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Hazard Screening Assessment

Clark County

Submitted by:

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

Page

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

TABLE OF CONTENTS (Continued)

1. HAZARD SCREENING ASSESSMENT

MMI Engineering (MMI), a subsidiary of Geosyntec Consultants, understands that there is a proposed project, a rail-to-marine oil terminal (terminal) in Vancouver, WA, subject to permitting through the Energy Facility Site Evaluation Commission (EFSEC), within Clark County's port of Vancouver, WA. Clark County is interested in understanding the potential consquences and risk of the proposed project, as they relate to the preservation of human health and safety at the Clark County Jail Work Center (JWC). The Clark County Jail Work Center is located within 500-1000 feet of the proposed new project and will border proposed piplines and ternminals on multiple sides.

1.1 Scope

MMI conducted a staged analysis which consisted of a preliminary consequence based screening assessment of the proposed oil terminal and followed by a quantitative risk assessment of the proposed transfer pipelines.

1.1.1 Consequence Based Screening Assessment

MMI performed a consequence-based screening assessment to evaluate the impact potential for fire, toxic, and explosion events that could impact the JWC. This was to aid Clark County in its understanding of health and safety impacts for the incarcerated, visitors, and jail employees who are located at the JWC. The screening assessment utilized "credible worst case" release events to assess whether the resulting thermal radiation, toxic gas, and/or explosion overpressures are capable of adversely impacting occupants located within the JWC. This assessment follows guidelines consistent with with OSHA's Process Safety Management (PSM) 29 CFR 1910.119 Recognized and Generally Accepted Good Engineering Practices (RAGAGEP) [1] with American Petroleum Institute (API) Recommended Practices (RP) [2,3]:

- 752, Management of Hazards Associated with Location of Process Plant Buildings, Third Edition, December 2009; and
- 753, Management of Hazards Associated with Location of Process Plant Portable Buildings, First Edition, June 2007.

These API Standards are applicable for use at onshore facilities covered by OSHA 29 CFR 1910.119

Additional resources used include [4,5]:

- Guidelines for Facility Siting and Layout, Center for Chemical Process Safety of the American Institute of Chemical Engineers, Wiley, 2003; and
- Guidelines for Hazard Evaluation Procedures, Center for Chemical Process Safety of the American Institute of Chemical Engineers, Wiley, 3rd edition, 2008.

1.1.2 Quantiative Risk Assessment

Based on results from the intial consequence based screening, Clark County requested MMI to perform a Quantitative Risk Assessment (QRA) to better understand the risk related to pipeline specific events which were determined to have the potential for on-site consequences at the JWC.

The QRA was conducted to classify the consequence and liklihood of loss of containment events originating from pipelines and pipeline operations. MMI conducted a conceptual level frequency assessment in order to develop base case leak frequencies and ignition probabilities. These frequencies and probabilities were then used to develop Location Specific Individual Risk metrics for the grounds and buildings of the JWC. High level commentary on how the claculated risk values compare to industry and governmental guidance is provided in the summary of this report.

1.2 Report Sections

In this report, Section 1 introduces the background for the hazard screening assessment. Section 2 includes the assumptions and the results for the hazards consequence modeling. Section 3 includes the assumptions and results fot the quantitative risk assessment (QRA). Section 4 is the summary and recommendations based on the consequence analysis and QRA assessment. Section 5 includes the reference literatures.

2. CONSEQUENCE BASED SCREENING ASSESSMENT

This section discusses the methodology and results of the consequence based screening assessment. As the current design is in a preliminary concept stage of design, several key assumptions were required to be made, which are detailed as necessary throughout this document. It is important to note that a site visit was not conducted as part of this assessment, the assumptions relating to facility layout, construction, etc. were based on preliminary layout drawings provided to MMI and the use of satellite imagery.

2.1 Site Overview

MMI worked with Clark County to review provided project data and establish an understanding of the proposed terminals, storage facility, and expected operations for the analysis. Information provided by Clark County through email communications included:

- Analysis Group, Inc. Assessment of Vancouver Energy Socioeconomic Impacts: Primary Economic Impacts. July, 2014
- The North Dakota Petroleum Council Study on Bakken Crude Properties, August, 2014
- August 22, 2013 Vancouver Energy Application for Site Certification
- Overall Site Plan for location characteristics
- Vancouver Energy's Preliminary Draft Environmental Impact Statement
- November 24, 2015 Draft Environmental Impact Statement
- October 30, 2015 Petition for Condemnation and Exhibits filed by the Port of Vancouver (describing the location of a planned electrical substation adjacent to the JWC property). Information regarding the function, operations and occupancy of the JWC.

The proposed site consists of a rail terminal, storage facility, and berth transfer operations all connected by two transfer pipelines which are expected to handle mid-continent North American crude oil, which is typically represented by Bakken crude. The crude supplied by rail car, will be transferred from a rail terminal to a storage facility consisting of a battery of atmospheric tanks. From there, crude will be transferred along another pipeline to a marine terminal for send-out. The provided site plan is shown on Figure 2-1 below.

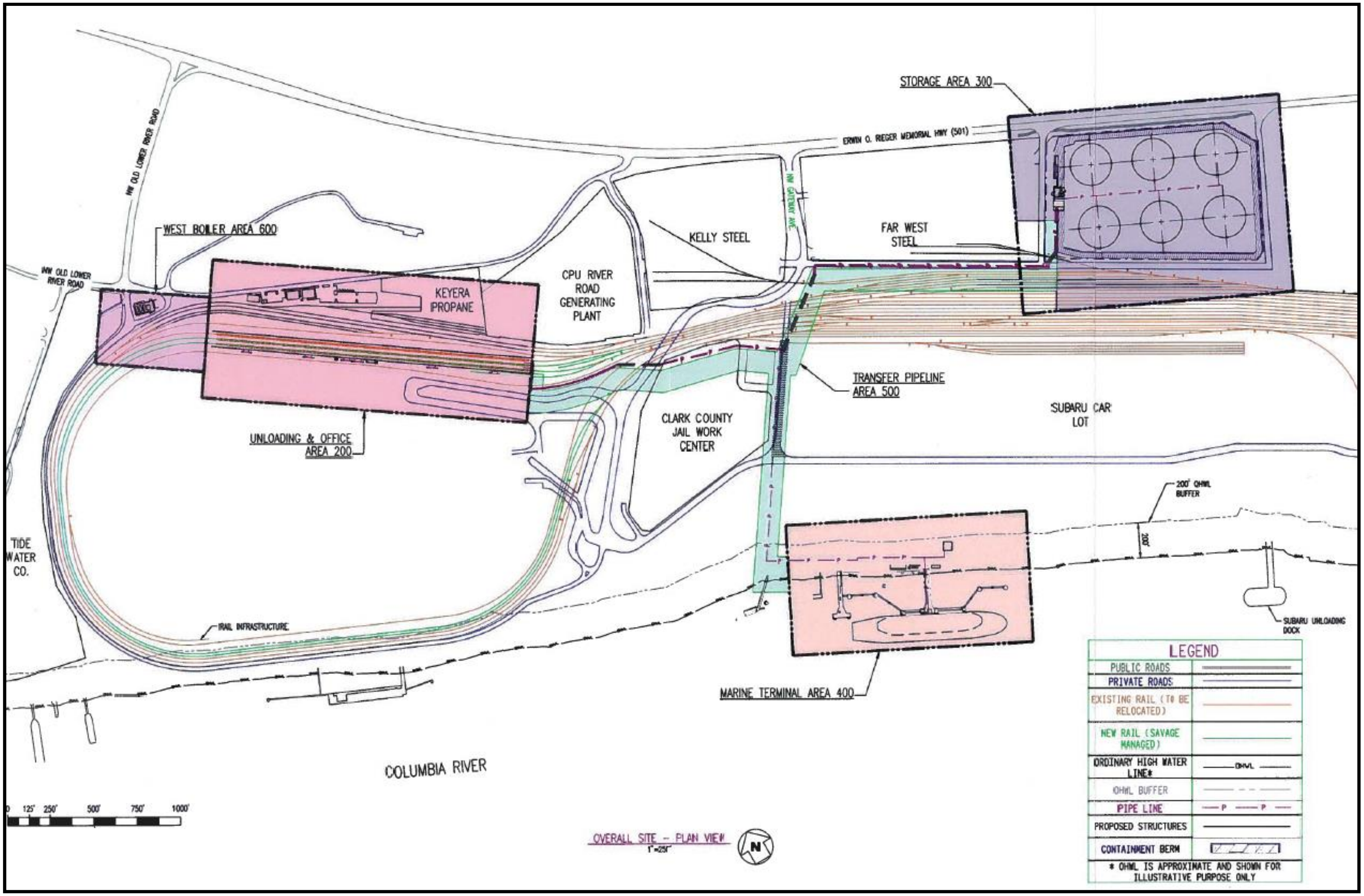


Figure 2-1 Overall Site Plot Plan

Based on the information provided from the County, it was assumed that the Bakken crude would be the likely source of the mid-continent North American crude oil delivered to the proposed facility. Based on the report of *The North Dakota Petroleum Council Study on Bakken Crude Properties, August 4, 2014* [6], the crude properties and compositions are summarized in Table 2-1 and Table 2-2.

Table 2-1 Typical Bakken Specifications

Specifications	Typical
API Gravity (hydrometer at 60°F)	42°
Vapor Pressure (ASTM D6377 @ 100°F)	11.5 psi
Initial Boiling Point (ASTM D86)	95°F
Sulfur	0.15%
Hydrogen Sulfide (H_2S)	<1 ppm
Light Ends (C2 – C4s)	5%

Table 2-2 Crude Quality based on Rail Test Results

Composition Data	Rail
API Gravity	41.7
SG	0.817
D86 IBP (°F)	100
VPCR D6377 (psi)	11.5
Light Ends (Liquid Vol. %)	
Ethane	0.23
Propane	1.39
Isobutane	0.58
n-Butane	2.75
Isopentane	1.42
n-Pentane	2.72
C2-C4s	4.95
C2-C5s*	9.10

*Excludes Cyclopentane

2.2 Scenario Identification

The objective of the study was to evaluate the potential for fire, toxic, and explosion events at the proposed terminal based on the equipment and operations of the site. A hazard evaluation was conducted to identify "credible worst case" release events which could result in potential consequences at the JWC. A total of six (6) hazardous scenarios were identified based on MMI's application of the RAGAGEP principals and experience with similar facilities. It should be noted that for the purposes of this assessment, rail and marine operations were not included as part of the scope. Thus, cases of derailment, rail crash, etc. on the rail lines, to and from the rail terminal, where not chosen as hazardous scenarios The list of consequence scenarios selected for modeling and associated properties are presented in Table 2-3 below.

Table 2-3 Scenario Definitions

Scenario No.	Scenario Origin/ Description	Site Location	Hazard Case	Fuel Component	Mass Flow / Volume	Temperature (°F)	Pressure (psig)	Release Direction	Hole Size (inches)
1	Rail Terminal – release during rail car transfer operations.	Area 200	Dispersion Pool Fire Explosion	Bakken Crude	211,000 lb	53.5	0	Horizontal	2" Most Probable
2	Rail Terminal – single car catastrophic failure.	Area 200	Dispersion Pool Fire	Bakken Crude	211,000 lb	53.5	0	Horizontal	-
3	Rail Terminal[1] – multiple rail car catastrophic failure resulting from escalation event.	Area 200	Dispersion Pool Fire (Fireball)	Bakken Crude	633,000 lb	53.5	0	Horizontal	-
4	Pipeline[2] – release during transfer from rail car to tank storage.	Area 500, North Side of JWC	Dispersion Jet Fire Pool Fire Explosion	Bakken Crude	4,220,000 lb/hr	53.5	120	Horizontal	2" Most Probable
5	Pipeline[2] – release during transfer from tank storage to marine terminal for send-out.	Area 500, East Side of JWC	Dispersion Jet Fire Pool Fire Explosion	Bakken Crude	4,220,000 lb/hr	53.5	120	Horizontal	2" Most Probable

Scenario No.	Scenario Origin/ Description	Site Location	Hazard Case	Fuel Component	Mass Flow / Volume	Temperature (°F)	Pressure (psig)	Release Direction	Hole Size (inches)
6	Storage Tanks[3] – loss of containment from tank or connected equipment.	Area 300	Dispersion Pool Fire Explosion	Bakken Crude	375,000 bbl	53.5	0	Horizontal	2" Most Probable

1. This event assumes a previous release and ignition, with thermal escalation of two adjacent rail cars. Rail Cars are assumed to be thermally degraded and fail at low pressure, contributing additional inventory to the ensuing pool fire.

2. Pipeline pressure is assumed as 8 bar_g (120 psi_g) for crude oil pipelines. Maximum capacity of four 120-car trains per day based on Analysis Group, Inc. *Assessment of Vancouver Energy Socioeconomic Impacts: Primary Economic Impacts*. July 28, 2014. Flow rate is averaged over 24 hours.

3. Tank size using storage tank API 650 maximum capacity including overfill protection.

The assumed location of each scenario is shown on the general layout drawing in Figure 2-2 below. It should be noted that the locations specified are approximate and chosen based on closest proximity to the JWC, which result in a conservative approach. In the case of transfer pipeline events, these could occur anywhere along the pipeline. For the purposes of the consequence representations, several discrete points along the pipeline have been chosen.

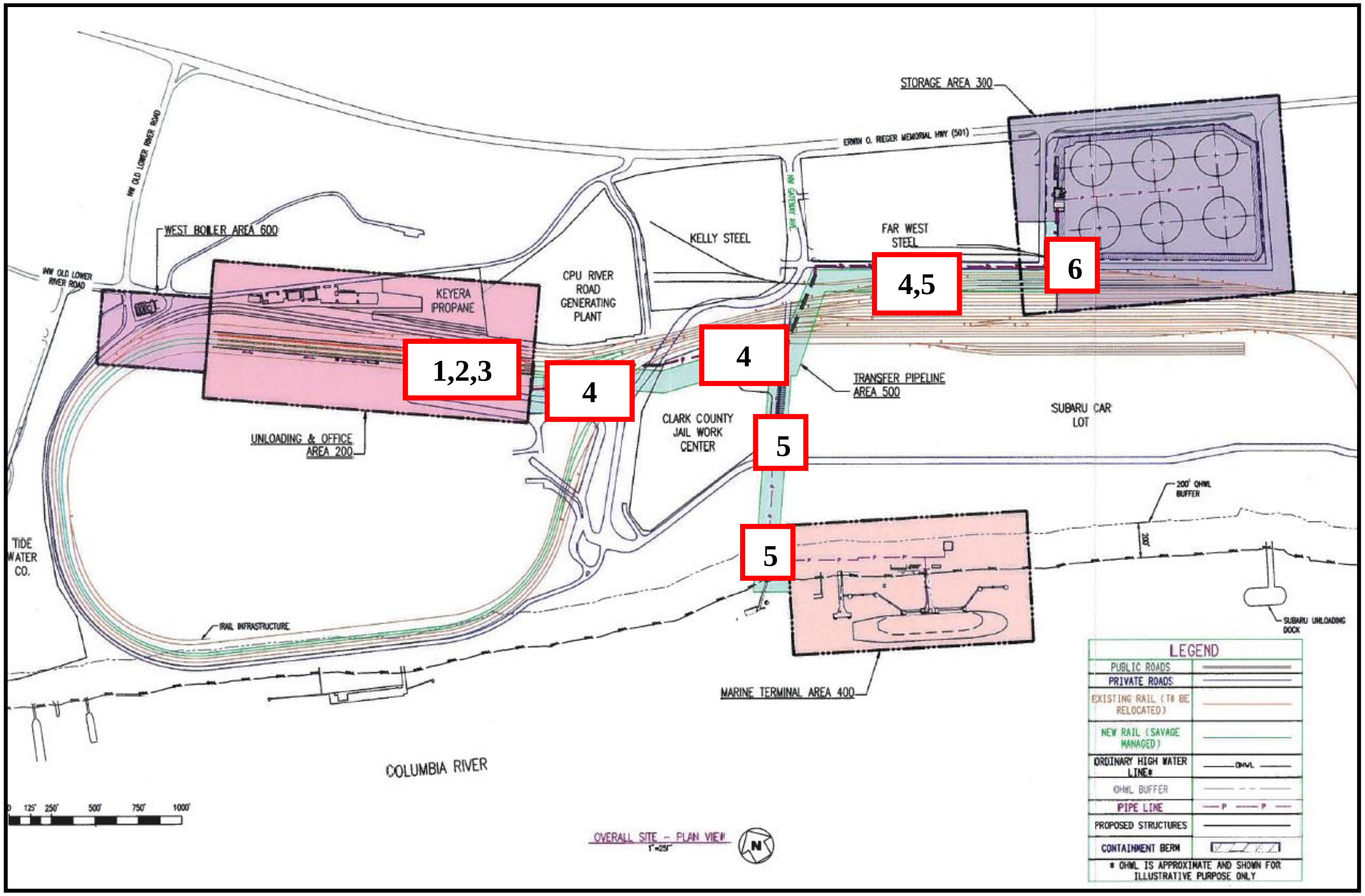


Figure 2-2 Approximate Hazard Scenario Locations

The above cases were evaluated using annual average meteorological conditions for Vancouver, WA. These conditions are summarized below:

- Average temperature: 53.5 °F.
- Average relative humidity: 73%.
- Average meteorological condition: wind speed of 4.1 m/s with Pasquill stability class D.

2.3 Consequence Criteria

This study utilized industry recognized and accepted criteria set by the following end points:

- Maximum downwind distance to lower flammable limit (LFL) and ½ LFL levels for flash fire scenarios at or near ground level.
- Maximum thermal radiation levels with impact to personnel and buildings/structures for fire scenarios.
- Maximum overpressure loads with impact to personnel and buildings/structures for explosion scenarios.

As the typical Bakken Crude contains less than 1 ppm H_2S [6] as shown in Table 2-1, which is lower than both the OSHA permissible exposure limit (PEL) and the NIOSH recommended exposure limit (REL), toxic vapor dispersion hazard was not considered in this study. If the crude composition changes (toxic material increase), toxic consequences should be re-evaluated. The summary of end point criteria is provided in Table 2-4:

Table 2-4 End Point Criteria

Flash Fire Concentration Criteria for Dispersion	
½ LFL	Maximum downwind distance range from ½ LFL to LFL for flash fire scenarios.
LFL	
Thermal Radiation Criteria for Pool or Jet Fire[1,2]	
5 kW/m²	Radiant heat intensity in areas where emergency actions lasting 2 minutes by personnel without shielding but with appropriate clothing.
25 kW/m²	Significant chance of fatality for extended exposure. Thin steel with insulation on side opposite fire may reach thermal stress level sufficient to cause structural failure. Wood ignites after prolonged exposure.
35 kW/m²	Significant chance of fatality for people exposed. Cellulosic material pilot ignition within one minute exposure.
Overpressure Loads Criteria for Explosion[3]	
0.5 psi	Typical window glass breakage
1.0 psi	Panels of sheet metal buckle
3.0 psi	Self-framing steel panel building, collapse

[1] Fire and Exposure Profile Modeling; Some Threshold Damage Limit (TDL) Data, Thomas F. Barry, TF Barry Publications

[2] American Petroleum Institute Recommended Practice 521, Pressure-Relieving and Depressurizing Systems, 5th Edition, Addendum 2008.

[3] Facility Damage and Personnel Injury from Explosive Blast, Montgomery and Ward, 1993.

2.4 Consequence Modeling Results

Consequence calculations for selected hazardous scenarios were modeled using the DNV PHAST v7 [7] software. The model calculates release rates, plume dispersion, thermal limits of pool fires and jet fires, and overpressure results based on supplied inputs. In this study, as is typical in consequence based screening assessments, the calculations represent open field; meaning, neither geometric or topography effects are taken into account. Consideration for these effects can be done on a qualitative basis as an additional screening level, but due to the limited information related to the configuration of the pipeline, it was assumed that all the pipelines are above ground with no bundings or trenches under the pipelines.

The releases were assumed to be oriented in a horizontal direction and assumed to be continuous with no mitigation measures, meaning all cases where calculated as steady state. In the case of directional events such as jet fires and downwind distance from pool fires, the maximum downwind extent was rotated and assumed possible in all directions. The summary of consequence modeling results for the different hazards are discussed below, with graphical results for each scenario contained in Appendix A.

Table 2-5 contains the potential impact results to the JWC, for each hazard type, from each of the six hazardous scenarios. In each case the end points, which have the potential to reach the boundary of the JWC, have been identified.

Table 2-5 Potential Impact to Clark County JWC from Consequence Screening Summary Events

Scenario No.	Dispersion Flash Fire	Jet Fire (kW/m2)	Pool Fire(kW/m2)	VCE (psi)
1	-	-	-	-
2	-	-	-	-
3	*	-	5	-
4	½ LFL, LFL	5, 12.5, 37.5	5, 12.5	0.5, 1, 3
5	½ LFL, LFL	5, 12.5, 37.5	5, 12.5	0.5, 1, 3
6	-	-	-	-

*While it is possible for the unignited dispersion of a multiple rail car release to reach the JWC, this event would be the result of an already assumed release and ignition, leading to escalated multi-car event. Thus the dispersion/flash fire effects are not considered credible.

2.5 Consequence Analysis Summary

The consequence summary table shows that hazardous effects from Scenarios 3-5 have the potential to affect the JWC. For Scenario 3, catastrophic multiple rail car failure, the event requires sequence of multiple failures with no, or limited, mitigations. The assumption for this event assumes a primary loss of containment from a rail car and subsequent ignition. The resulting pool fire could lead to thermal degradation of adjacent rails cars, resulting in additional supply of flammable inventory, thus increasing the size of the pool fire. It is important to note that this case assumes no bunding or localized grading/drainage around the rail cars and does not take into account additional shielding effects from the elevated roadway that separates the rail terminal and JWC. Accounting for escalation probabilities, this event would be considered a remote likelihood. Further, considering the application of design mitigations, the potential for site impacts from a multi-car event could be reduced to a negligible or manageable level.

Scenarios 4 and 5, transfer pipeline releases, have the potential to impact the JWC with respect to all hazard types. This means that a release of hydrocarbons, for events representing a 2 inch or larger release, could result in a pool fire, explosion, jet fire, or flash fire that could be hazardous to people on site and within site buildings. This is mainly due to the close proximity of the pipeline to the JWC boundary. As with the other scenarios, mitigation effects were not accounted for the in the analysis. Thus effects of localized grading/drainage, line of sight impacts, nor release monitoring were considered at this stage of the analysis. If no further analysis or design improvements were expected to be made, mitigation actions would be required to comply with 29 CFR 1910.119 and the guidance contained in API 752. At this stage, a more detailed risk based analysis, outlined in API 752 was considered and is outlined in the following sections.

3. QUANTITATIVE RISK ASSESSMENT

The Consequence Based Screening Assessment (Section 2.4 and 2.5), determined that releases from the transfer pipelines had the potential for significant impact to the Clark County JWC for all hazard types. Thus, a preliminary quantitative risk assessment of the transfer pipeline risk was conducted. A quantitative risk analysis allows increased understanding of the risk associated with the hazards and allows a relative comparison to known generally accepted risk. The following section outlines the activities conducted to determine the potential Location Specific Individual Risk (LSIR) to personnel located on the grounds and in buildings at the JWC site.

3.1 Scope

MMI conducted a preliminary quantitative risk assessment to further understand and quantify risk from major accident hazards from the proposed crude oil terminal transfer pipeline operations, to aid Clark County in its understanding of health and safety risk for the incarcerated, jail employees, and visitors at the Clark County Jail Work Center. The scope of the analysis consisted of the following tasks:

- Develop isolatable sections of process equipment based on supplied data and operational understanding.
- Conduct a release frequency evaluation of transfer pipelines based on identified hazardous events.
- Calculate consequences to the JWC based from hazardous releases (from the transfer pipelines). Consequences will be calculated for a selection of potential hole sizes, intended to represent a number of incidents/failures resulting in a loss of containment.
- Conduct a preliminary ignition probability analysis. An additional sensitivity calculation was conducted to include the potential increased ignition probability from a planned electrical substation to be located between the transfer pipelines and the JWC.
- Determine consequences to occupants of JWC site based on fatality probits and occupied building impairment criteria.
- Conduct risk calculations and determine LSIR for personnel located on the facility ground and within buildings on the JWC site.

The methodologies, input data, and assumptions for each of the above tasks are defined in detail in the subsequent sections.

3.2 Frequency Determination

3.2.1 Release Frequency Determination

3.2.1.1 Isolatable Inventories

Release frequencies were calculated based on isolatable sections, identified by assumed locations of Emergency Shutdown (ESD) and/or safety actuated control valves throughout the transfer pipeline systems. The assumed location of isolation valves was based on previous experience with similar types of facilities and operations. The number of parts (valves, flanges, length of pipe, equipment items, etc.) located within each section's inventory was multiplied by their respective item leak frequency [8] to determine a total leak frequency at a representative hole size. Figure 3-1 provides a breakdown of the proposed facility plot plan into isolatable segments that were used to carry out the risk analysis. The five (5) isolatable sections are designated as "T01" through "T05".

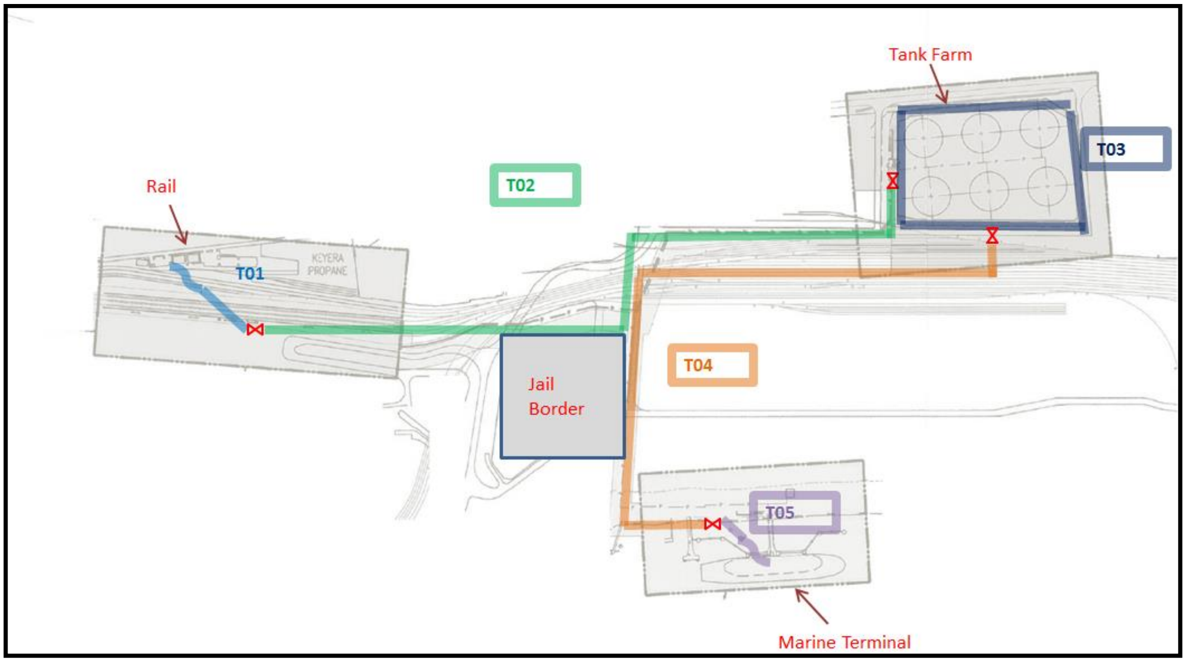


Figure 3-1: Proposed Crude Terminal Plot Plan broken down into Isolatable Segments

Table 3-1 provides inventory tag numbers along with descriptions of all the isolatable inventories used in the analysis.

Table 3-1: Isolatable Segments/Inventory Definition

Isolatable Section Inventory Tag Number	Description
T01	Hose connection from rail car to an isolation valve downstream of the rail terminal manifold.
T02	Pipeline downstream of rail terminal isolation valve to isolation valve at header of the Tank Farm.
T03	Tank farm header piping, fill and send-out lines and valving.
T04	Pipeline downstream of Tank Farm header isolation valve to isolation valve upstream of Marine Terminal manifold.
T05	Manifold isolation valve to hose connection from Marine Terminal off-loading connection.

3.2.1.2 Parts Count

The number of parts (valves, instruments, flanges, lengths of pipe, equipment items) located within each section's inventory were multiplied by their respective item leak frequency to determine a total leak frequency at a representative hole size. The representative hole sizes used in the study are shown in Table 3-2.

Table 3-2: Representative Hole Sizes

Hole size (mm)	Representative Hole size (mm)	Definition
1-3	2	Small
3-10	6	Medium
10-50	20	Major
50-150	80	Large
150+	200	Full Bore

The following assumptions were made during the parts count estimation:

- All the fixed pipe sizes and associated parts are taken as 16 inches in diameter.
- All isolation valves are to be welded. Allowance for flanges within terminal and storage manifold sections was included.
- All hose connections are flanged on the header to pipeline connection.
- The length of the hose connection and piping between the rail car and the isolation valve was assumed to be 5 meters. Similarly the length of the hose connection and piping from the isolation valve to a ship was also considered to be 5 meters. A singular connection between rail car and transfer pipeline was assumed.
- A 10% increase in frequency has been applied to allow for some variation in pipe length and equipment count, as detailed equipment information was not available at this stage of the design.

Table 3-3 provides a breakdown by hole size of the base leak frequencies.

Table 3-3: Base Leak Frequencies by Hole Size

Isolatable Inventory	Leak Frequency ($year^{-1}$) by Hole Size					
	Small	Medium	Major	Large	Full Bore	Total
T01	1.12E-03	5.64E-04	5.44E-04	2.43E-04	9.60E-05	2.57E-03
T02	1.96E-02	1.06E-02	1.31E-02	9.69E-03	9.53E-04	5.40E-02

Isolatable Inventory	Leak Frequency (year^{-1}) by Hole Size					
	Small	Medium	Major	Large	Full Bore	Total
T03	5.44E-03	7.14E-03	1.29E-02	1.05E-02	1.60E-03	3.76E-02
T05	2.27E-02	1.23E-02	1.52E-02	1.12E-02	1.10E-03	8.03E-03
T05	1.12E-03	5.64E-04	5.44E-04	2.43E-04	9.60E-05	2.57E-03

3.2.2 Fluid Properties and Operating Conditions

Fluid properties and operating conditions for each of the inventories that were used for the analysis are taken from the consequence assessment in 2 and are provided in Table 3-4.

Table 3-4: Operating conditions per Inventory

Inventory	Phase	Fluid	Pressure (psig)	Temperature (˚F)	Isolated Volume (m^3)
T01	Two-phase release	Bakken Crude	120	53.5	1
T02	Two-phase release	Bakken Crude	120	53.5	205
T03	Liquid release	Bakken Crude	Atmospheric	53.5	305826
T04	Two-phase release	Bakken Crude	120	53.5	238
T05	Two-phase release	Bakken Crude	120	53.5	1

3.2.3 Event Trees

Final event frequencies for liquid and two-phase releases are determined using an event tree approach. The event tree has two types of input, as follows:

- Base event frequency, i.e. the release frequency; and
- A set of nodal probabilities (ignition, timing, consequence type, etc.).

The event tree used for the QRA for two-phase leaks is shown in Figure 3-2 below:

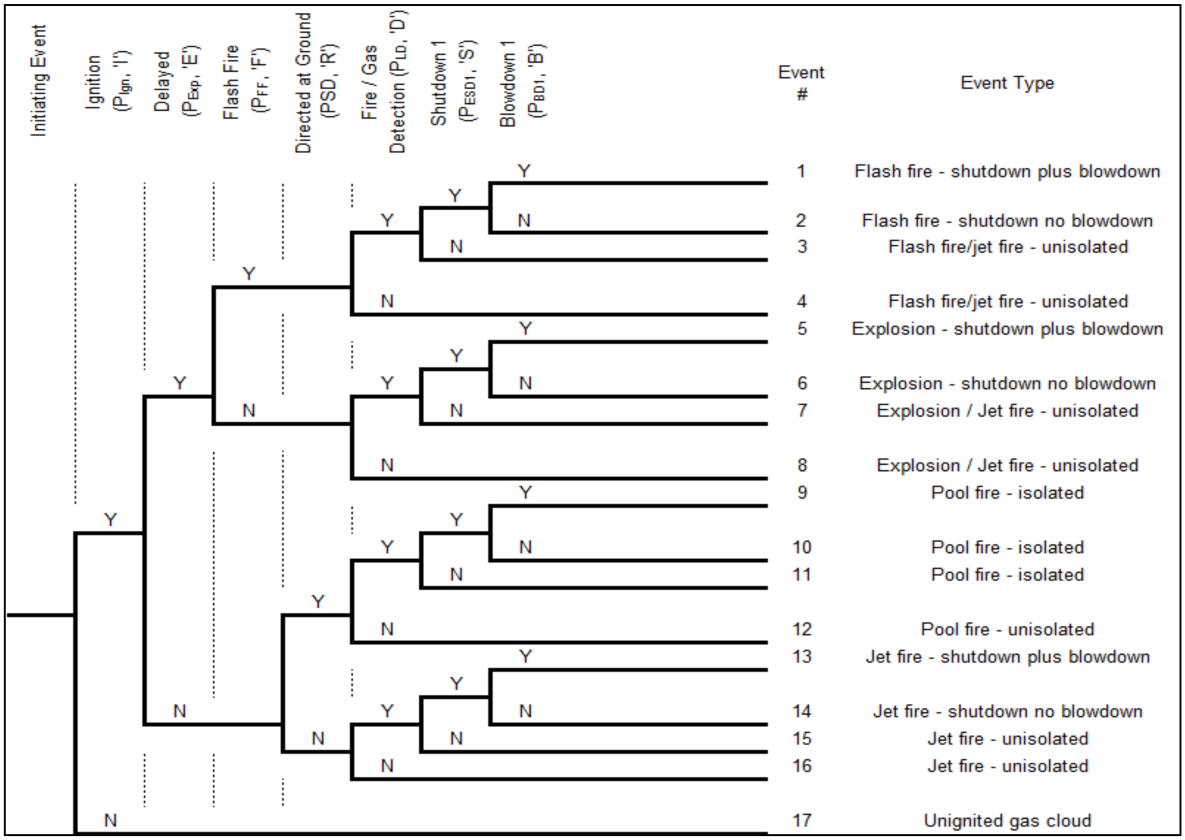


Figure 3-2: Two-Phase Release Event Tree

For this facility, there is no known blowdown system or fire and/or gas detector system and as such, these were not taken into account. Nodal probabilities for ignition and probability of failure on demand of an isolation valve in the event of a leak are discussed below.

3.2.4 Ignition Probability

MMI used the Occupational Health assist Oil and Gas UK (UKOOA) (IP) ignition model look-up correlations defined in the IP Research Report on ignition probabilities [9]. Due to the existing industrial facilities at the vicinity of the proposed site location, for the two-phase inventories, the ignition probabilities applied to this study were Look-up Correlation 1 – Pipe Liquid Industrial. For the liquid leak at the tank farm, the ignition probabilities applied were from Look-up Correlation 12 – Tank Liquid 300x300m Bund form the UKOOA ignition models.

Use of the UKOOA ignition models account for the fact that higher hydrocarbons have lower ignition energies as the correlations used are based on mass flow rate.

Based on data summarized in OREDA [10] the following distribution of consequences (given ignition) was assumed:

- Immediate Ignition, Jet Fire – 30% of ignition events
- Delayed Ignition, Flash Fire – 40% of ignition events
- Delayed Ignition, Explosion – 30% of ignition events

Probability of failure on demand of isolation valve [8], for a single isolation failure "Fail to Close on Demand", the failure rate is defined as 2 x 10^{-2} /year with a test interval assumed to be once per year.

Probability of Failure on Demand = $\lambda t/2$; [10]

Where;

λ = Annual failure rate

t = Test interval (in years)

Inventories have isolation valves both on upstream and downstream side. Therefore, the value from above equation was multiplied by 2 to take into account two valves. Hence, the probability of failure on demand of two isolation valves (minimum required for isolation from upstream and downstream inventories) is 0.0198.

3.2.4.1 Isolation Delay after the release:

It was assumed that the shutdown of an isolation valve would be a manual process and closure of the valve manually can take up to 600 seconds (10 min for manual shutdown due to operator intervention). Thus, it was assumed that normal process conditions would be sustained for this time period.

3.3 Consequence Analysis

Consequence end points were calculated in a similar manner to those described in 2 of the consequence assessment. The particulars of probit calculations for impacts to personnel and buildings are discussed in this section.

3.3.1 Heat Radiation Fatality Probability

Heat fluxes and their respective probability of fatality are detailed in Table 3-5. Chemical Industry Association (CIA) building types are taken from the Chemical Industry Association [11] and are defined as:

- Type 1: Hardened structure building: special construction, no windows.
- Type 2: Typical office block: four story, concrete frame and roof, brick block wall panels.
- Type 3: Typical domestic building: two-story, brick walls, timber floors.
- Type 4: Portable, semi-portable or fixed timber construction, single story.

Fatality probabilities to personnel outside are taken using the Eisenburg probit function [12,13,14], based on 90 seconds to escape. CIA Type 1 buildings are considered capable to withstand any fire event. Direct flame impingement for any significant duration is not considered feasible, and personnel are expected to wait out the incident. As such, the probability of fatality if located within such a building is taken as 0.

Type 2 and 3 buildings are considered to have double glazed windows, which are considered to fail at a heat flux of approximately 10 kW/m^2 [11]. Similar to Type 4 buildings, personnel are expected to evacuate at this point. They will be afforded more radiative shielding, and have a more diverse range of escape routes available. Thus, they are not considered to be at the same risk as personnel in open areas.

Type 4 buildings are expected to have single glazed windows. At a heat flux of 7 kW/m^2, single glazed windows start to crack [11], which would force personnel inside to evacuate, exposed as though he/she were located outside.

Table 3-5: Fatality Probability at Heat Flux [11]

Heat Flux (kW/m^2)	Outside	CIA Type 1	CIA Type 2	CIA Type 3	CIA Type 4
0	0	0	0	0	0
1	0	0	0	0	0
5	0	0	0	0	0
6	0.015	0	0	0	0
7	0.05	0	0	0	0.05
8	0.12	0	0	0	0.12
10	0.33	0	0.10	0.20	0.33
12	0.56	0	0.30	0.50	0.56
15	0.84	0	0.50	0.70	0.84
20	0.97	0	0.80	0.90	0.97
30	1	0	1	1	1

Heat Flux (kW/m^2)	Outside	CIA Type 1	CIA Type 2	CIA Type 3	CIA Type 4
100	1	0	1	1	1
125	1	0	1	1	1
150	1	0	1	1	1
250	1	0	1	1	1
400	1	0	1	1	1

As building construction details were not available, a conservative selection of CIA Building Type -3 was chosen for determining the thermal effects to people located inside of the 3 JWC structures.

3.3.2 Overpressure Fatality Probability

Overpressures and their respective probability of fatality are detailed in Table 3-6. CIA building types and fatality probabilities are taken form the Chemical Industry Association [11] as with those described for thermal radiation above. As with the thermal loading selection, CIA Building Type 3 was assumed for determining the overpressure effects to people located inside of the 3 JWC structures.

Table 3-6: Fatality Probability at Reflected Overpressure [11]

Overpressure (bar)	Outside	CIA Type 1	CIA Type 2	CIA Type 3	CIA Type 4
0	0	0	0	0	0
0.05	0	0	0	0.01	0.01
0.06	0	0	0	0.02	0.02
0.07	0	0	0	0.02	0.03
0.08	0	0	0	0.03	0.04
0.1	0	0	0.01	0.05	0.07
0.2	0.01	0	0.13	0.20	0.33
0.3	0.20	0	0.61	0.49	0.82
0.4	0.57	0.01	0.72	0.57	0.89
0.5	0.68	0.07	0.82	0.64	0.95
0.6	0.79	0.57	0.90	0.69	1
0.7	0.88	0.66	0.93	0.76	1
0.8	0.95	0.78	0.96	0.81	1
0.9	1	0.88	0.99	0.88	1
1	1	1	1	0.93	1
20	1	1	1	1	1

For personnel outside, overpressure may cause harm due to whole body displacement, or due to a missile or projectile picked up by the blast wave. A person must survive both events to not be considered a fatality following a hazards event.

At an overpressure of 0.21 bar, a 1% fatality probability is taken for whole body displacement, whereas no fatalities due to missiles or projectiles are anticipated [13]. The probabilities of fatality due to missile and whole body displacement increase with increasing overpressure leading to 100% probability of fatality at 0.9 bar [13].

3.3.3 Release Rate Calculation

Given a release, the maximum sustainable flow is considered to be equal to that flowing through the system during normal production. Large releases therefore quickly equilibrate to this release rate. Upon activation of isolation, the release rate decays. For gases, and liquids with a gas head driving pressure, this flow rate decays exponentially when isolation is activated. For liquids without a gas head to drive the fluid out of the system, the flow reduces to a nominal value.

Figure 3-3 shows a generic representation of the pressure decay and release rate decay over time as inventory is depleted and isolation is activated. Note, that this figure provides an additional decay rate supplied by the initiation of Blowdown systems. For this assessment and as would be typical for liquid pipelines, no blowdown systems were included in the analysis. Thus, rate decay following isolation would be due to system pressure and inventory loss.

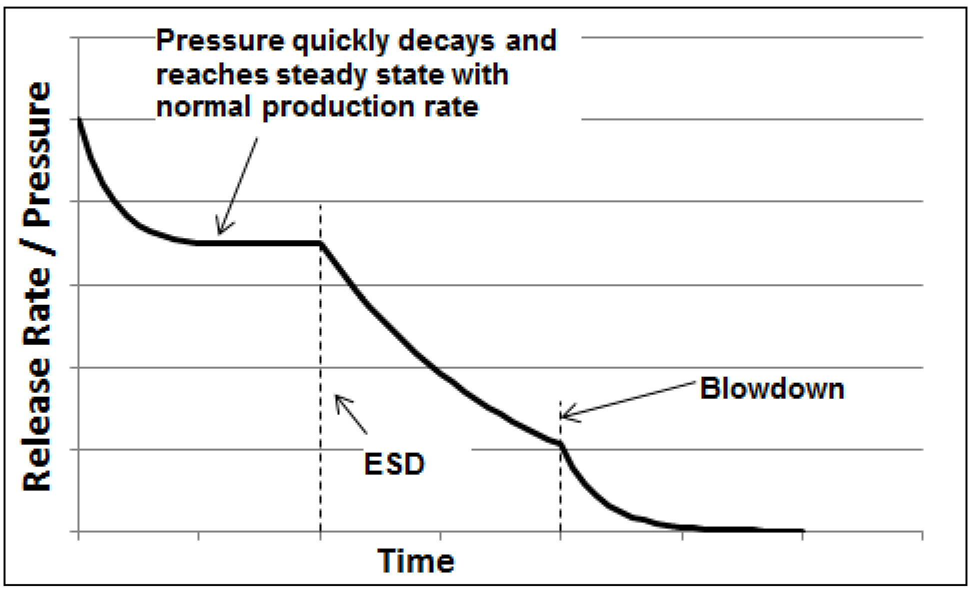


Figure 3-3: Generic Release Rate / System pressure versus Time profile modeled for each inventory hole size and shutdown condition

3.3.4 Dispersion Assessment

Steady state gas cloud sizes were estimated using the DNV PHAST methodology [15]. Horizontally obstructed leaks were simulated at 2 m elevation. Where a release had the potential to rain out (liquid on ground), a pool and subsequent cloud were considered.

3.3.5 Jet/Spray Fire Assessment

Jet fires were modeled using DNV PHAST's [15] Cone model, based on a horizontal release at 2 m elevation. A directional probability of 1/6 was considered to account for a jet oriented in each of 6 directions (up, down, N, E, and S, W).

3.3.6 Pool Fire Assessment

Based on the results of the previously conducted consequence assessment, it was determined that the jet/spray fire consequences were greater than the pool fire consequences for all hole sizes and events considered in the QRA. Thus, pool fires were not explicitly modeled and the consequence probability was shifted to the jet/spray fire case.

3.3.7 Explosion Assessment

Fatalities from explosion are addressed in two ways: (1) all personnel located within the gas cloud at ignition are considered to be immediate fatalities and (2) personnel not in the gas cloud will be subject to an overpressure, which may also cause fatality. Since an explosion represents a delayed ignition, personnel are assigned a 50% escape probability as they will likely be alerted by alarms, hear or see the release prior to ignition.

Explosions were modeled using The Netherlands Organization of Applied Scientific Research (TNO) multi-energy method [14] (as used in PHAST). The size of the gas cloud was limited to either a steady state gas cloud, or the maximum gas cloud that could form due to the mass released over a period of 5 minutes. For the purpose of calculating overpressure, only the portion of the cloud that was located within a congested volume was considered in the energy calculations.

Congested volume or congestion, is defined as the fractional area in the path of the flame front occupied by equipment, piping, fittings and other structures such as buildings and supporting columns. For each area of plant, a maximum congested volume was considered that could give rise to significant overpressure. Gas cloud fractions located outside of the congested area do not contribute to overpressures generated at a distance from the explosion.

The TNO ignition curve selected for each area was based on the assessment technique described in the TNO Yellow Book [14].

Based on results from consequence modeling, explosions due to potential releases from rail and tank farm are not expected to have an effect on the JWC, hence TNO curve 1 was used for inventories T01 and T03. For transfer piping around JWC, consequence modeling results determined a maximum potential pressure of 3 psi, hence TNO curve 5 was conservatively selected which corresponds to 0.4 bar.

3.3.8 Flash Fire Assessment

The gas cloud size for flash fires was calculated in a similar manner as that for explosions. All personnel located in an ignited gas cloud were considered to be immediate fatalities, however a 50% escape probability based on engineering judgment was assigned to account for personnel being alerted to, hearing, or seeing the release prior to ignition.

3.4 Risk Determination

QRA model was used to calculate Location Specific Individual Risk per annum (LSIR). LSIR is the probability of a fatality if located in a particular area for 24 hours a day, 365 days a year. LSIR was calculated for each inventory using the event trees shown in Figure 3-2.

3.4.1 QRA Results

3.4.2 QRA Base Case

The base case risk results for the JWC estimated LSIR as 2.35 $x10^{-5}$ /year for people outside and 1.62 $x10^{-5}$ /year for people within the site buildings. Table 3-7 and Table 3-8 provide a breakdown of LSIR by event type. It is important to note, that the risk from explosions to people located outside is effectivily zero while the risk from explosion to people within buildings is on the order of 10^{-8} /year. This is because the probit for people in the open allows for higher pressures than people within certain structures. While a person can survive high blast wave effects outside, a building may collapse at the same load, increasing the likelihood of a fatality.

Table 3-7 LSIR /year per Event type - Outside

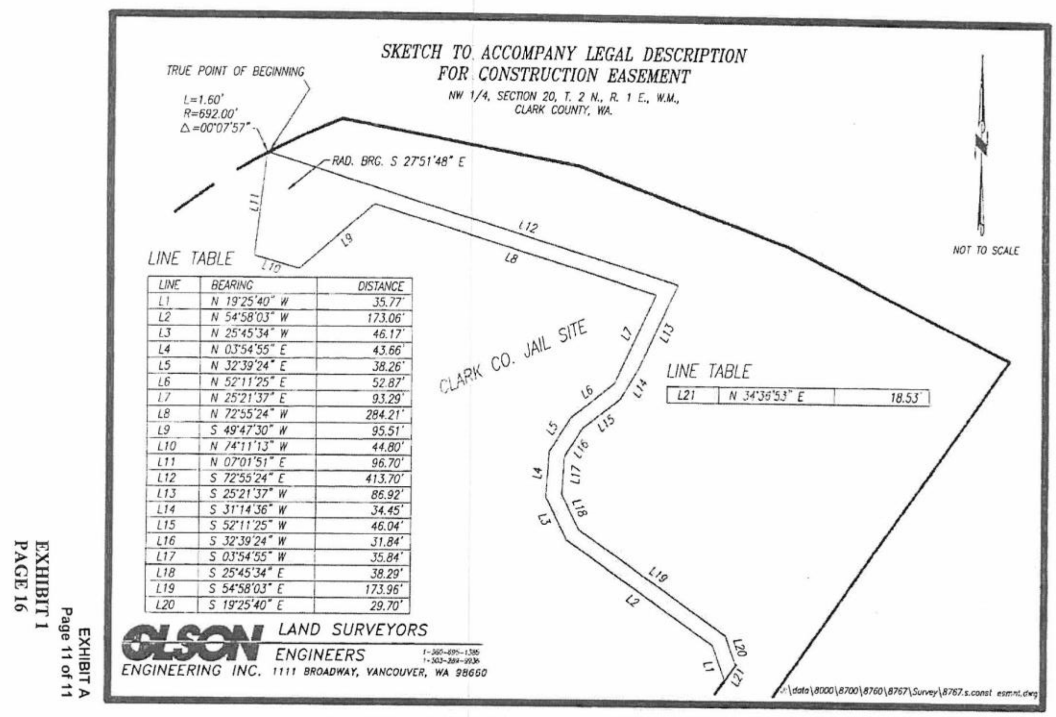
Event Type	LSIR (/year)
Jet Fire	1.08×10^{-5}
Pool Fire	0
Explosion / Flash Fire	0
JF + Explosion / Flash Fire	1.27×10^{-5}
Total	**2.35 $x10^{-5}$**

Table 3-8 LSIR /year per Event type – CIA Building Type-3

Event Type	LSIR (/year)
Jet Fire	7.44×10^{-6}
Pool Fire	0
Explosion / Flash Fire	1.09×10^{-8}
JF + Explosion / Flash Fire	8.80×10^{-6}
Total	**1.62×10^{-5}**

3.4.3 QRA Sensitivity – Electrical Substation

It was communicated to MMI that there is a plan to install an electrical substation in the north-east corner of the JWC. For purposes of verifying the planned location of this electrical substation MMI relied upon the Port of Vancouver's Petition for Condemnation and accompanying exhibits. Additionally, DEIS maps of the proposed terminal site appear to reflect the future location of the planned substation. The following diagram from the Port of Vancouver's Petition for Condemnation sets forth the location of the proposed substation in what is currently the north eastern corner of the JWC property.



The inclusion of this type of equipment can increase the probability of ignition of flammable releases. To account for this, a sensitivity of the risk assessment was conducted in which ignition probabilities were modified to account for the location of a substation between the proposed transfer pipelines and the JWC.

UK HSE and CCPS [16,17] provide some guidance on the quantification of ignition probabilities. While most of the guidance is specific to on-site equipment, there are discussions and recommendations provided for off-site equipment/facilities. Electrical substations are a relatively typical equipment package located in an industrial site, as such, a range of ignition probabilities is given from negligible (0) to 0.5+. This range is due to significant differences in substation design across different applications. As the details are unknown for this application, a conservative ignition probability of 0.1 was taken as a facility with "typical" quality of ignition controls. For each release, in which the flammable limits had the potential to reach the substation the ignition probability was modified to 0.1. This provides a significant (minimum order of magnitude) increase in ignition probability that if the base UKOOA correlation was used.

Following this modification, the sensitivity case LSIR results for the JWC were estimated as 3.64 $x10^{-5}$ /year for people outside and 2.45 $x10^{-5}$ /year for people within the site buildings. Table 3-9 and Table 3-10 below provide a breakdown by event type for each case.

Table 3-9 LSIR /year per Event type (w/Electrical Substation modification) - Outside

Event Type	LSIR (/year)
Jet Fire	1.67×10^{-5}
Pool Fire	0
Explosion / Flash Fire	0
JF + Explosion / Flash Fire	1.97×10^{-5}
Total	**3.64 $x10^{-5}$**

Table 3-10 LSIR /year per Event type (w/Electrical Substation modification) – CIA Building Type-3

Event Type	LSIR (/year)
Jet Fire	1.12×10^{-5}
Pool Fire	0
Explosion / Flash Fire	1.80×10^{-8}
JF + Explosion / Flash Fire	1.32×10^{-5}
Total	**2.45 $x10^{-5}$**

4. CONCLUSIONS

MMI conducted a series of concept level consequence and risk based screening calculations for a proposed crude terminal and storage facility. The site, which consists of a rail terminal, tank farm, marine terminal, and transfer pipelines is to be collocated to the Clack County Jail Work Center. The analysis was conducted in two stages:

- A preliminary consequence based screening assessment in which potential hazards were identfied and consequence end points were calculated for identified worst credible scenarios. From the results of this assessment, it was identified that transfer pipeline events posed the greatest likelihood of impacting the JWC site.
- Second, a quantitative risk assessment of the transfer pipelines was conducted in order to increase the understanding of poential risk and develop preliminary concept level risk metrics for people on-site and within buildings of the JWC. An additional sensitivity was conducted which included modifications to ignition probabilities from a proposed electrical substation.

The consequence results, show that a catastrophic multi rail car event, in the rail terminal during transfer operations, could produce consequences that could reach the JWC. While historical incidents of these types of events can be found for crude rail operations, they typically involve additional influences which would not be expected at this site (e.g. high speeds and derailment). The event in question, would arise as the result of a primary failure during transfer operations, resulting in an unbounded release of hydrocarbons to the ground with subsequent ignition. The resulting fire could then have the potential to impact more than one additional rail car, leading to additional failures and additional inventory to the primary fire event; the result, being a large uncontained fire. This event, requires multiple failures and, in general would be considered a remote likelihood, if mitigation and safety measures typical of hazardous rail operations were considered. It is important to note that MMI's analysis and conclusions regarding the likelihood of rail events were limited to its assessment of threats to the JWC property and should not be extrapolated to other scenarios.

Transfer pipeline events, due to their proximity to the JWC, provide the most likely hazard to the JWC. The consequence calculations show that unbounded events from the pipelines have the potential to impact the JWC for all hazard types.

4.1 Risk Metrics

In order to further understand the potential risk posed from the crude terminal operations a follow-on quantitative risk assessment was conducted, with the focus being on transfer pipeline operations. As the design is in concept stages, the conservative consequence evaluation was adopted for the risk assessment to develop a bench mark risk profile.

The US has not adopted explicit land use planning risk criteria but rather typically relies on development and evaluation of criteria on an individual project and location basis. It is common to use metrics from other countries as a reference; such as the UK Health and Safety Executive and the Netherland External Safety Decree [18,19]. In these cases, risk is typically addressed as a function of Societal Risk (F-N curve). This evaluation requires detailed information about population distributions in both time and location and categorization of population types. In concept level evaluations, if this information is not readily available, then the metric of Individual Risk per Annum (IRPA) and Location Specific Individual Risk (LSIR) are used for evaluation.

In the UK HSE guidance, a risk level of 1 in a million ($1\ x10^{-6}$ /year) would generally be considered "broadly acceptable". Subsequently a risk level of 1 in ten thousand ($1\ x10^{-4}$ /year) would generally be considered "tolerable if ALARP". Where ALARP is the practice of developing and applying risk reduction methods in an effort to levels of "As Low As Reasonably Practicable".

In this analysis, population distributions, categories, and details of time spent on site and in specific locations was not available. Thus, the risk metric calculated was for LSIR. In the absence of population specific data, the assumption of a person located on the site 24 hours a day, every day would result in individual risk being equal to the location specific risk.

The LSIR for the JWC site was calculated at values in the range of $1.62 - 2.35\ x10^{-5}$ /year for the base case model and $2.45 - 3.64\ x10^{-5}$ /year for the sensitivity case (electrical substation modification). The dominate contributor to the risk from the pipeline are related to hazards from jet/spray fires.

While UK HSE typically refrains from using only individual risk for a decision basis, it can be used as an indicator in preliminary screening to aid in forward decision making. In the case of most housing developments, UK HSE advises against granting planning permission for any significant development where individual risk of death for a hypothetical person is more than 10 in a million per year (1 x10-5 /year) [18]. The concept level risk from the transfer pipeline indicates an elevated risk presence above this level. As evaluated, in concept form and with no mitigation considerations, the risk would be considered generally unacceptable for off-site facilities such as the JWC. Based on experience, with the application of inherently safer design measures and through ALARP mitigation efforts, it would be expected that risk to the JWC could be shown to be in the broadly acceptable range. This assumption, includes consideration for increased detail in the analysis as design details are refined, reduction of conservative assumptions, and inclusion of detail population data for the development of societal risk calculations.

The following section outlines recommendations that should be considered for future analysis and for application in the design to reduce risk to the JWC, if the project progresses.

4.2 Recommendations

As is, the current consequence and risk assessments utilized several conservative assumptions, consistent with a concept level design assessment. Modification of these, as the design progresses and greater design details become available, could serve to show reduced risk to people on the JWC site. This includes but is not limited to: refinement of the directional probabilities, process conditions, location of pipelines and length, building types, site location limits, equipment counts, etc.

This assessment did not take into account mitigation measures which could be implemented or may be included into the design, to reduce and manage risk to the JWC. Based on the hazards and risk identified in this analysis several mitigation and design considerations have been developed and are discussed below. Note, that the following lists are not exhaustive coverage of all potential mitigation measures which could be used to reduce risk and may not all be required for implementation to reach risk reduction goals.

4.2.1 Mitigations for consequences resulting from the release and spread of hydrocarbons from Transfer Pipeline.

The following recommendations have been developed for consideration to address mitigations for consequences resulting from releases and the spread of hydrocarbons from the crude transfer pipelines:

- Use of secondary containment for liquids which could include the use of double-walled piping or placement of piping within secondary containment structures
- Burying the pipeline
- Manage corrosion through appropriate material selection and use of coatings
- Minimize the use of flanges and utilize welded pipe as possible

- Minimize the use of small bore or instrument fittings
- Employ long-term condition- based monitoring; especially for fatigue due to vibration
- Localized bunding and grading throughout transfer pipelines
- Shielding effects from thermal radiation (including the addition of thermal barriers)
- Impact protection - Since there are roadways present around the JWC and proposed pipeline runs, there is a potential for motor vehicle impact. Impact would be a likely cause for incidents depending on the amount and type of vehicle traffic. Signage, bollards, adjustments to speed limits, and safety training should be considered.

4.2.2 Mitigations for consequences resulting from the release and spread of hydrocarbons from Terminal areas.

The following recommendations have been developed for consideration to address mitigations for consequences resulting from releases and the spread of hydrocarbons from the crude terminal:

- Area grading and bunding to control containment
- Local drains/sumps under loading/unloading areas
- Documented procedures for unloading – as connection of hoses and unloading processes have a high rate of failure
- Documented inspection requirements/procedures for flexible hoses and pipeline.
- A collaborative emergency response procedure should be in place which includes site personnel and local emergency response (fire) – which also has communication with the JWC as to what they should do. An education for them is a risk mitigation tactic. This should also consider adding an additional emergency escape route to the South; away from the pipeline should the need to evacuate arise.

4.2.3 Mitigations for the mitigating ignition probability and consequences resulting from the location of the proposed electrical substation near the JWC.

The following recommendations have been developed for consideration to address mitigation for consequences resulting from the potential presences of increased ignition likelihood due to the colocation of an electrical substation and the JWC.

- Provide a minimum separation of 250 feet between terminal infrastructure and the electrical substation (if pipeline is not buried).
- Minimizing the potential releases – physical mitigations of limiting flanges or welding pipelines, regular inspection, grading under pipeline to limit pool surface area, deflector shielding against spray jets (see Section 4.2.1)
- Minimizing ignition sources at the substation (all relative to the design) and in the vicinity of the pipeline.
- Early warning, detection of a leak to initiate shutdown and development emergency procedures between the terminal operations and the JWC site.

4.2.4 General Considerations

The level of mitigations required are dependent on the composition and properties of crude transported through the terminal. If the proposed terminal brings in other variations of crude (such as the presence of toxics in higher concentrations) or other types of products, further evaluation should be considered to properly identify risks and mitigations.

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APPENDIX A

GRAPHICAL CONSEQUENCE SCREENING RESULTS

The following figures and their contours represent the extents of consequence endpoints related to hazards of the crude terminal, storage, and transfer operations. The contours are shown as discrete approximate locations. In each case a potential release and hazard could emanate anywhere from a set of equipment within a given area. Thus, the plotted potential contours cloud be extended to other areas of the map. An example of this would be an event originating from the transfer pipelines. A single location, selected close to the Clark County Jail Work Center (JWC) was chosen for display purposes only and is shown in the figures below. A release could occur at any location along the transfer pipeline, thus the effect contours shown could be translated to other areas along the pipelines.

1. Rail Terminal – Release during Rail Car Transfer Operations

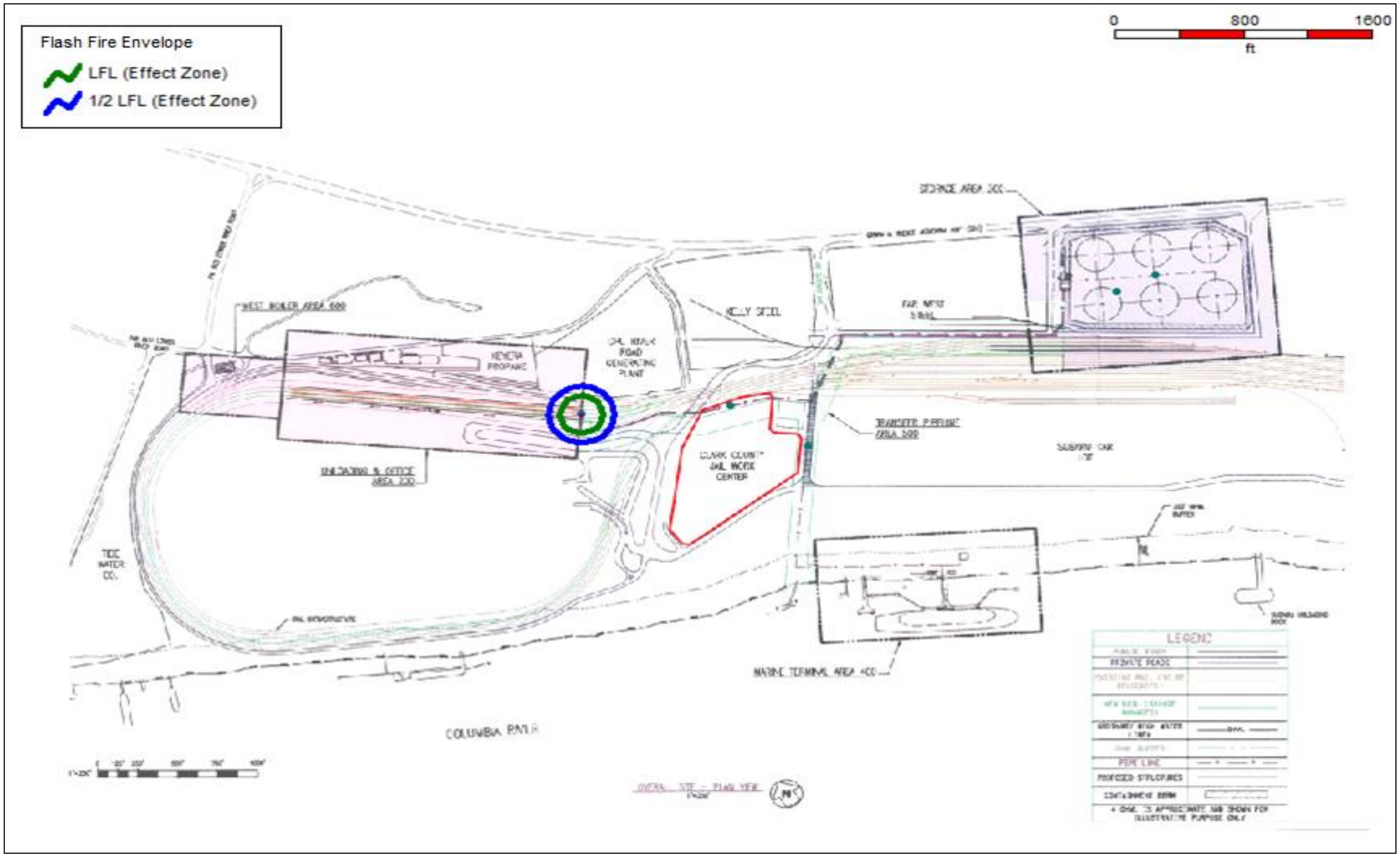

Figure Error! No text of specified style in document.**-1 Rail Tanker Release – Flash Fire Contour**

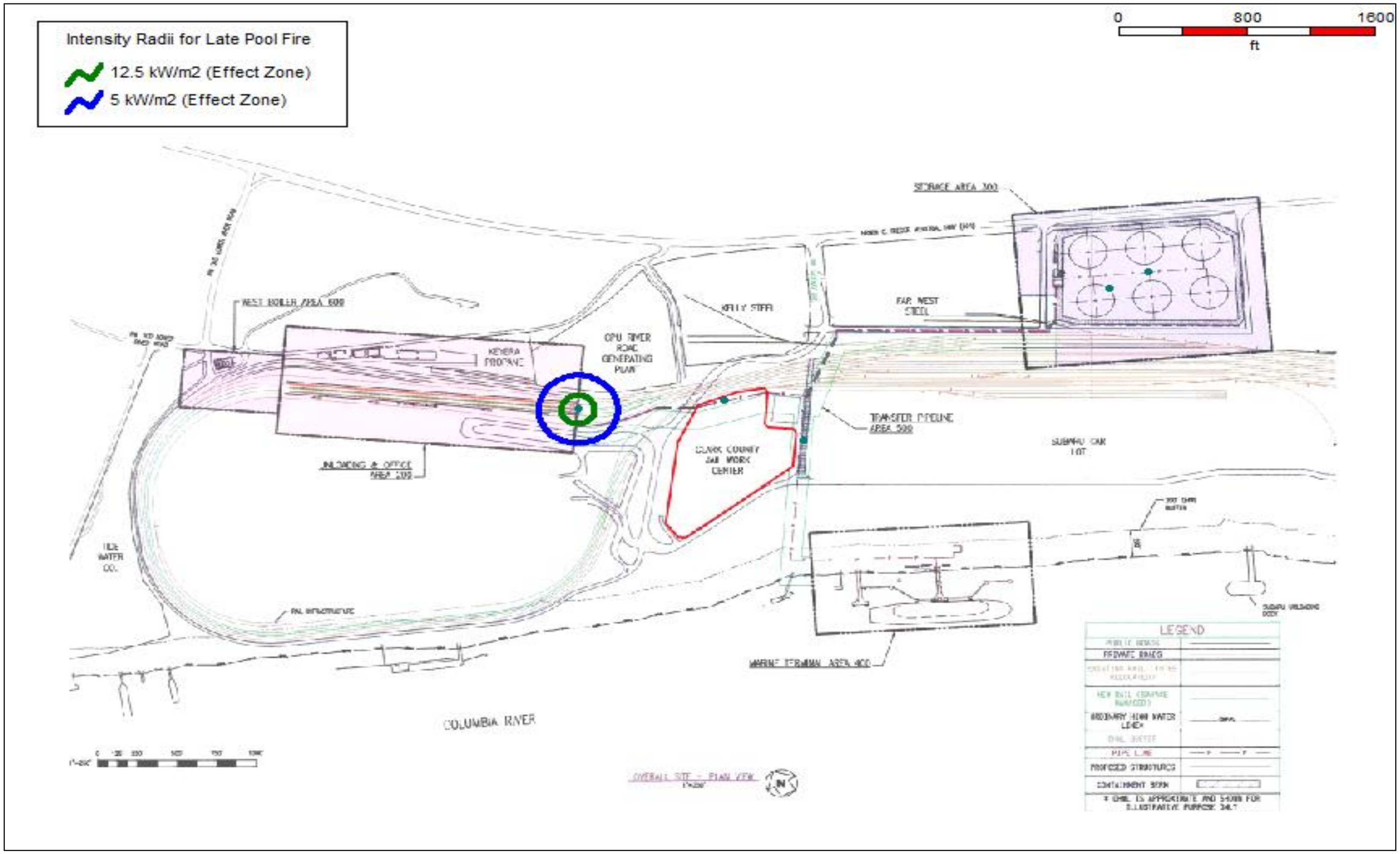

Figure Error! No text of specified style in document.**-2 Rail Tanker Release – Pool Fire Contour**

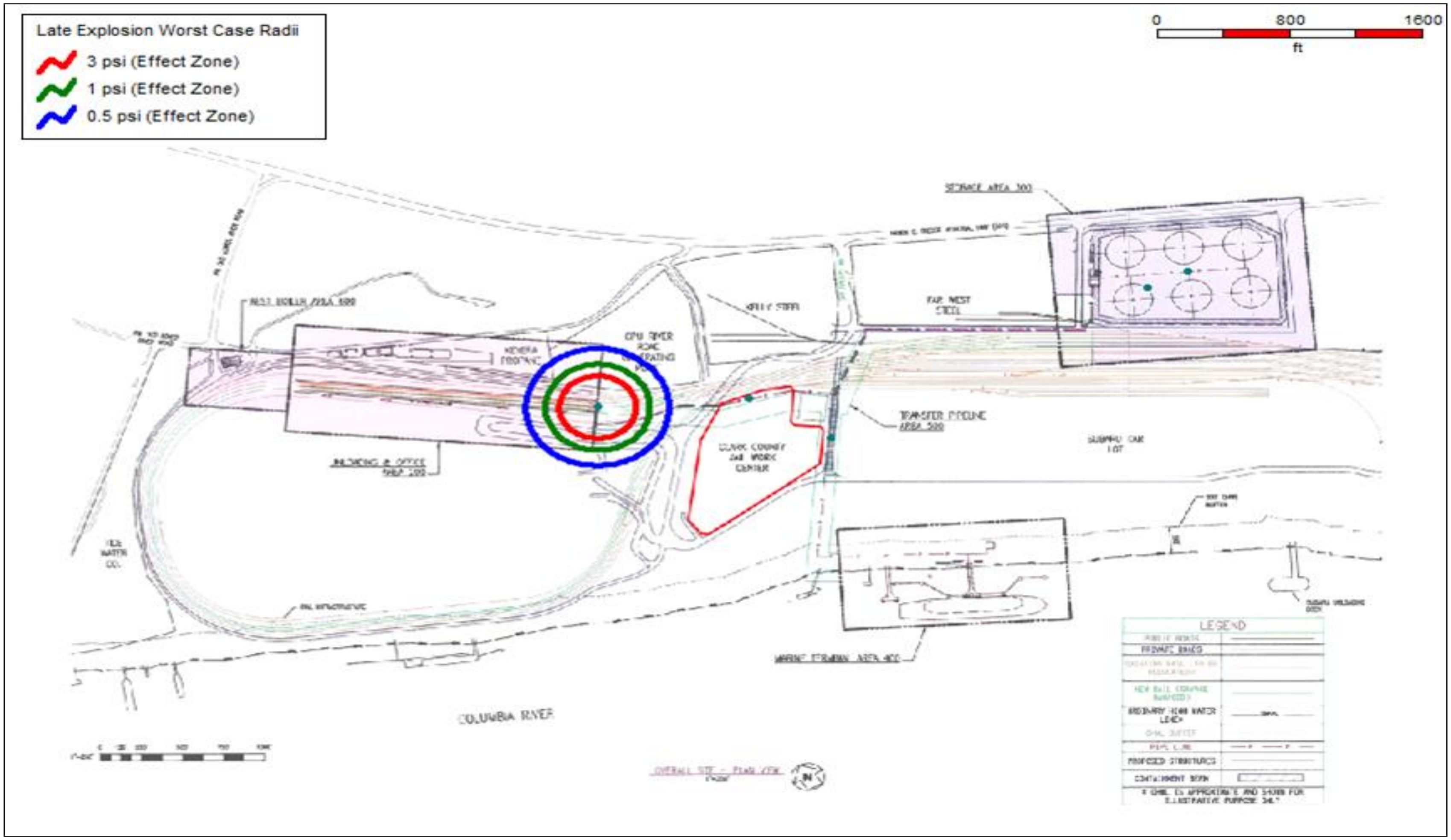

Figure Error! No text of specified style in document.**-3 Rail Tanker Release – Explosion Contour**

2. Rail Terminal – Single Car Catastrophic Failure

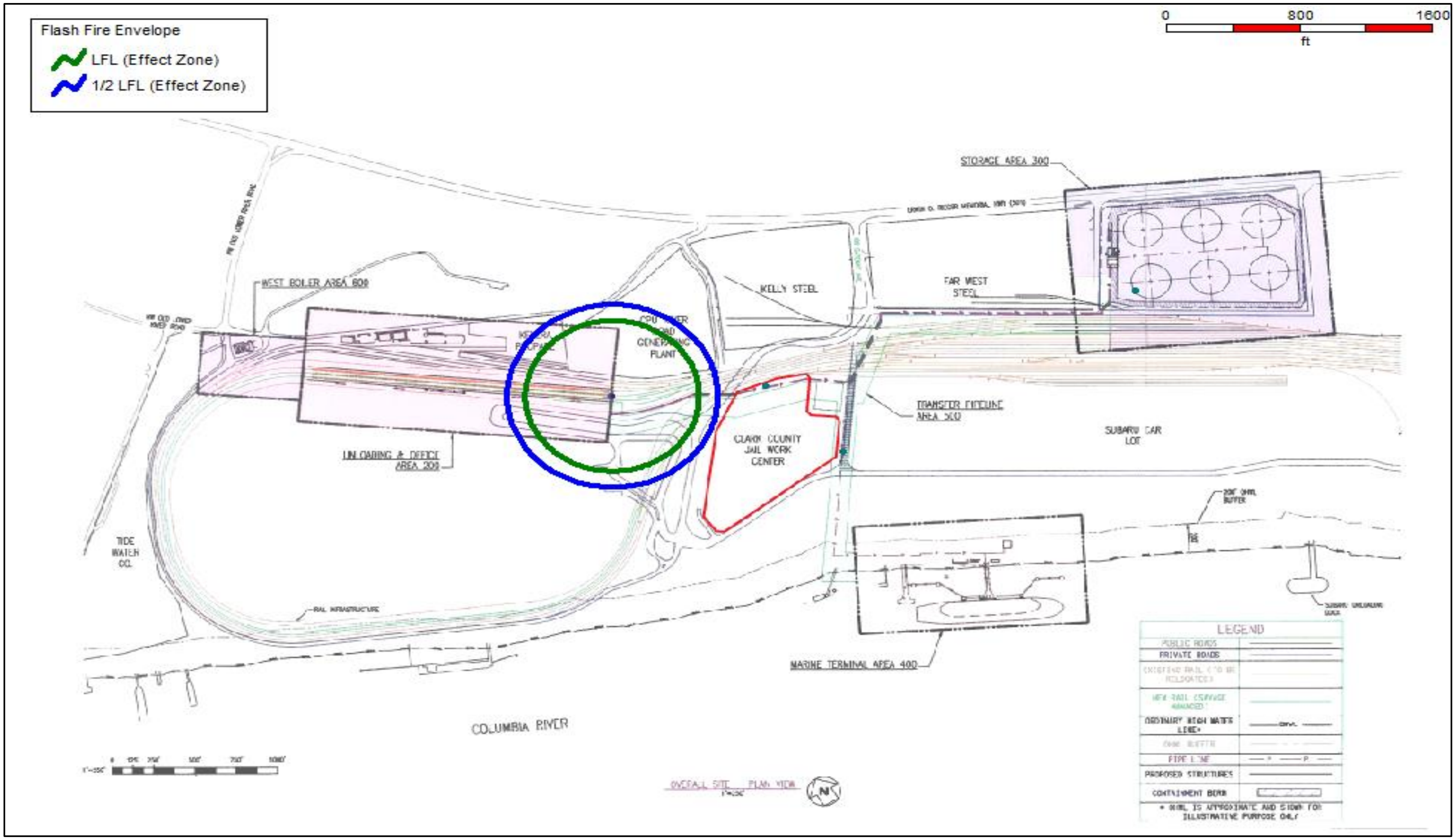

Figure Error! No text of specified style in document.**-4 Single Car Catastrophic Failure – Flash Fire Contour**

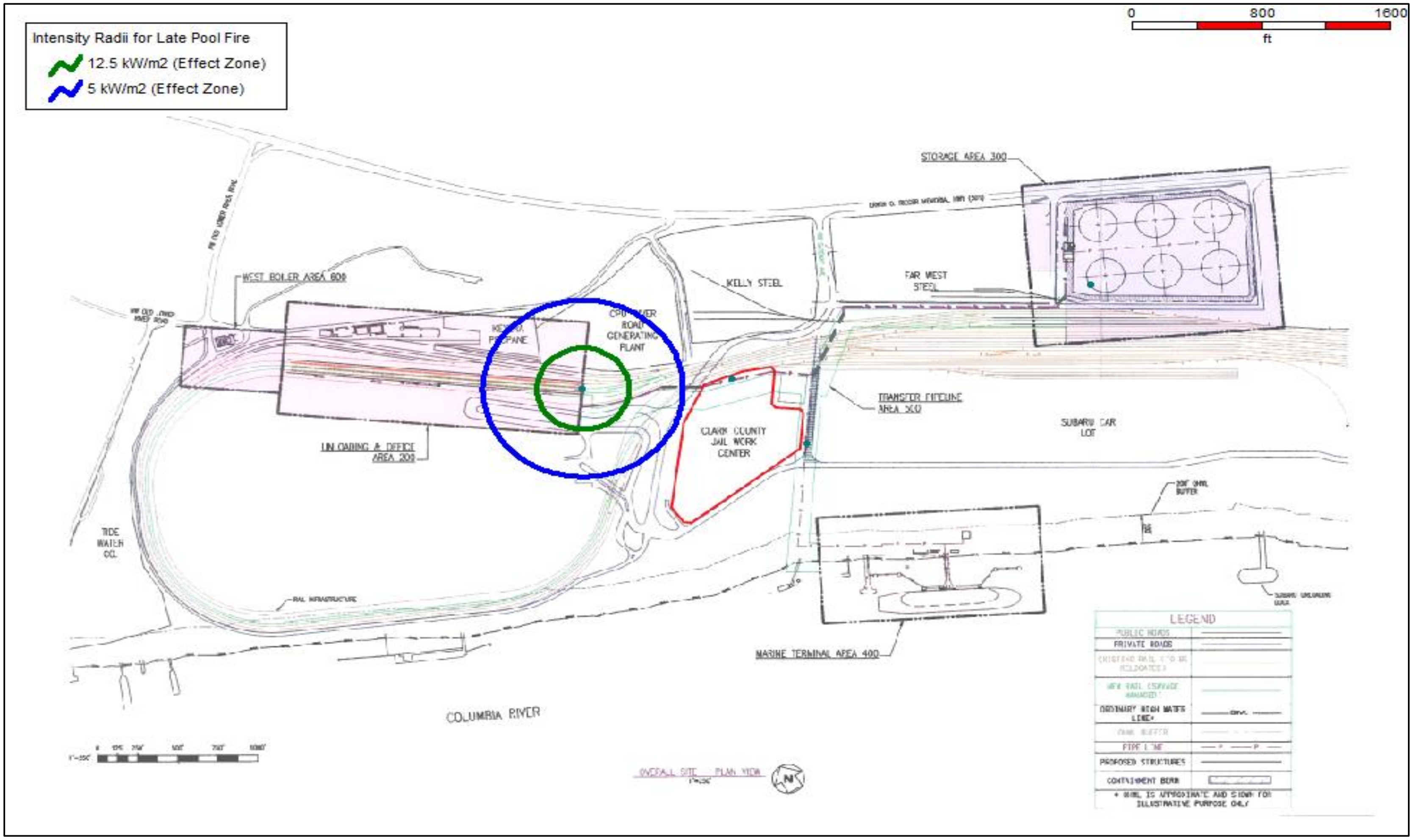

Figure Error! No text of specified style in document.**-5 Single Car Catastrophic Failure – Pool Fire Contour**

3. Rail Terminal – Multiple Rail Car Catastrophic Failure from Escalation Events

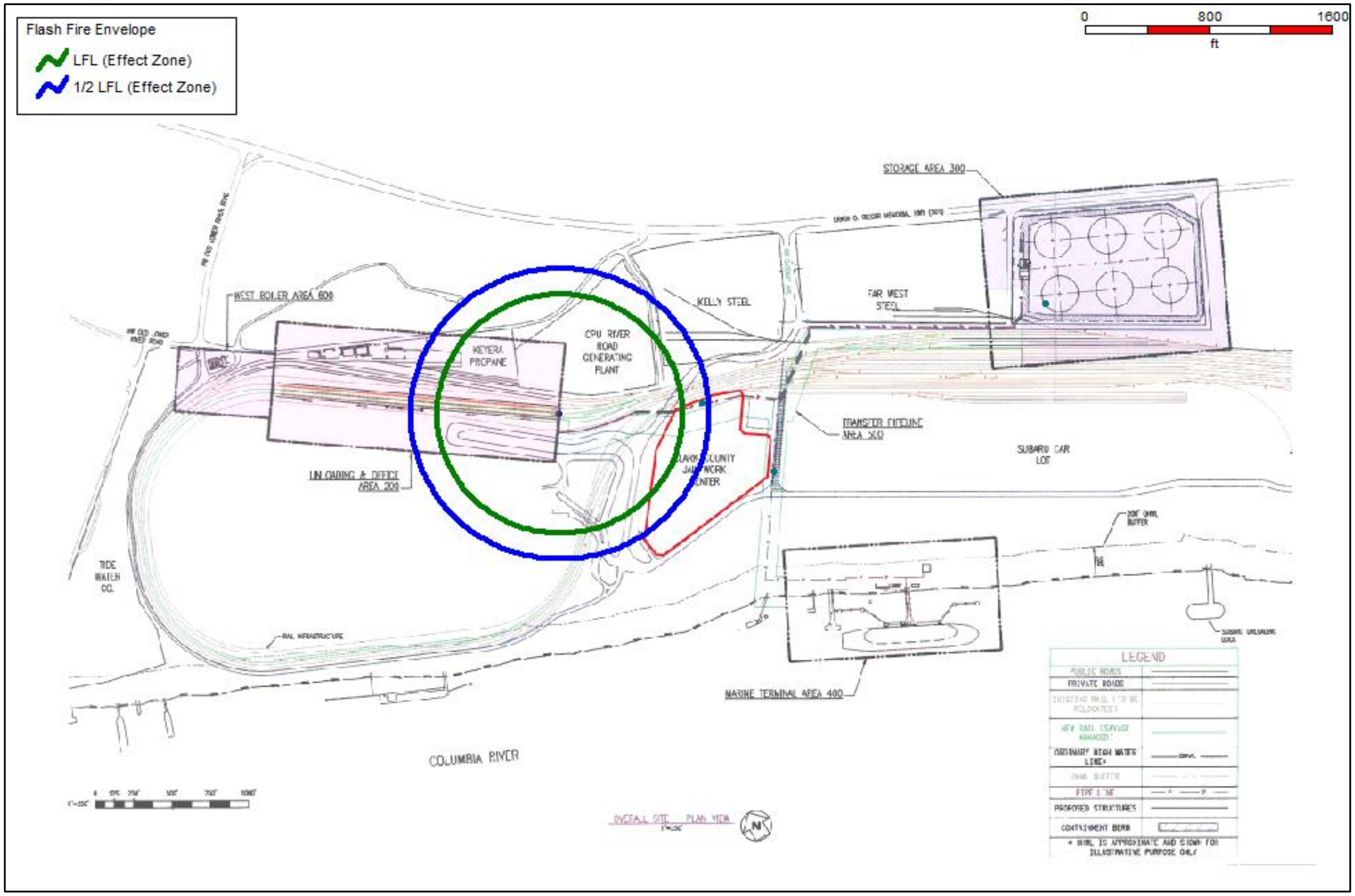

Figure Error! No text of specified style in document.**-6 Multiple Rail Car Catastrophic Failure – Flash Fire Contour**

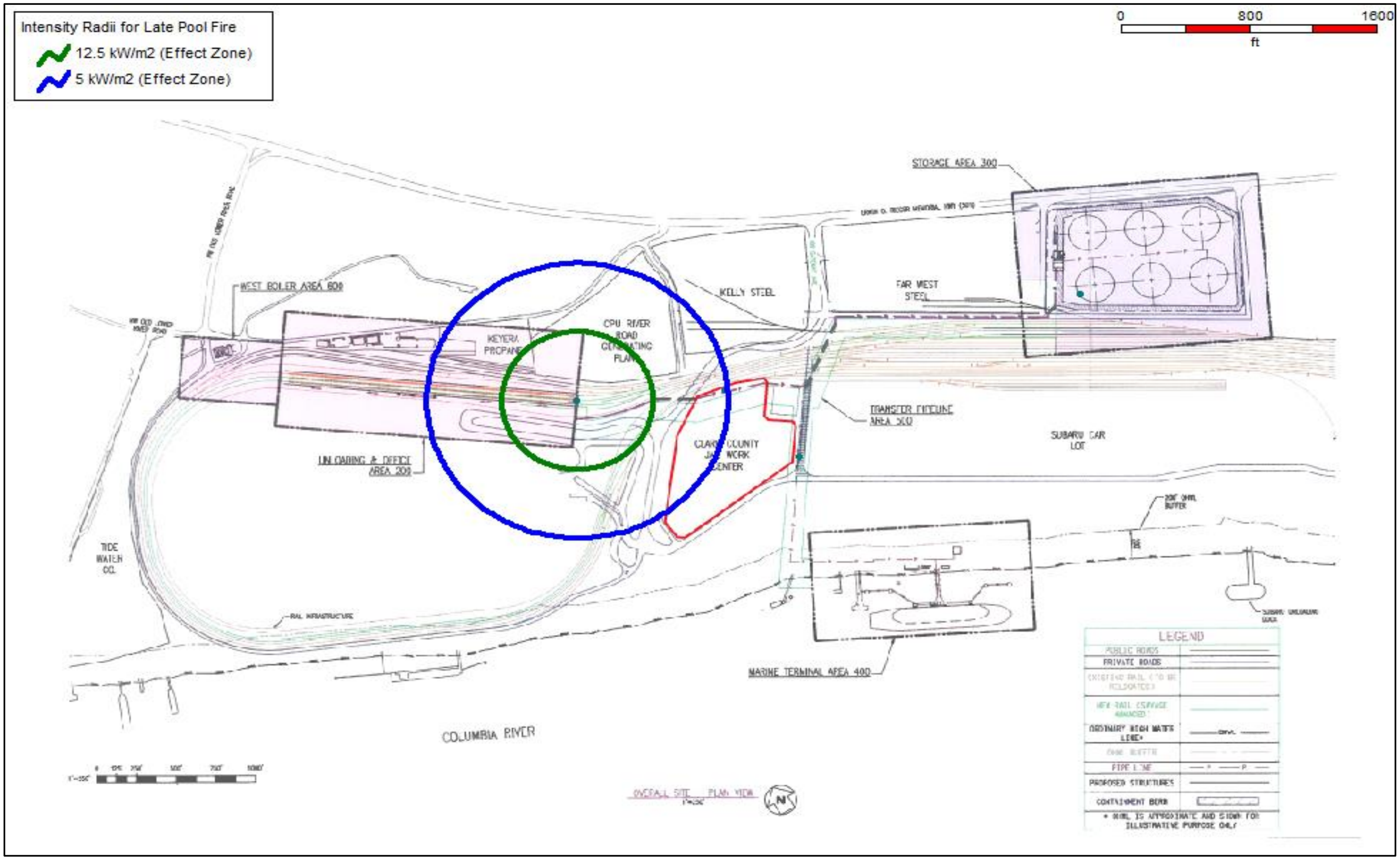

Figure Error! No text of specified style in document.**-7 Multiple Rail Car Catastrophic Failure – Pool Fire Contour**

4. Pipeline – Release during Transfer from Rail Car to Tank Storage

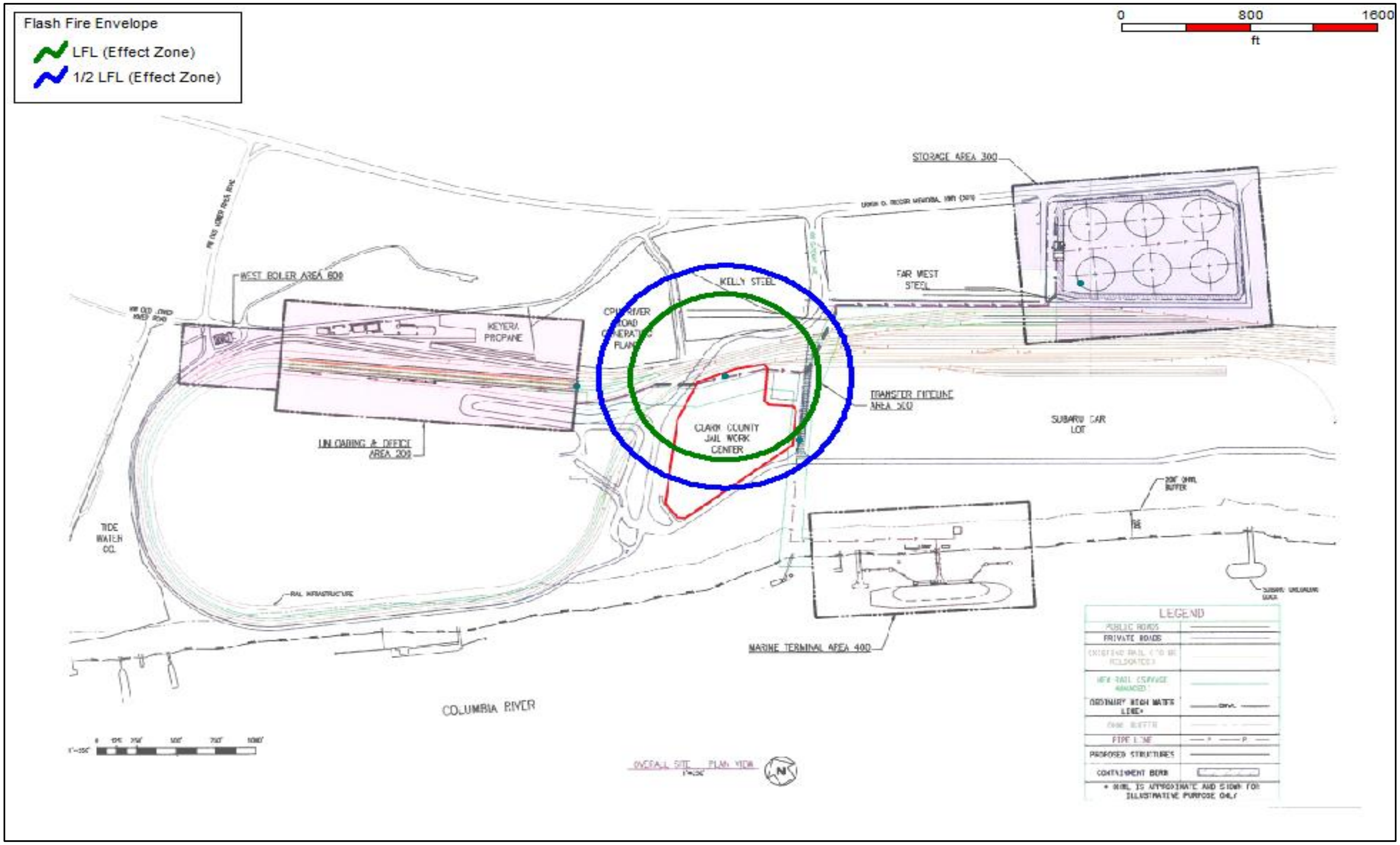

Figure Error! No text of specified style in document.**-8 Rail to Storage Pipeline Release – Flash Fire Contour**

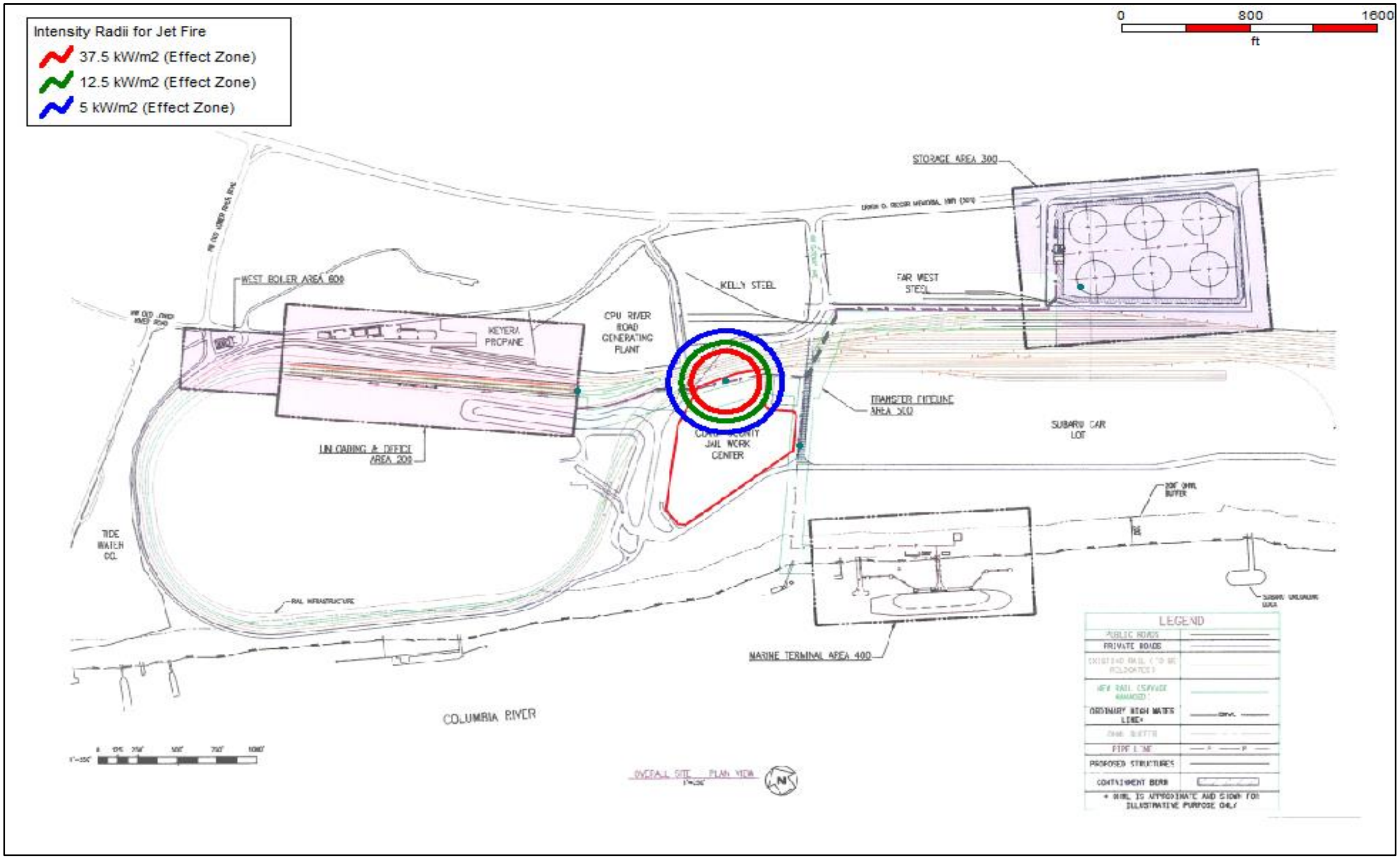

Figure Error! No text of specified style in document.**-9 Rail to Storage Pipeline Release – Jet Fire Contour**

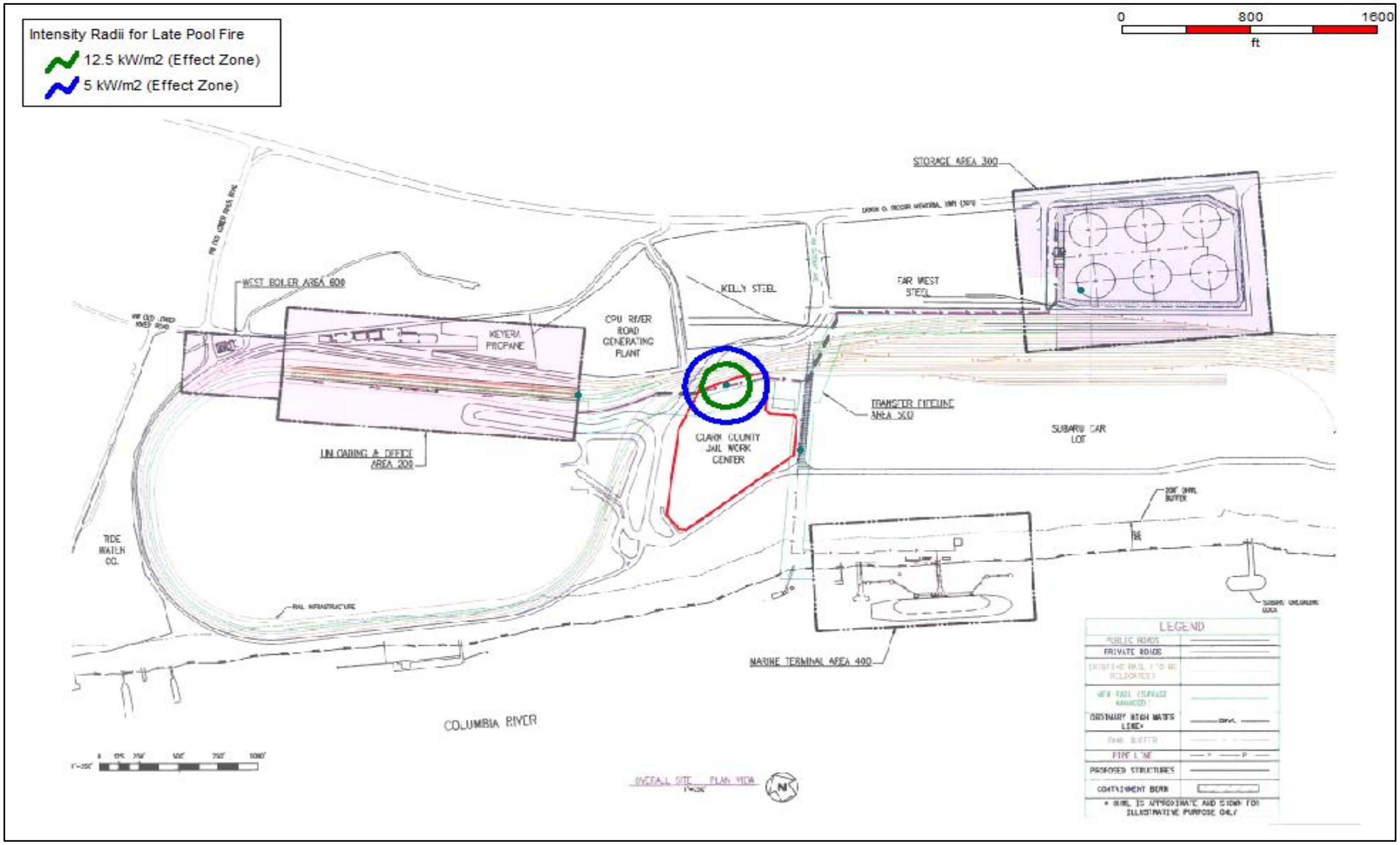

Figure Error! No text of specified style in document.**-10 Rail to Storage Pipeline Release – Pool Fire Contour**

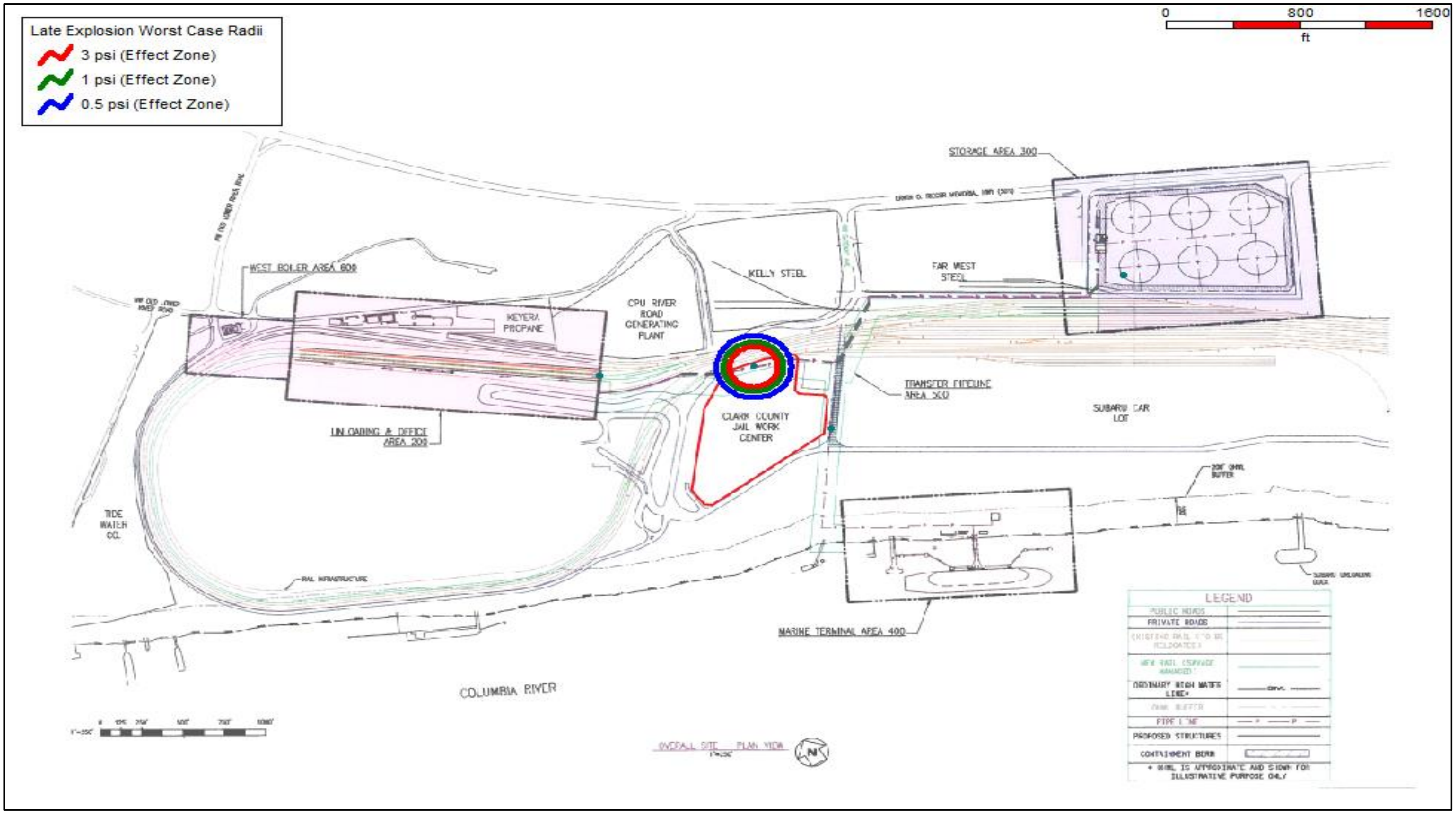

Figure Error! No text of specified style in document.**-11 Rail to Storage Pipeline Release – Explosion Contour**

5. Pipeline – Release during Transfer from Tank Storage to Marine Terminal

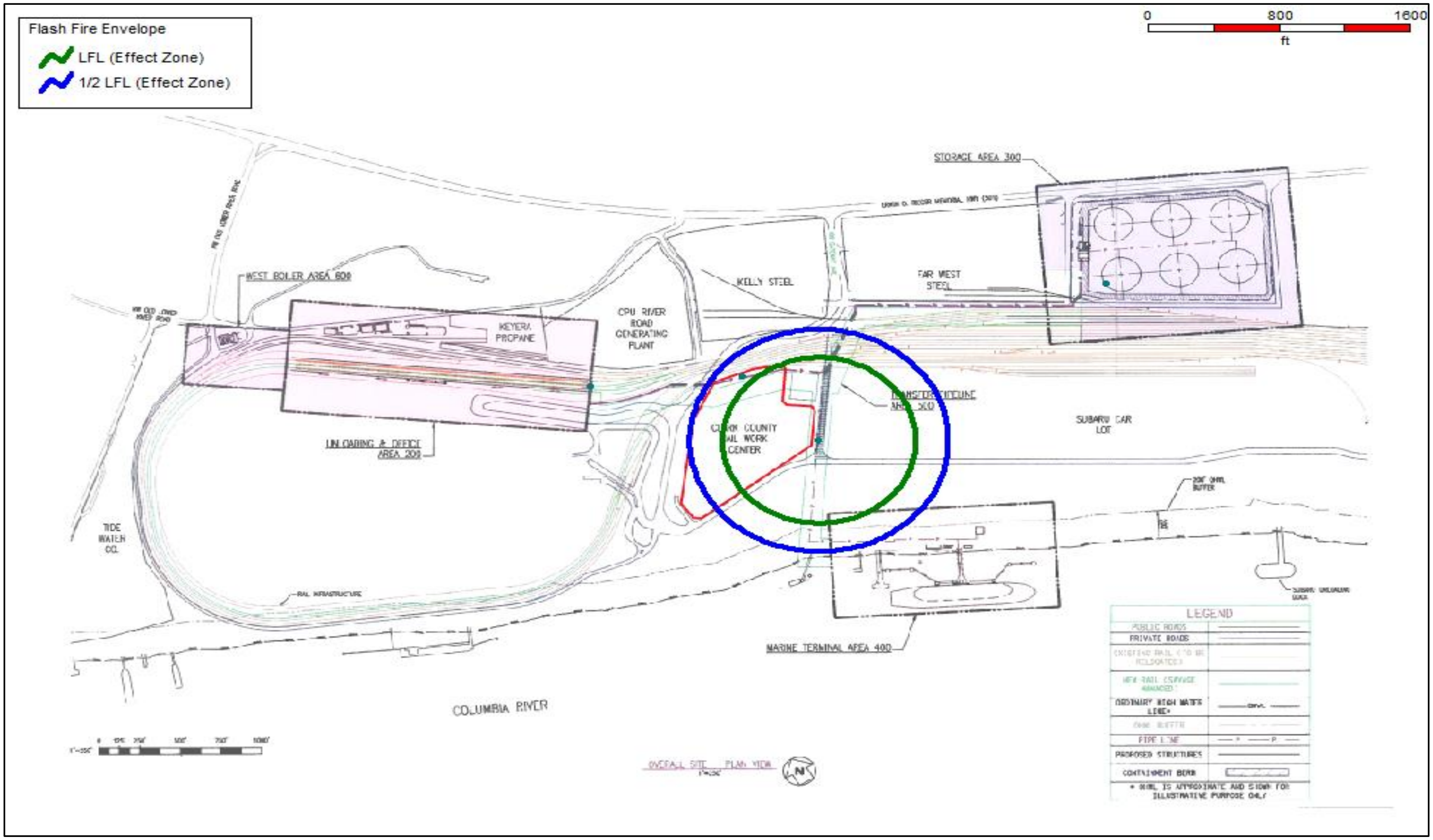

Figure Error! No text of specified style in document.**-12 Storage to Marine Pipeline Release – Flash Fire Contour**

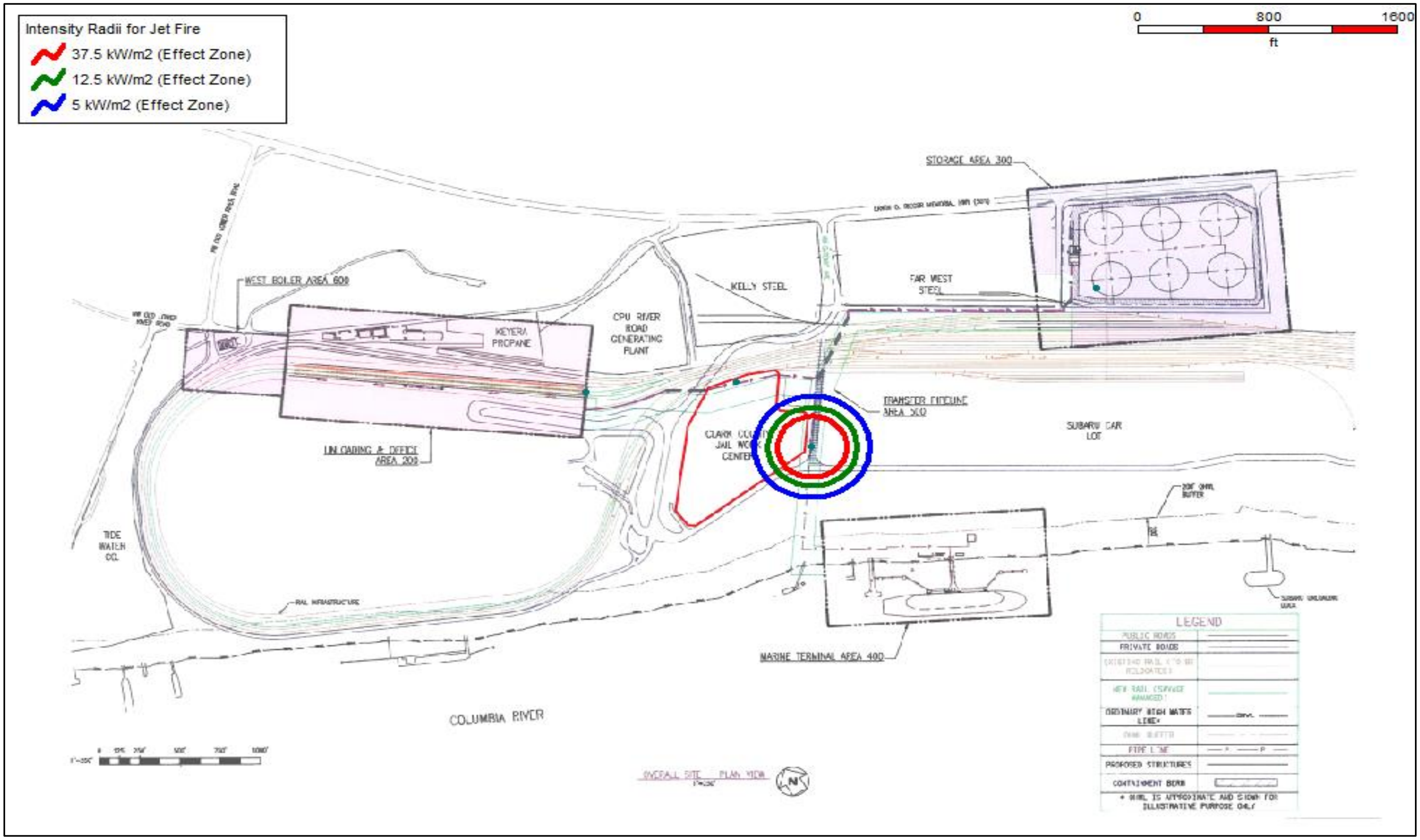

Figure Error! No text of specified style in document.**-13 Storage to Marine Pipeline Release – Jet Fire Contour**

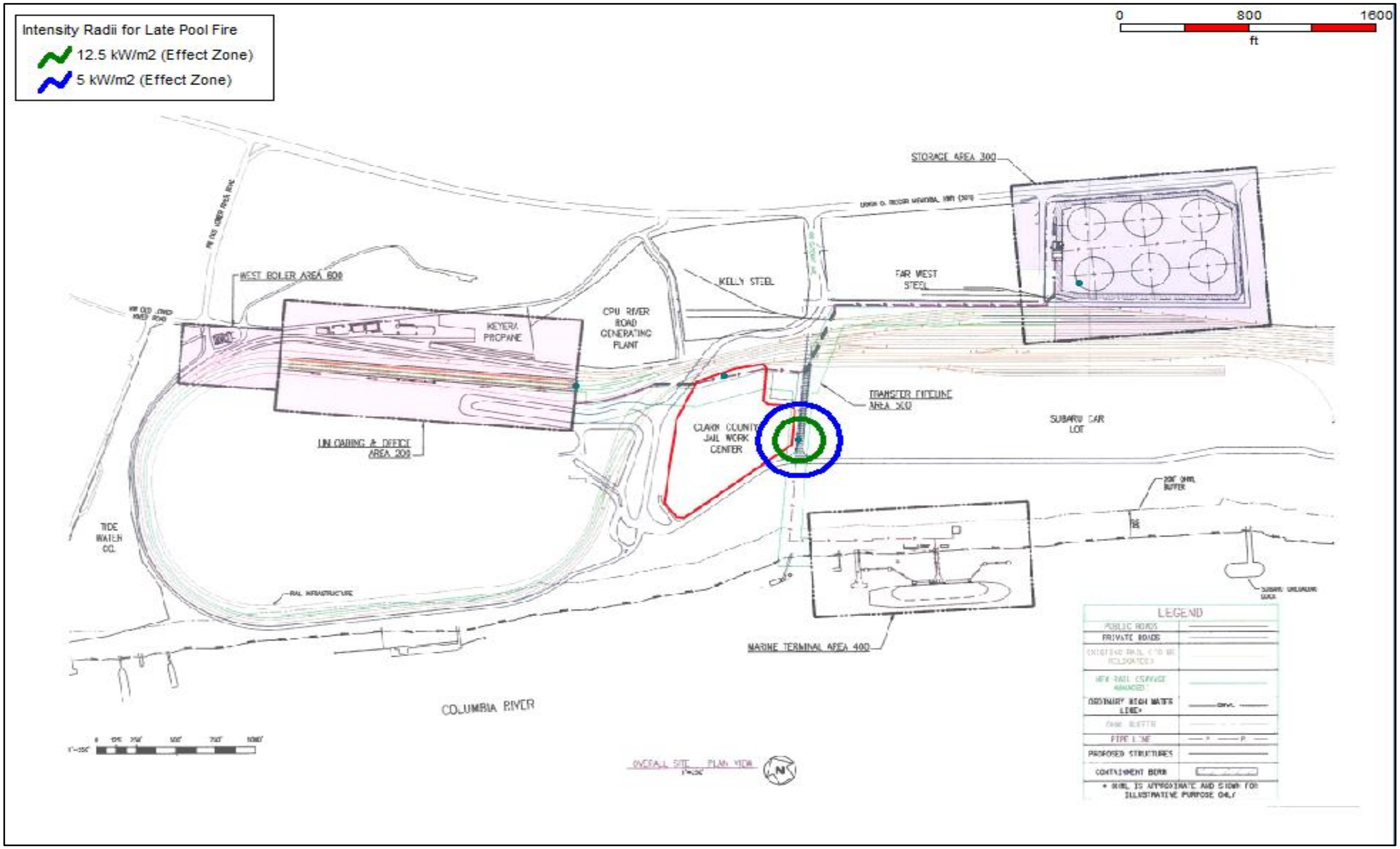

Figure Error! No text of specified style in document.**-14 Storage to Marine Pipeline Release – Pool Fire Contour**

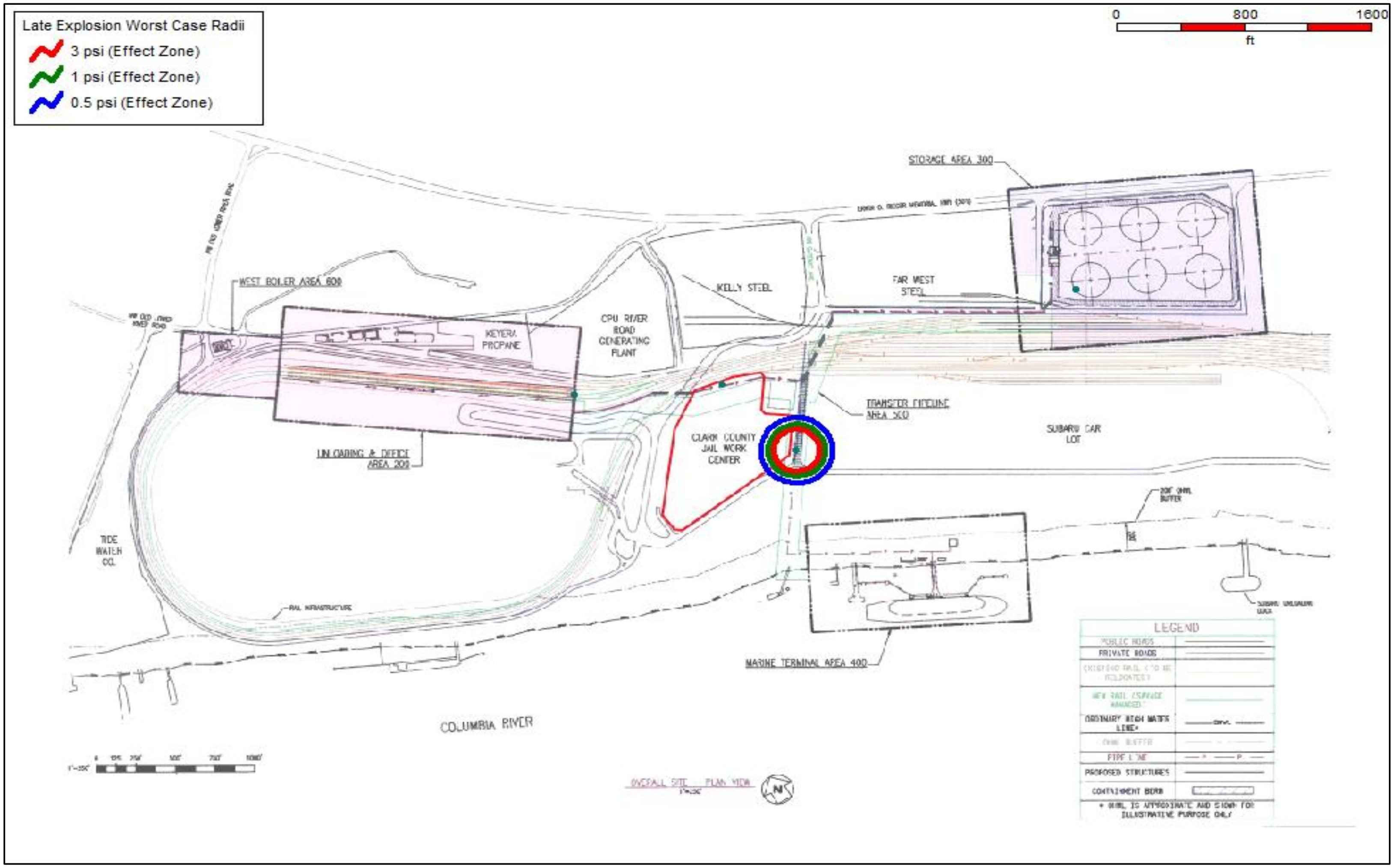

Figure Error! No text of specified style in document.**-15 Storage to Marine Pipeline Release – Explosion Contour**

6. **Storage Tanks – Loss of Containment from Tank or Connected Equipment**

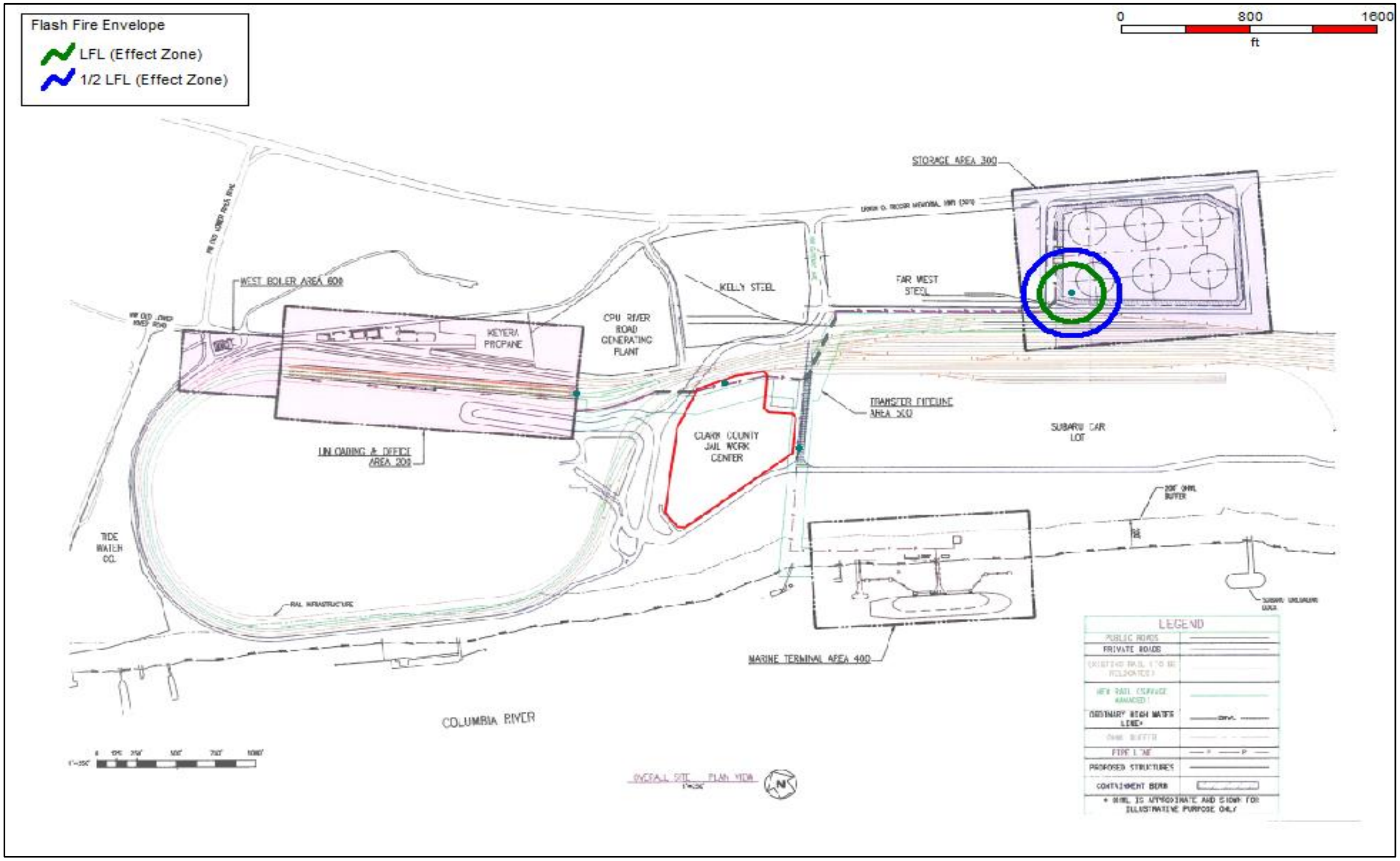

Figure Error! No text of specified style in document.**-16 Storage Tank Release – Flash Fire Contour**

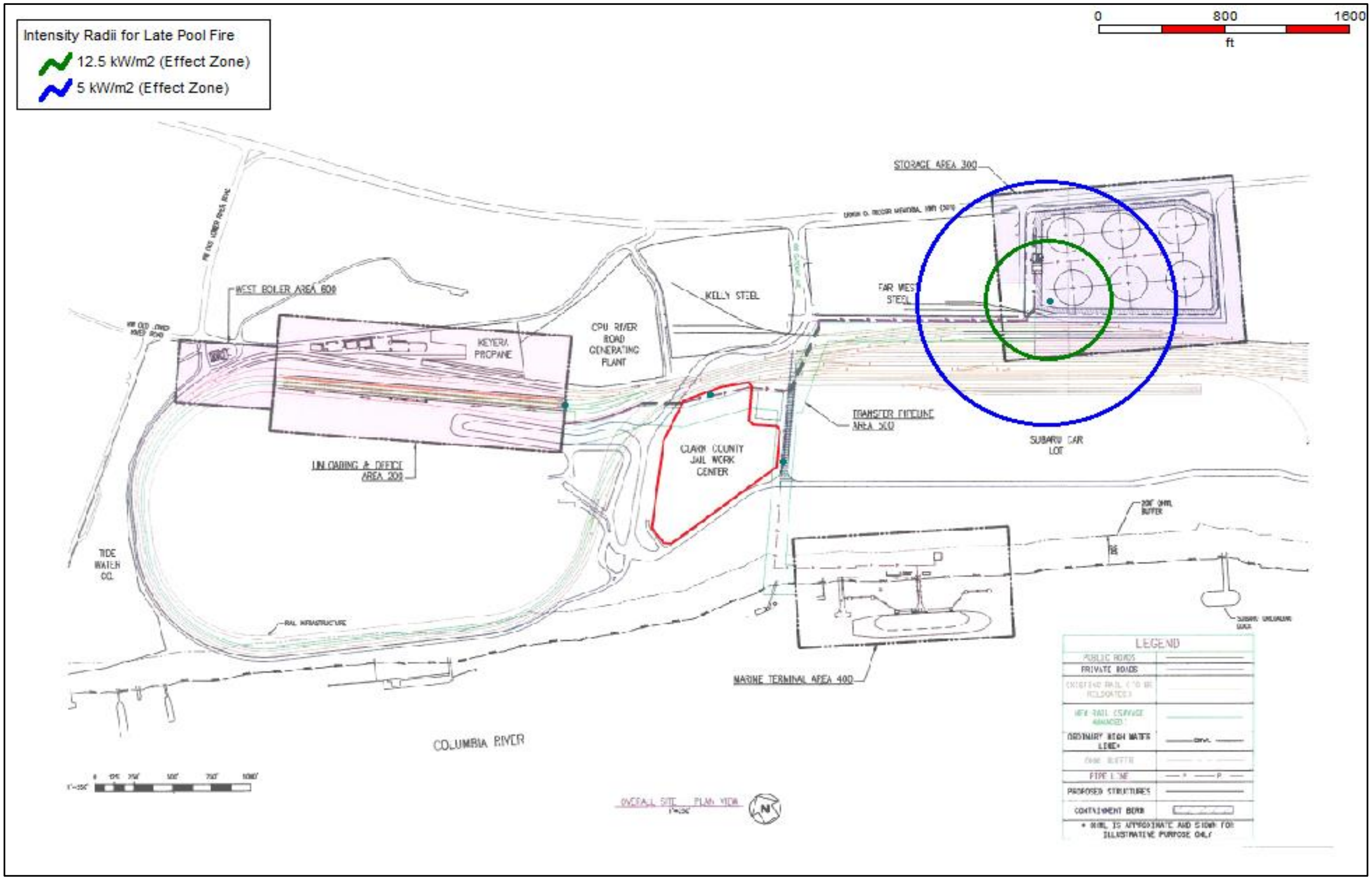

Figure Error! No text of specified style in document.**-17 Storage Tank Release – Pool Fire Contour**

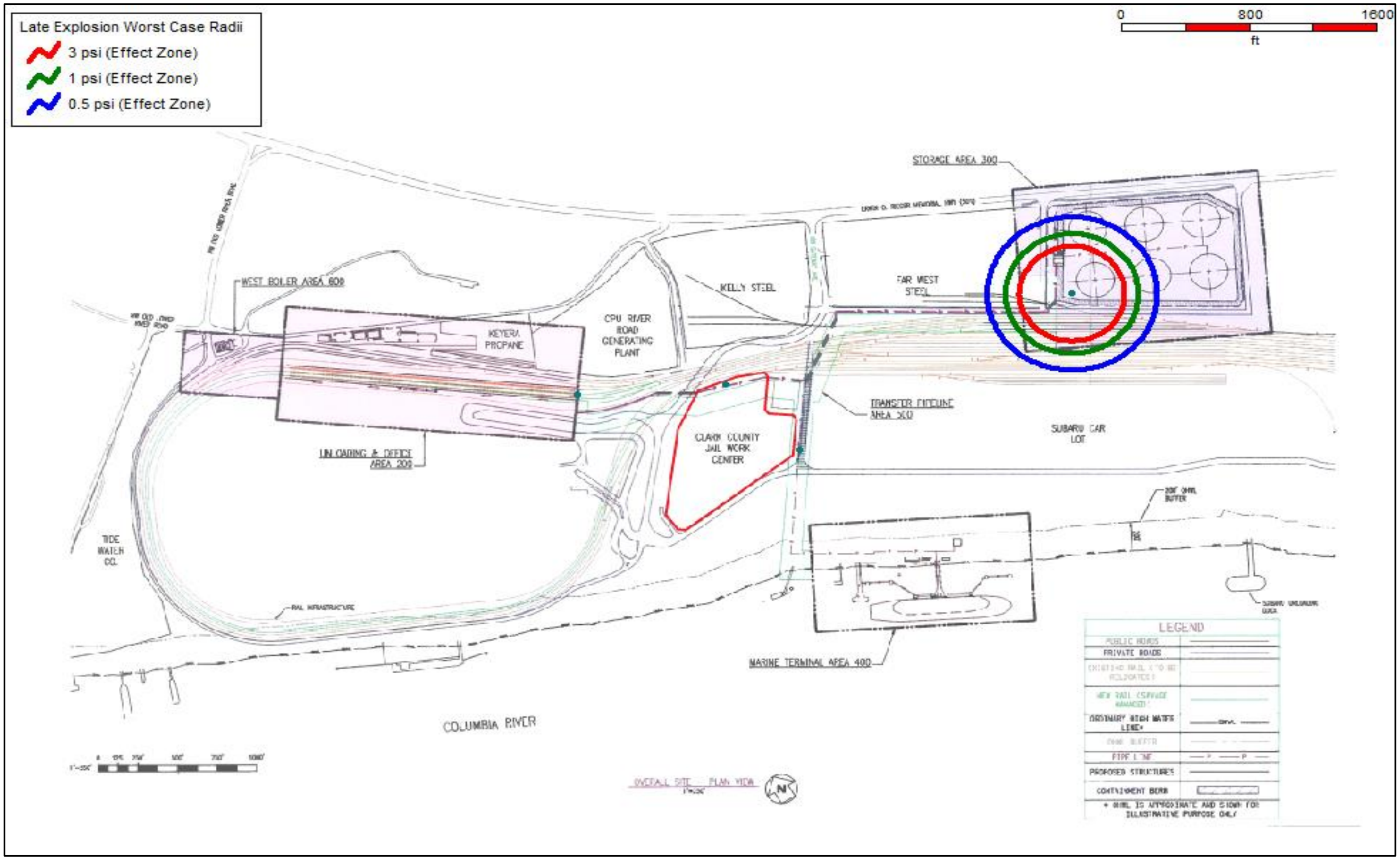

Figure Error! No text of specified style in document.**-18 Storage Tank Release – Explosion Contour**