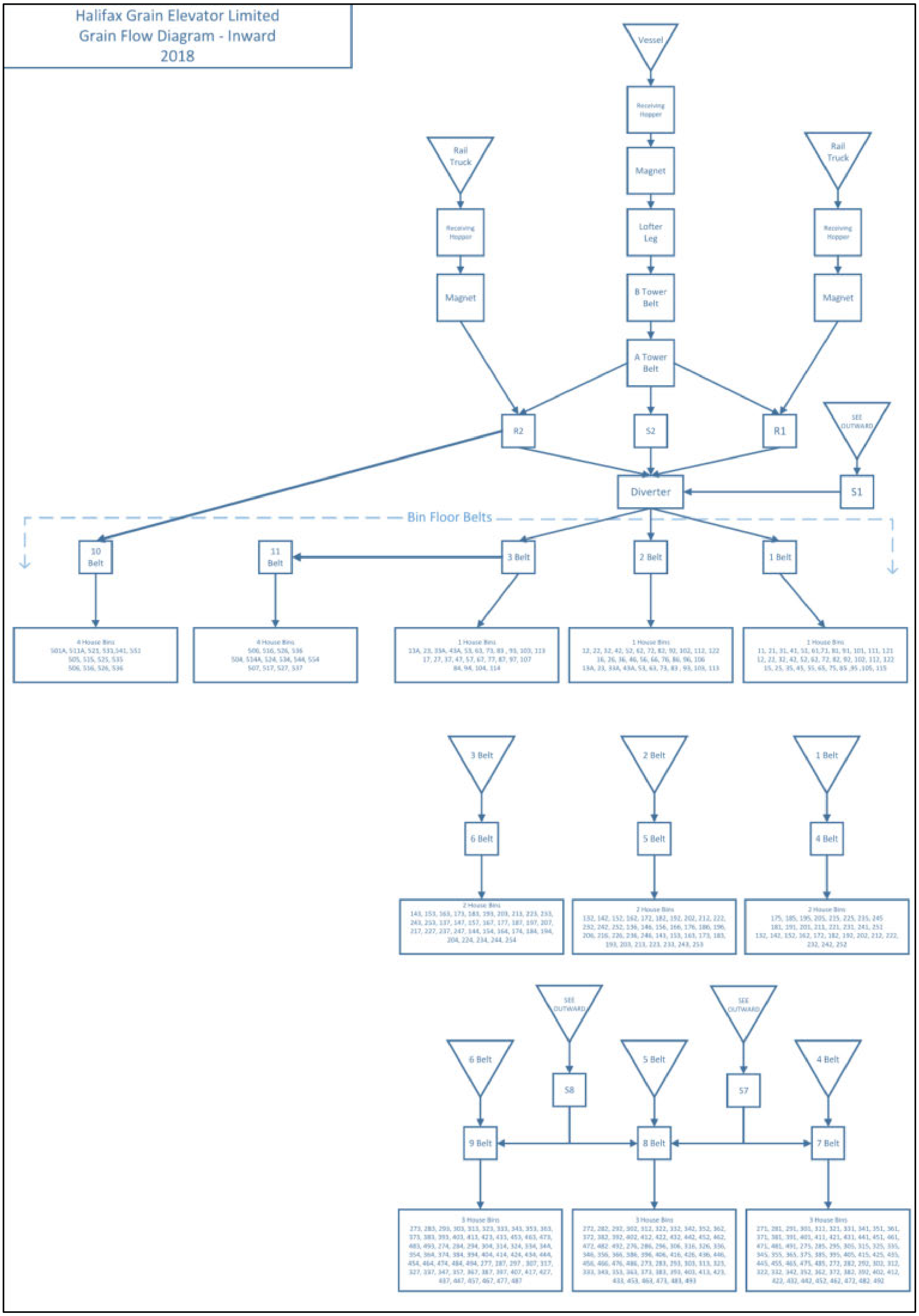

SLIP FORM BEAM KEY PLAN
OUTSIDE WALL BEAM POCKET LINERS
NATIONAL HARBOURS BOARD
HALIFAX, NOVA SCOTIA





C.2 LAYOUT DRAWINGS AND PROCESS FLOW


N
W
E
S
ANNEX NO. 4
SEE PAGE 5
ANNEX NO. 1
SEE PAGE 2
ANNEX NO. 2
SEE PAGE 3
ANNEX NO. 3
SEE PAGE 4
PLAN VIEW
SCALE 1:1000
GRAIN ELEVATOR SILO DESIGNATION
PLAN VIEW


Halifax Grain Elevator Limited
Grain Flow Diagram - Inward
2018
Vessel
Receiving Hopper
Magnet
Lofter Leg
B Tower Belt
A Tower Belt
Rail Truck
Receiving Hopper
Magnet
Rail Truck
Receiving Hopper
Magnet
R2
S2
R1
SEE OUTWARD
S1
Diverter
Bin Floor Belts
10 Belt
11 Belt
3 Belt
2 Belt
1 Belt
4 House Bins
4 House Bins
1 House Bins
1 House Bins
1 House Bins
3 Belt
2 Belt
1 Belt
6 Belt
5 Belt
4 Belt
2 House Bins
2 House Bins
2 House Bins
SEE OUTWARD
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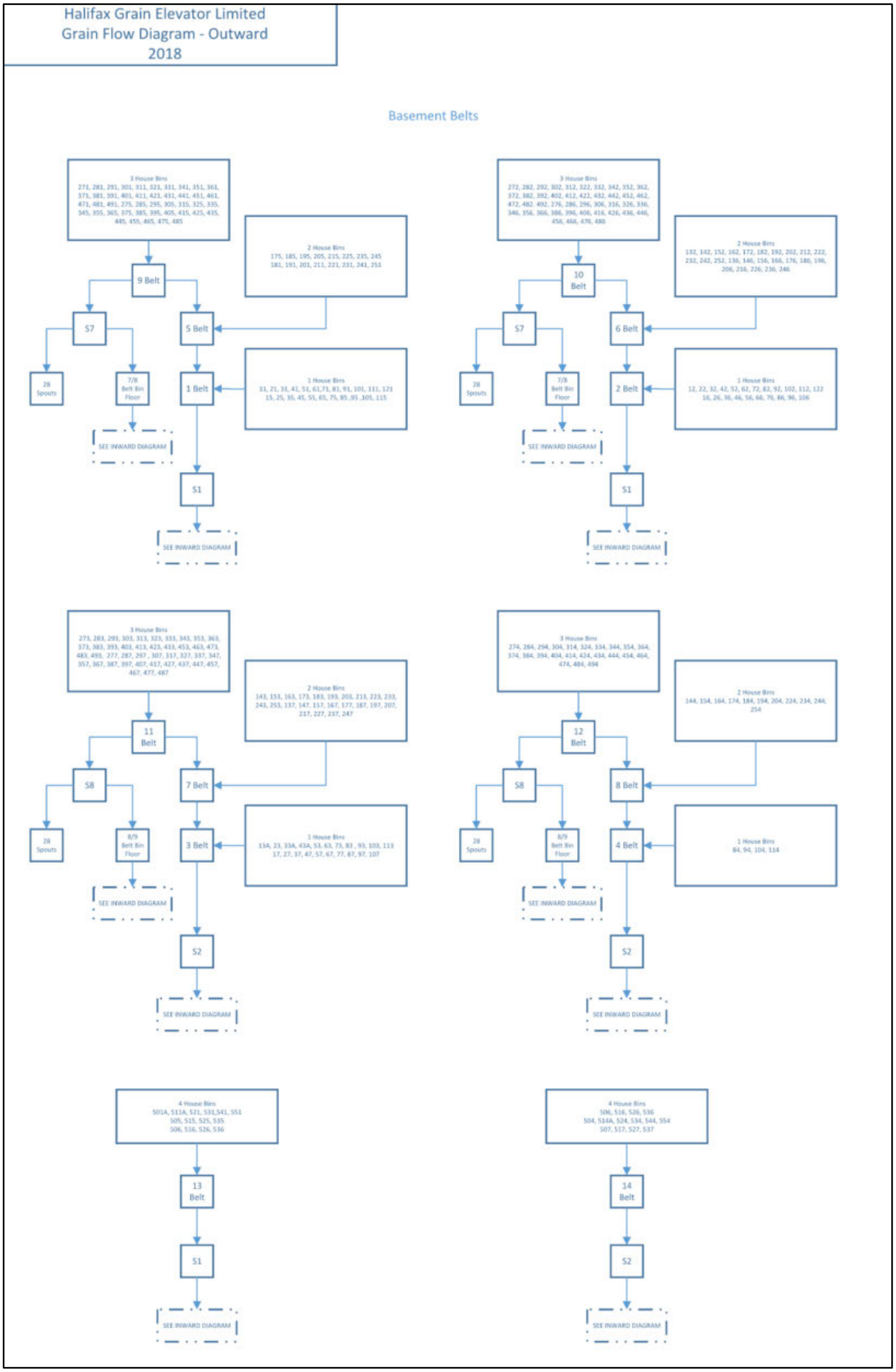
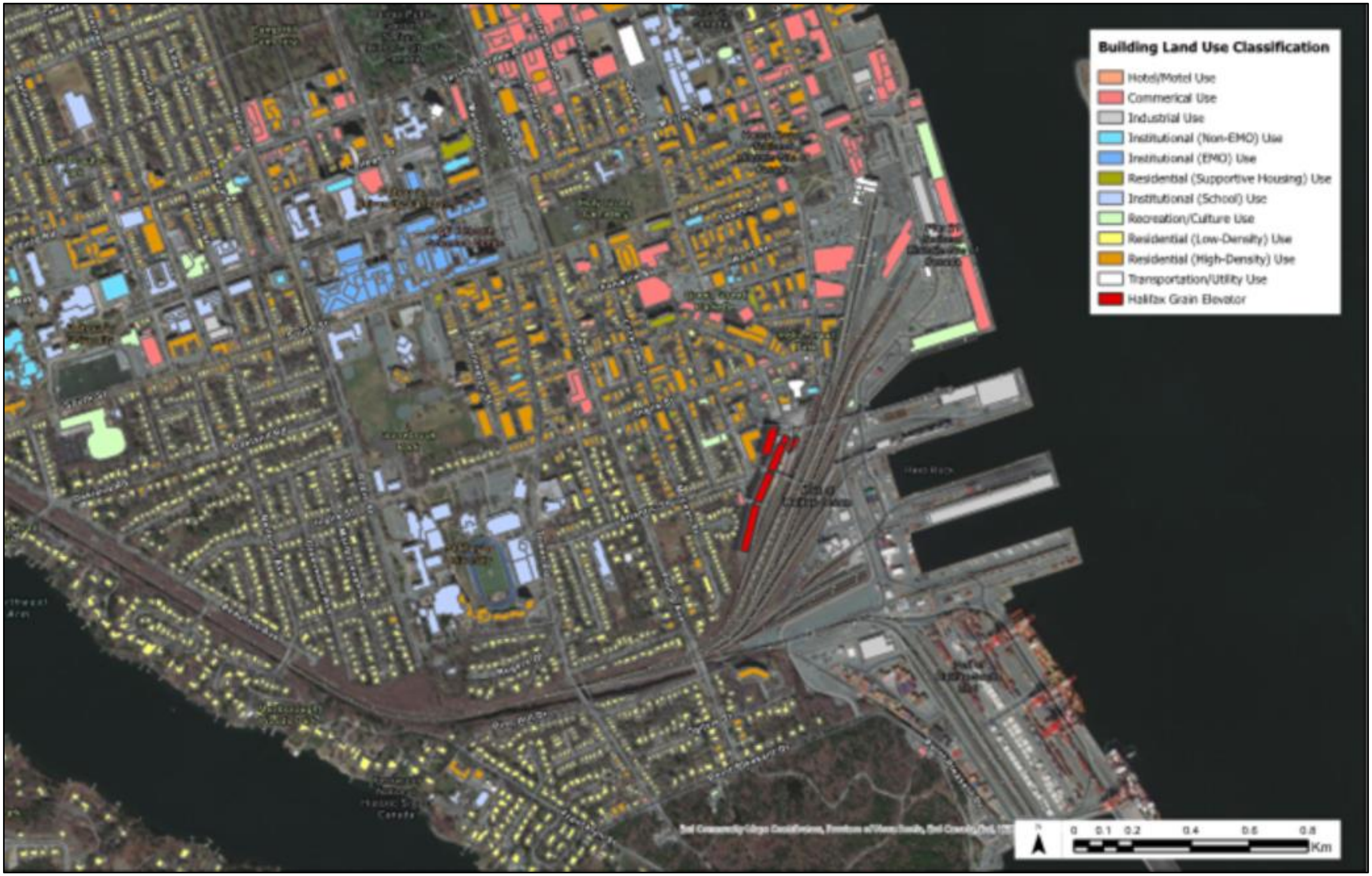
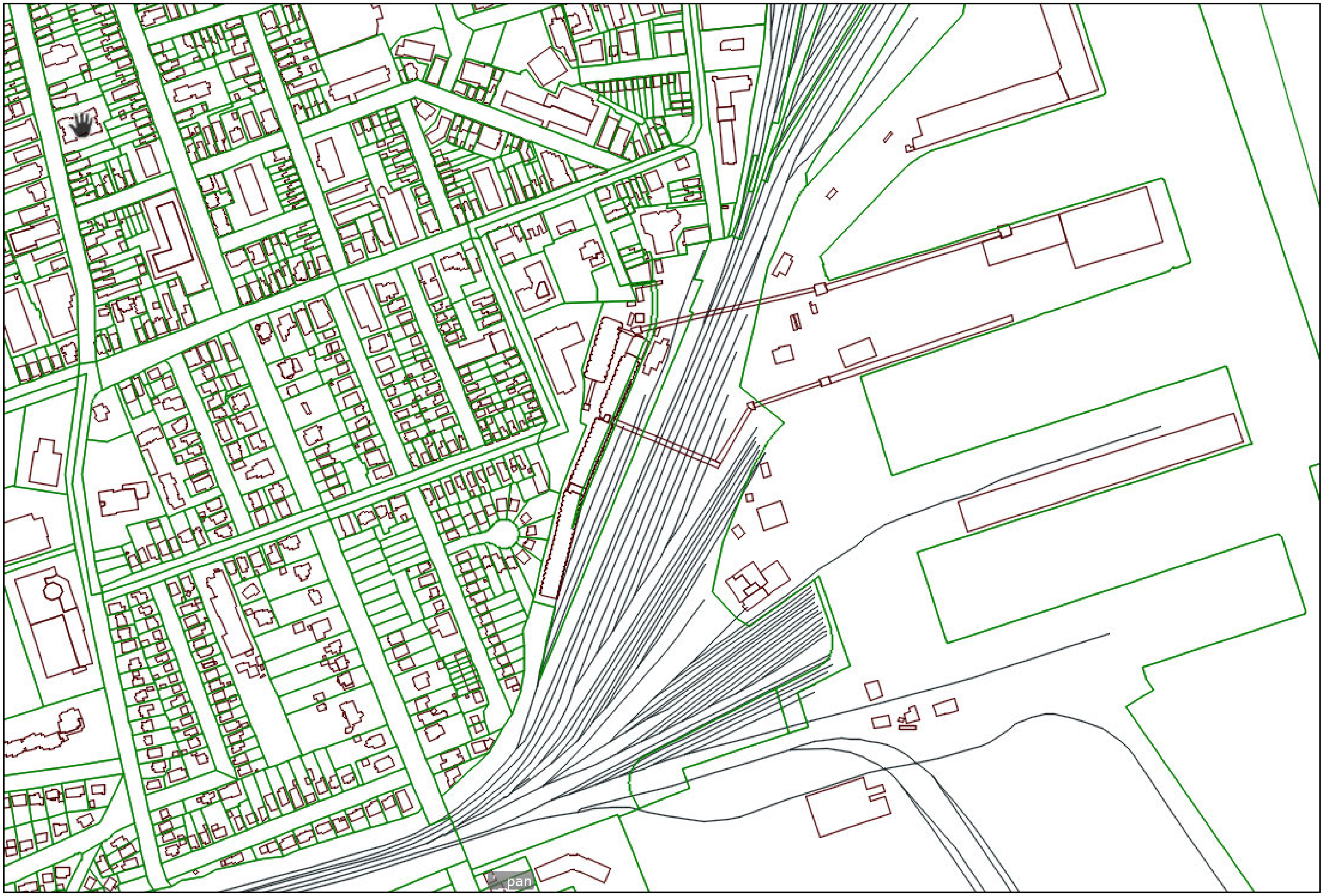
3 House Bins
3 House Bins
3 House Bins


Halifax Grain Elevator Limited
Grain Flow Diagram - Outward
2018
Basement Belts
3 House Bins
271, 281, 291, 301, 311, 321, 331, 341, 351, 361, 371, 381, 391, 401, 411, 421, 431, 441, 451, 461, 471, 481, 491, 275, 285, 295, 305, 315, 325, 335, 345, 355, 365, 375, 385, 395, 405, 415, 425, 435, 445, 455, 465, 475, 485
2 House Bins
175, 185, 195, 205, 215, 225, 235, 245
181, 191, 201, 211, 221, 231, 241, 251
9 Belt
S7
5 Belt
28 Spouts
7/8 Belt Bin Floor
1 Belt
1 House Bins
11, 21, 31, 41, 51, 61,71, 81, 91, 101, 111, 121
15, 25, 35, 45, 55, 65, 75, 85 ,95 ,105, 115
SEE INWARD DIAGRAM
S1
SEE INWARD DIAGRAM
3 House Bins
272, 282, 292, 302, 312, 322, 332, 342, 352, 362, 372, 382, 392, 402, 412, 422, 432, 442, 452, 462, 472, 482. 492, 276, 286, 296, 306, 316, 326, 336, 346, 356, 366, 386, 396, 406, 416, 426, 436, 446, 456, 466, 476, 486
2 House Bins
132, 142, 152, 162, 172, 182, 192, 202, 212, 222, 232, 242, 252, 136, 146, 156, 166, 176, 186, 196, 206, 216, 226, 236, 246
10 Belt
S7
6 Belt
28 Spouts
7/8 Belt Bin Floor
2 Belt
1 House Bins
12, 22, 32, 42, 52, 62, 72, 82, 92, 102, 112, 122
16, 26, 36, 46, 56, 66, 76, 86, 96, 106
SEE INWARD DIAGRAM
S1
SEE INWARD DIAGRAM
3 House Bins
273, 283, 293, 303, 313, 323, 333, 343, 353, 363, 373, 383, 393, 403, 413, 423, 433, 453, 463, 473, 483, 493, 277, 287, 297 , 307, 317, 327, 337, 347, 357, 367, 387, 397, 407, 417, 427, 437, 447, 457, 467, 477, 487
2 House Bins
143, 153, 163, 173, 183, 193, 203, 213, 223, 233, 243, 253, 137, 147, 157, 167, 177, 187, 197, 207, 217, 227, 237, 247
11 Belt
S8
7 Belt
28 Spouts
8/9 Belt Bin Floor
3 Belt
1 House Bins
13A, 23, 33A, 43A, 53, 63, 73, 83 , 93, 103, 113
17, 27, 37, 47, 57, 67, 77, 87, 97, 107
SEE INWARD DIAGRAM
S2
SEE INWARD DIAGRAM
3 House Bins
274, 284, 294, 304, 314, 324, 334, 344, 354, 364, 374, 384, 394, 404, 414, 424, 434, 444, 454, 464, 474, 484, 494
2 House Bins
144, 154, 164, 174, 184, 194, 204, 224, 234, 244, 254
12 Belt
S8
8 Belt
28 Spouts
8/9 Belt Bin Floor
4 Belt
1 House Bins
84, 94, 104, 114
SEE INWARD DIAGRAM
S2
SEE INWARD DIAGRAM
4 House Bins
501A, 511A, 521, 531,541, 551
505, 515, 525, 535
506, 516, 526, 536
13 Belt
S1
SEE INWARD DIAGRAM
4 House Bins
506, 516, 526, 536
504, 514A, 524, 534, 544, 554
507, 517, 527, 537
14 Belt
S2
SEE INWARD DIAGRAM

C.3 EXISTING LAND USE DESIGNATIONS


Building Land Use Classification
Hotel/Motel Use
Commercial Use
Industrial Use
Institutional (Non-EMO) Use
Institutional (EMO) Use
Residential (Supportive Housing) Use
Institutional (School) Use
Recreation/Culture Use
Residential (Low-Density) Use
Residential (High-Density) Use
Transportation/Utility Use
Halifax Grain Elevator
0 0.1 0.2 0.4 0.6 0.8
Km

C.4 SITE CAD DRAWING


pan

C.5 DOCUMENTATION FROM HRM AND HPA

C.5.1 Background Information

HALIFAX

PO Box 1749
Halifax, Nova Scotia
B3J 3A5 Canada

Background Information
Halifax Grain Elevator Land Use Risk Assessment

Issue

The Port of Halifax has an operational grain elevator at the edge of its property, abutting established low and medium density residential areas. The grain elevator is the only one on the Eastern Seaboard and is considered critical economic infrastructure. The Port advised during Centre Plan stakeholder consultations that there is the potential for explosions inside these elevators, and HRM may want to consider measures to restrict nearby development or require risk assessments.

Background

1. Halifax Grain Elevator

The Halifax Port Authority's grain elevator was constructed in 1924. The Port advises that at the time there were setbacks in place from existing residential uses. The Halifax Grain Elevator is the only grain elevator on the Eastern Seaboard and is considered essential economic infrastructure. The Port Authority advises that they have no plans to move the elevator, and that the facility is managed by Halifax Grain Elevator Ltd. on behalf of the Port.

As federal land, HRM has no jurisdiction over land use or operations at the Port. This includes vital safety legislation such as the Nova Scotia Building Code Act and Fire Safety Act. The Port is not required to have P&D review and inspect any construction work and they do not have to allow access to Halifax Regional Fire and Emergency (HRFE) to inspect the life safety systems in the buildings. HRFE is not aware of what materials are stored on site, what safety systems and protocols are in place, or what condition of those systems are in. It is also a possible that recent renovations performed on the property do not meet Building Code requirements. As a result, if HRFE is called to respond to an incident at the Port, their operational teams may encounter increased risk due to hazards such as uncommon building design or safety systems that are inoperable or incompatible with their procedures and equipment.

The Halifax Peninsula south end has densified over the past century and residential uses are now in close proximity to the grain elevators. Currently there are two undeveloped lots that abut the elevator: 5490 Atlantic St, which is private green space and a parking lot, and 950 Mitchell St, which appears to be a scrapyard. Neither the Halifax Peninsula Land Use By-law nor the Centre Plan Package A have any restrictions on development in the area.

2. Halifax Secondary Municipal Planning Strategy

Prior to Centre Plan Package A, properties near the Port were zoned C-3 Industrial, a zone which permitted low and medium density residential uses in addition to industrial uses. The Land Use By-law for C-3 uses in the South End Area permitted any industrial enterprise, except when the operation would cause a

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nuisance or hazard to the adjacent residential uses. The C-3 zone required a minimum 25-foot setback for industrial uses on a city street opposite to a residential zone, and a minimum of 25-foot side yard where adjacent to a residential zone. There were no other mitigation requirements for industrial land uses encroaching on residential uses, or vice versa.

In 2007, Peninsula Community Council approved a Development Agreement (DA) for a 6-storey, 106-unit apartment building at 927 South Bland Street (Case 00796). This property immediately abuts the grain elevators. The DA does not include any reference to explosive potential or risk mitigation from the grain elevator. It does mandate a 25-foot (7.5 m) right-of-way access between the apartment and the elevator. This is the closest point between the constructed building and the elevator. At the public hearing for the development, architects confirmed that they were working with a civil engineer and the Port Authority on the design of a blast wall for the rear of the building, meant to be one storey high and of a stacked block construction to direct a blast skyward. This is the only mention of mitigation efforts.

The Port Authority is not on record in either the original 2005 public information meeting minutes for Case 00796, or the November 2007 public hearing. However, the Port advised staff recently that they did write a letter to Halifax Regional Fire and Emergency in August 2010 (with a copy to Planning and Development) when the development was being considered. The letter asked HRM to ensure a safe separation distance between the apartment building and the elevator. It also recommended following the American National Fire Prevention Association standards as a best practice, which recommend a 15m buffer. A copy of the letter recently provided to staff by the Port is attached to this memo (Attachment 1).

3. Centre Plan Package A

Centre Plan Package A zoned most of the properties abutting the Port property south of Inglis Street and grain elevator as Corridor (COR) and Higher Order Residential – 1 (HR-1) with a maximum height of 26 m. This was intended to recognize the current residential context and prevent the introduction of new industrial uses in this area. One property (966-968 Mitchell Street) is zoned HR-2 with a maximum height of 38 m. Outside of this area properties are proposed to largely maintain low density residential zoning as ER-1 or ER-2. Staff is not aware of the issue of risk associated with the grain elevator being raised during the extensive Package A public consultation process.

Analysis

1. Land Use Conflicts and Risks

Discussions with the Port and its consultant identified the following as the main issues to consider when elevator coexist with residential uses:

- *Traffic* - vehicles require large parking areas, with roads having large turning radius, and long waiting periods to deliver / receive commodities.
- *Noise* - elevators need large dust control equipment, which causes high frequency as well as high intensity noises. These operations are scheduled 24/7.
- *Dust* - fugitive dust often escapes and accumulates on all surfaces within the normal settlement distances, which can be several hundred meters depending upon the wind speed.
- *Explosions* – high concentrations of combustible dust in the air combined with an ignition source can cause violent explosions. These have accounted for some of the worst workplace accidents in the US history.

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In 2003 the Halifax grain elevator experienced an explosion that required 400 people in a several-block radius to be evacuated. After that the Port worked with a consultant to develop and implement recommendations on mitigation strategies. These included retrofitting the elevator with measures to minimize the risk to adjacent areas, such as tethering all explosion release cladding that could otherwise become projectile, increased fire protection, risk mitigation for airborne dust, and the installation of blast shields on the residential side of the elevator.

2. Jurisdictional Scan

There are few Canadian guidelines on risk mitigation for grain elevators in urban settings. The Port Authority indicated that safety codes from the US are more detailed and are considered best practices, likely due to the number of past incidents[1]. The US Occupational Safety and Health Administration has standards for grain-handling facilities, but they mainly deal with safe working conditions, dust control systems, ventilation, and entryways. They do not address built form or the potential impact of grain elevators on surrounding land uses.

Setbacks are the most common way to protect incompatible nearby uses. A jurisdictional scan of some Canadian and US cities that have grain elevators in urban areas shows that the most common practice is to zone the sites Industrial and apply Industrial built form requirements to the surrounding area. However, there is no standard setback cities use. The American cities surveyed have far greater setback requirements (200 feet or 61m), which may be because they experienced grain elevator explosions that resulted in significant loss of life. Canadian cities tend to require 6 metre setbacks and some screening. These rules do not appear to envision scenarios where grain elevators immediately abut residential uses. HRM Fire staff is not aware of an established buffer area outside of which damages would not occur during a grain elevator explosion.

3. HRM Land Use By-laws Comparative Scan

For comparison's sake, existing land use bylaws in HRM require the following setbacks ranging from 6.1 m to 70 m for intensive uses that could be considered nuisances:

Zone/Use	Min Lot Area	Min Front Yard	Min Rear Yard	Min Side Yard	Screening
C&D materials (Halifax Mainland LUB)	40,000 sq. ft (3716 m2)	25m	30m	30 m	
Salvage zone (Dartmouth LUB)	5000 sq. ft (464.5 m2)	20 ft (6.1m)	20ft (6.1m)	20 ft (6.1 m)	Completely enclosed and screen from view with fence minimum 12 feet high
Cannabis production (when abutting a residential use or zone) (All LUBs)		230 feet (70m) from lot lines	230 feet (70m) from lot lines	230 feet (70 m) from lot lines	

[1] See US Dept, of Labor Grain Elevator Explosion Chart which includes the number of grain elevator incidents, injuries and fatalities (1976-2011).

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Livestock operations (Musquodoboit Valley-Dutch Settlement LUB)	40,000 sq. ft (3716 m2)	150 feet (45.7m) from residential uses	150 feet (45.7m) from residential uses	150 feet (45.7m) from residential uses	

4. Halifax South End Context

HRM staff spoke with the consultant recommended by the Port to better understand how to establish an appropriate setback:

- In general most grain elevators have a physical height limitation in the order of 50m to 70m. The lower 30m elevator is usually filled with storage products and is designed to withstand the high loading of the product. This makes it quite resistant to release of an explosion.
- In the Halifax grain elevator, the venting (windows) in the lower transfer area have been fitted with release hoods which are designed to re-direct what would normally be a horizontal flame or pressure upwards along the side of the elevator, to hopefully release harmlessly rather than destroying the adjacent buildings.
- Explosions are more common above the 30m level and tend to spread their damage horizontally as projectile equipment parts or building cladding.

The consultant suggested a 50m setback as a useful minimum distance within which no new construction would be permitted, and a 50m to 100m buffer limited to industrial buildings. This staggered approach would reflect the progressive level of risk that proximity entails. HRM has mapped setbacks of 30m, 50m, 70m and 100m from the elevator to show which properties would be affected by any change to zoning (Attachment 2).

Given that the recommended buffer area is already largely residential, zoning it to industrial uses may not be practical or warranted until a more detailed study is completed. Introducing new industrial uses within a residential area would also potentially introduce new risks.

Next Steps

Grain Elevator and Land Use Study

Given the risks to public safety raised by the Port Authority and the additional information contained in this memo, staff advise that there is a need to address these risks as part of Centre Plan Package B planning documents. However, while there is sufficient information on general risk to raise concerns, a more detailed study is needed to understand the specific risks in the South End Halifax context. This study is envisioned to address the following:

- identify the specific risks related to the design and operation of the grain elevator, such as the specific portion of the building where risks are highest and other factors;
- place risks associated grain elevator in the context of other industrial uses that are often located close to residential areas, such as distilleries, propane storage etc.;
- assess relative risks of the Halifax Grain Elevator, including the current and proposed land use context;
- outline best practices to mitigate risks based on jurisdictional scan and research;
- recommend mitigation strategies that should be implementing through land use planning tools (setbacks, zoning, building designs, further site-specific studies etc.); and

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- recommend mitigation strategies that can be implementing through operational measures, such as monitoring, grain silo improvements and other measures.

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Attachment 1: Port Authority Letter

Port of Halifax

September 28, 2010

Via Email /Courier

Division Chief Donald Day
Divisional Captain Craig MacDonald
Halifax Regional Fire Services
40 Alderney Drive, 1st Floor
Dartmouth, NS B3J 3A5

Gentlemen:

Re: South Bland Street Development – Southwest Properties Ltd.

This is in follow up to our meeting on August 31, 2010.

Since that meeting, Southwest Properties has withdrawn its request for consent to create a berm on the Halifax Port Authority's (HPA) maintenance right-of-ways and accordingly, the fire access issues which we discussed are no longer of concern.

However, the HPA remains very concerned about the small separation distance of 31 feet shown on the current project plans of Southwest Properties between the grain elevators and the proposed Southwest Properties residential building on South Bland Street.

As we have previously indicated, Section 61 of the *N.F.P.A. Standards*, which are the only recognized standards applicable to grain elevators in North America, and which we understand to be based on empirical evidence pertinent to grain elevator explosion risk recommends that a minimum separation of 15 metres or 50 feet be maintained between a concrete storage elevator and human use facilities because of the inherent explosion hazard associated with grain elevators. We understand from our meeting on August 31, 2010 that the *N.F.P.A. Standards* have not been incorporated explicitly into the *National Building Code*. Nevertheless the *N.F.P.A. Standards* are an appropriate indicator of fire and explosion safety risk.

At the meeting on August 31, 2010, you confirmed that Halifax Fire Services was not consulted in the Development Agreement process for the property. The HPA has no record of being notified of the Development Agreement hearing, and did not participate in that process. A Development Agreement has been entered into between HRM and Southwest. It appears that the only recourse at this juncture for enhancing the separation distance would have to be either under the *Building Code Act* or the *Fire Safety Act*:

.../2

Canada

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Division Chief Donald Day
Divisional Captain Craig MacDonald
Re: South Bland Street Development
September 28, 2010

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We ask that the HRM use all available authority to ensure safe separation distance between the existing grain elevators and proposed human use facilities on the adjacent property.

We are taking the liberty of copying this letter to Mr. Don Donovan (Manager, Permits & Inspections, HRM Planning and Development).

Thank you in advance for your consideration.

Yours truly,

Krista Dempsey

Krista A. Dempsey, CLO
Vice-President, Real Estate

c. Jim Donovan, Manager, Permits & Inspections, HRM Planning & Development
Jim Spatz, Chairman & CEO, Southwest Properties Ltd.
Gordon Laing, President & COO, Southwest Properties Ltd.

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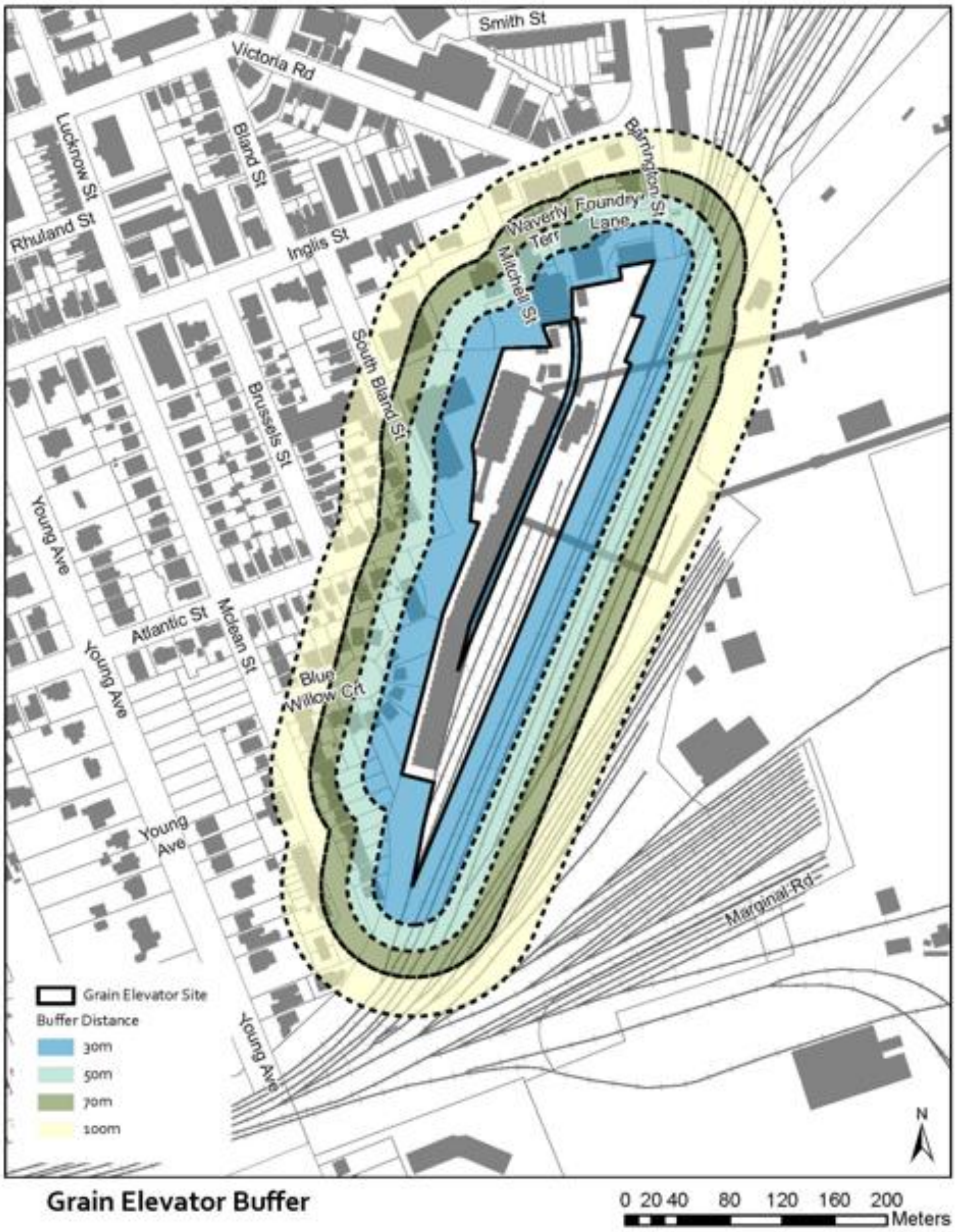
Attachment 2: Potential Grain Elevator Land Use Buffers



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C.5.2 Grain elevator incident report – 2003 explosion

HALIFAX REGIONAL MUNICIPALITY

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News Release

Investigation of Grain Elevator Explosion and Fire Concluded

(Tuesday, December 2/2003)-- "Mechanical heat from friction" has been ruled the most probable cause of an explosion and fire at the Halifax Grain Elevator this past summer, according to a Fire Cause Summary submitted to the Halifax Regional Fire and Emergency Service this week.

The report, prepared by investigators from the HRM Fire Service; the provincial Fire Marshall's Office; Human Resource Development Canada (Labour division) and engineering consultants, stated that "most consensus reports (during the investigation) dwelled on the lack of cleaning and maintenance carried out throughout the complex."

"Findings of heat safety sensors on bearings did not work and have not for several years. In general, it did not appear that maintenance and housekeeping duties were priorities. The Halifax Grain Elevators could not supply any maintenance records to equipment. Magnets in the receiving tunnel were not in operation, " the report read.

As the investigation proceeded, investigators focussed on #5 and #6 shippers at the grain elevator.(This is a conveyor belt system that moves grains or wood pellets from the storage area to waiting vessels for transport.)

The report stated that Shipper #5 showed signs of friction at the drum shaft and its external cap. "Excessive heat certainly would have been generated to be an ignition source."

Shipper #6 was also examined. "Due to lack of proper maintenance, the bearing system failed and this elevator was also off-centre. There was damage to the shaft on the drum and bearings. Our findings indicated that this damage certainly would be a major factor in causing an ignition source," the report stated.

"In our opinion, during this inspection, both elevators $5 and #6 should not have been operating to transport combustible products creating an explosive atmosphere," it read.

Investigators stated that electrical could not definitely be ruled out as a possible cause, and due to the humidity at the time of the explosion, static could not be ruled out. However, in the end it was agreed that mechanical heat from friction was the "most probable cause" of the late August explosion and fire, which forced local neighbourhoods to be evacuated.

The document also makes mention of several fire and safety surveys carried out at the grain elevator facilities in recent years. They included:

- a report by Profession Loss Control Inc., dated December 14, 2000, to Halifax Grain Elevator Limited. There were code deficiencies and deviations noted and *they now are to be corrected throughout the plant.*
- a report dated July,1996, prepared by Fenco Shawinigan Engineering (1991), *is to be re-visited and code deviations corrected.*
- the latest maintenance program evaluation in January 2001, prepared by SNC Lavalin Incorporated, to the Halifax Grain Elevator Limited *is to be re-visited. All recommendations and code deviations are to be completed.*

The investigators' report concluded "The Halifax Grain Elevator Limited is willing to operate the facility safely. They will accept all recommendations from all agencies involved with this investigation."

It also stated that Halifax Grain Elevators Limited has adopted a continual maintenance system and that safety issues are being adhered to.

–30---

Deputy Chief Bruce Burrell
Halifax Regional Fire and Emergency Service
(902) 4430-3772

John Blandin
HRF&ES Media Relations Officer
(902) 430-3884

Appendix D. Facility photos

D.1: Photograph of the facility from the marine tower (east side).

D.2: Workhouse #1 and the bucket elevator outside legs (east side).

D.3: Exterior of Annex 4 silos.

D.4: Exterior of Annex 1 bin level gallery (western side).

D.5: Exterior of the Annex 2 bin level gallery (western side).

D.6: Annex 4 gallery (looking north).

D.7: Workhouse #1 and Annex 4 (looking south).

D.8: Western side of Annex 2 silos and Workhouse #3.

D.9: Proximity of Annex 4 to the Grainery Lofts.

D.10: Annex 4 bin level gallery.

D.11: Annex 4 basement gallery.

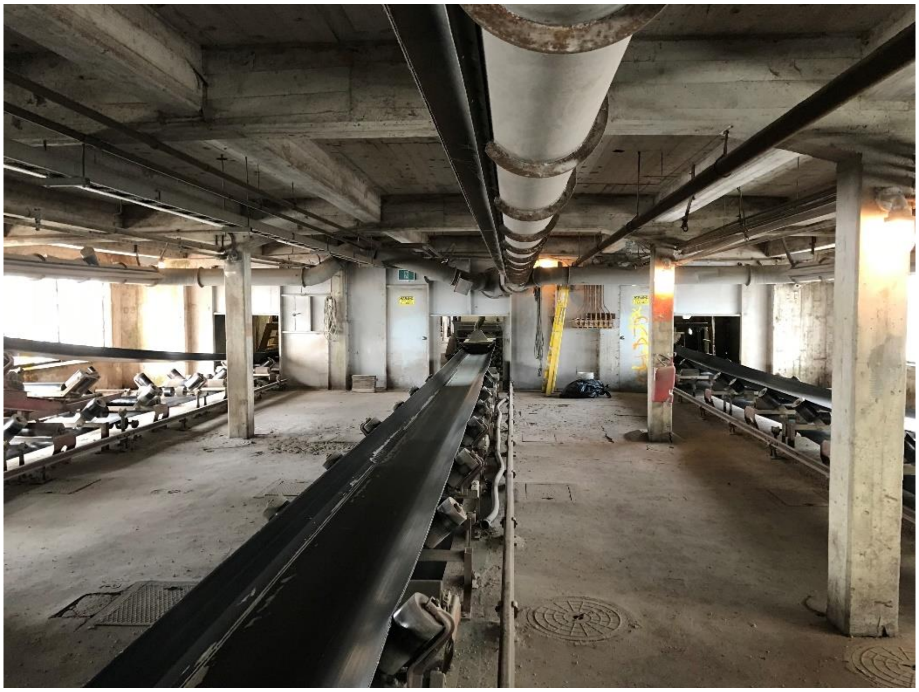
D.12: Annex 4 silo metal cone.

D.13: Partition between Annex 1 and Workhouse 1.

D.14: Silo chute in the Annex 1 bin level gallery.

D.15: Annex 2 bin level gallery.

D.16: Annex 2 basement gallery.



D.17: Partition between Annex 1 and Annex 2.

D.18: Belt tripper in Annex 2.

D.19: Annex 3 bin level gallery.

D.20: Annex 3 basement level gallery.

D.21: Bucket elevator boot in Workhouse 1 basement.

D.22: Bucket elevator head in Workhouse 1 motor floor.