CONSEQUENCE MODELLING USING ALOHA FOR ESTIMATION OF TOXIC GAS DISPERSION FROM A CHEMICAL PLANT AND EVACUATION PLANNING IN TELUK KALONG INDUSTRIAL AREA

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Thesis submitted in partial fulfilment of the requirements
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Dedicated to my family,

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ABSTRACT

The aim of this study is to estimate the toxic gas dispersion by using consequences modelling software which is Areal Location of Hazardous Atmosphere, ALOHA version 5.4.7 at one of chemical plant in Teluk Kalong Industrial Area, Kemaman, Terengganu for the whole year starting from January to December of 2016.The result of this study have been analyzed with a view to determine the threat zone and estimate toxic gas dispersion which is the release of sulfuric acid from the storage tank from the source point for the worst case. Analysis of 12 simulations of toxic gas dispersion for the whole year has also been done to assess the damage potential of such events. It is revealed that toxic gas dispersion poses a great risk as it can disperse up to 1.3 miles not to only workers but also to the public. The study highlights the need for having safe evacuation route at the risky area in chemical plant.

ABSTRAK

Tujuan kajian ini dijalankan adalah untuk menganggarkan jarak penyebaran gas berbahaya iaitu asid sulfurik dengan menggunakan kesan perisian pemodelan iaitu Areal Lokasi Atmosphere Berbahaya, ALOHA versi 5.4.7 di salah sebuah kilang kimia di Kawasan Industri Teluk Kalong Kemaman, Terengganu sepanjang tahun ini bermula dari Januari hinga Disember 2016. Kajian ini telah dianalisis untuk menentukan zon ancaman dan menganggarkan penyebaran gas toksik. Analisis 12 simulasi penyebaran gas toksik sepanjang tahun ini juga telah dilakukan untuk menilai potensi bahaya yang akan mengancam pekerja dan juga penduduk yang tinggal berdekatan. Ia mendedahkan bahawa penyebaran gas toksik menimbulkan risiko besar. Faktor ini diambil kira daripada jarak penyebaran sulfuric acid yang paling jauh iaitu pada bulan Disember. Daripada analisis yang dilakukan, asik sulfurik boleh tersebar sejauh 1.3 batu bersamaan dengan 2.09 kilometer. Radius penyebaran asik berbahaya ini tidak hanya mengancam pekerja tetapi juga kepada orang ramai. Kajian ini menekankan keperluan untuk mempunyai laluan pemindahan selamat di kawasan berisiko di kilang kimia.

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LIST OF ABBREVIATIONS

MAE	Major Accident Event
ERP	Emergency Response and Preparedness
MIDA	Malaysian Industrial Development Authorities

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

In most developing countries, one of the contributor of the industrial sector growth is chemical industry. It gives important contributions to the economic development. In Asian countries including Malaysia, the increasing demand for chemical products has resulted in the rise of manufacturing sector. The overall chemical production in the Asia-Pacific region is forecast to increase by 5.2% by 2015 and afterwards (*World of Chemicals, 2015*). One of the cluster which is in developing stage is chemical industry including major chemical sector located in Teluk Kalong, Kemaman (*MIDA, 2017*).

As the growth of the chemical sector rise, the other aspect that should be greatly concerned is chemical safety-related. In industry, there are high potential for major accident events (MAE), where the problem become more serious with the increasing production, storage and use of hazardous substances. Chemical accident such as chemical release can cause catastrophic consequences not only to the employees but also to residents and the environment as the dispersion of the toxic gas will become worst as the wind speed increase (*Faisal and Abbasi, 1999*).

At any processing plant, process safety becomes the most crucial factor in ensuring the safety of the plant. It focuses on preventing fires, explosions and accidental chemical releases in chemical process facilities or other facilities dealing with hazardous materials such as refineries, and oil and gas (onshore and offshore) production installations (Daniel and Joseph, 2002). Unexpected releases of toxic, reactive, or flammable liquids and gases in processes involving hazardous chemicals have been reported for many years and continue to occur in various industries.

In this regard, chemical plant in general has a high risk for developing accidents. As such, in reaction of such disaster, the workers and residents that is living nearby need to take shelter in a safer place within short period of time. Hence, the evacuation routes that safe from the incident need to be figured out (Vania et al.,2012). Evacuation route is a major part of Emergency Response and Planning which itself a part of Process Safety Management. Hence, a proper action should be taken to avoid the catastrophic incident from happening.

1.2 Motivation

Recently, major accident in chemical plant had been frequently reported in Malaysia. On September 16, 2016, there was a chlorine explosion in a chemical plant. The explosion sent a stinging odor to the air and had caused the residents suffered itchy throats and severe coughs accompanied by a burning sensation in their throats. Not only that, some workers of the plant had been diagnosed suffers from pneumonia. (The Star Online, 2016). On the next cases, on August 16 2016, two workers were killed in ammonia leak in a chemical plant located in Sipitang, Sarawak (Malaymail Online, 2016).

According to the Chris Kilbourne, workers need to be trained well to stay safe from the gas leak. He also added that the workers need to be trained to escape from the gas leakage area. However, the area of gas leakage cannot be discovered in a short time, unlike fire explosion, gas dispersion cannot be detected earlier due to its color. Hence, there is a need for a simulation of gas leakage before the incident occur. This will help the person in charge during the day of the incident to give a safe command to the other workers to escape to a safer place and the affected area will be avoided.

1.3 Problem Statement

Emergency Response and Preparedness (ERP) is to provide safe and proper operations at the workplace. It includes emergency response plan which is the actions taken in the initial minutes during an accident occur. This plan is very crucial as it can save lives of workers and also public by preparing the plan for the evacuation during the day of the accident (Ralph, 1990). In the study area, it is found out that there are no evacuation routes has been planned and it will only be decided by the person in charge at the plant. Accident is an unexpected event which cannot be predicted when and where it will occur. Hence, it is a crucial need for an evacuation planning especially in chemical industry which is dealing with hazardous substances. Thus, potential threat needs to be identified first (Moura et al., 2016).

1.4 Objectives

The following are the objectives of this research:

1) To identify the potential hazards from the sulfuric acid dispersion at the chemical plant.
2) To study the downwind concentration of the sulfuric acid for the impact on the toxic release from the storage tank.
3) To develop the evacuation routes for the sulfuric acid release.

1.5 Scopes of Study

The following are the scopes of this research:

1) Process Safety Concept is the main principle and it is carried out in a chemical facility.
2) Process hazard analysis specifically using the Areal Location of Hazardous Atmospheres (ALOHA) software as our consequence modelling approach; thus to predict any incident which might occur.
3) Elements such as the route planned, incident command post and assembly area are taken into consideration for a safe emergency evacuation.

CHAPTER 2

LITERATURE REVIEW

2.1 Process Safety Management

The major objective of Process Safety Management (PSM) for hazardous chemicals is to prevent unwanted releases of hazardous chemicals especially into locations that could expose employees and others to serious hazards. An effective process safety management program requires a systematic approach to evaluating the whole chemical process (Daniel and Joseph, 2002). Using this approach, emergency response and preparedness is considered in the evaluation. Thus, we seek to evaluate the safe emergency evacuations in the context of a toxic release.

2.1.1 Emergency Response Planning

The actions to be taken by the employees must be addressed by each are to take when there is an unwanted release of highly hazardous chemicals. Emergency preparedness is the employer's third line of defense that will be relied upon along with the ability to control the release of chemical which is the second line of defense. Control releases and emergency preparedness will take place when the first line of defense to operate and maintain the process and contain the chemicals fails to stop the release as prescribed by the OSHA (2013).

Chao and Henshaw (2001) states that when developing an emergency action plan, some responsible person must be selected to lead and coordinate your emergency plan and evacuation. It is imperative that employees know who the coordinator is and understand that person has the authority to make decisions during emergencies.

An Emergency Response Plan (ERP) is an important method for dealing with different types of accidents, such as fires, explosions, toxic releases, earthquakes, floods, typhoons, and landslides as stated by Tseng, Kuo, Liu and Shu (2008). Kowalski said (as cited by Tseng et al. 2008) it also is crucial reducing impact of disaster, preparing, responding, and restoring. ERP can be used for various types of accidents to decrease the degree of hazard efficiently. Fitzgerald said (as cited by Tseng et al. 2008) in case an accident occurs instead of being exacerbated, an emergency system, safety equipment, and manpower should be integrated in order to cope most effectively and efficiently.

2.2 Hazards of Sulfuric Acid

Sulphuric acid (98%) is a hazardous substances and highly corrosive. If it is exposed to metal, it will cause the corrosion and will lead to permanent damage and might cause a serious damage to health by prolonged exposure. For long term effect, it may cause cancer by inhalation. The following table shows the hazard of the sulphuric acid to our health.

Table 2.1: Material safety data sheet of Sulfuric Acid (Nicholas, 1999)

Hazards	**Description**	**Health Effect**	**First Aid Measurement**
Eye Contact	The solution is accidentally sprayed into the eye.	1) Burning 2) Pain and blurring to the eye	1) Quickly and gently removes the excess acid off the face. 2) Immediately flush the contaminated eye with lukewarm, gently flowing water for at least 30 minutes with eyelid open. 3) Quickly transfer the victim to the hospital.
Inhalation	Accidentally inhale the toxic release containing sulphuric acid.	1) Nose throat 2) Lung irritation 3) Coughing 4) Wheezing	1) Removes source of exposure or evacuate the victim from exposure area to fresh air and keep comfortable for breathing. 2) Call a doctor or seek medical treatment if not feeling well.

Ingestion	Accidentally ingest the solution	1) Burning and pain in the mouth.	1) Have victim rinse mouth thoroughly with water 2) Rinse the mouth with water again 3) Quickly transport the victim to an emergency care facility and bring a copy of material Safety of Data Sheet (MSDS)

Sulphuric acid can cause serious corrosion to the storage tank by pitting and cracking and thus lead to the damage of storage tank ().The corrosion is dependent on the factor of temperature, concentration and activity of tank and purity of acid. The plant used in this study area is using the sulphuric acid with the highest concentration which is 98%. There are lot of causes which will lead to the release of toxic gas from storage tank. Most of the causes are caused by the age deterioration, corrosion and seismic motion (). According to the James (2005), natural disaster can be one of the factor which will result in catastrophic acid spills. The following table below shows the recent cases involving gas release reported in Malaysia and all over the world.

Table 2.2: The recent cases involving gas release in Malaysia and worldwide

Type of Release	Date	Location	Description	Source
Environmental Release	12 August 2016	Menglembu, Perak	Storage tank containing hydrogen fluoride had accidentally release a quite huge amount of that toxic gas to the atmosphere. This has caused the residents living at the close area having nausea and had a burning throat cause by the inhalation of that toxic gas. Not only that, 2 workers of that plant had been diagnosed from having pneumonia also due to the excessive inhalation of hydrogen fluoride.	The Star Online, 2016
Environmental Release	16 December 2016	Kuala Sipitang, Sarawak	The leakage of the ammonia from the storage tank to the atmosphere at a PETRONAS plant in Sipitang had killed 2 of their workers while 18 others injured. This is due to the huge ammonia dispersion. This shows how dangerous the toxic gas dispersion can cause to human health.	Malay Borneo Online, 2016

Environmental Release	September 27, 2012	Gyeongsangbuk,South Korea	Korea is a developed country and some might think that its technology will turn the incident like toxic dispersion into an impossible thing to happen. Whatever it is, a huge leakage of Hydrogen fluoride from a storage tank caused 5 workers were killed immediately and 18 others were injured. During the day of the incident, it is reported that a relatively long time was required to plan the immediate activities, treatment and evacuation. This cause more than 3600 residents of Gu-mi city sought medical treatment for rashes, nausea, chest pain and sore eyes. This incident proves the importance of having the right evacuation routes which will ensure the safety by simulating the toxic dispersion using consequences modelling software.	Kwanghee et al., 2015
Environmental Release	August 14, 2016	Geismar, Los Angeles	Leakage from a storage tank containing thousand meter cubic of sulfuric acid at	ISSS,2016

			Honeywell Plant occurred. The release cause about 1500 residents and worker to be evacuated to a safer place. As a plant that has a storage tank stored huge amount of toxic acid, a consequence modelling is supposed to be simulated before an incident of release occur. This will help the management to predict which area will be affected	

2.3 Consequences Modelling

Risk assessment in chemical process industry is a very important issue for safeguarding human and the ecosystem from damages caused to them. Consequence assessment is an integral part of risk assessment. Major accidents around the world have impacted fatalities, economic losses and damage to environment. Various action have been taken to curb the regularity of such accident as low as reasonably practicable (ALARP). Moreover, chemical industry remains the major high risk industry worldwide; the hazards associated with it are that of fire, explosion and toxic chemical release. As such, the consequence modelling aims to quantify the negative impacts when a hazardous event takes place as stated by (Arunraj and Maiti, 2009).

In the market right now, there are widely available software packages available for the purpose of consequence and risk assessment in chemical industries. Chiefly among them are MOSEC, HAZDIG and DOMIFFECT from Khan and Abbasi (1999). Yet in this, the ALOHA software developed by the Environmental Protection Agency of the United States (USEPA) shall be instead used for the purpose of this study. The main attractive points of this software is it is widely available and used for the low cost of zero dollars.

2.3.1 Dispersion

The term dispersion is often used by modelers to include advection (moving) and diffusion (spreading). In a case of a dispersing vapor cloud, it will generally move (advect) in a downwind direction and the spread (diffuse) will be in a crosswind and vertical direction (crosswind is the direction perpendicular to the wind). A gas is called a heavy gas once the cloud of gas is denser or heavier than air and can also spread upwind to a small extent (EPA and NOAA, 2007)

Modelers find these air dispersion models are central to predicting hazard zones associated with toxic or flammable gas clouds. The concentration of a pollutant can be determined by using these models to predict how, once it has been released into the air, varies with time and position. ALOHA provides information about the concentration and duration of exposure, but does not resolve the probability that an exposed individual will be injured.

Assael and Kakosimos (2010) characterized every leak dispersion as either continuus or instantaneous source as dependent on time duration. Moreover, according to them lethal concentration 1 or LC1 (mg/m3 air) is represented by the concentration of a toxic substance in the air, which is possibly cause death to one percent population, by the inhalation for over thirty minutes of exposure time.

2.3.2 Atmospheric Stability Classes

As stated by Jones, Lehr, Simecek-Beatty and Reynolds (2013) the rate of dispersion of a pollutant cloud is impacted by the atmospheric turbulence. Stability as a concept is often used to characterize the property of the low-lying atmosphere that governs the vertical movement of air. Specifically, stability refers to the tendency of the atmosphere to resist or enhance vertical motion and thus turbulence.

In cases of like a stable atmosphere which inhibits the vertical mixing; a neutral atmosphere neither enhances nor inhibits vertical mixing; and an unstable atmosphere increases vertical mixing and turbulence. Solar radiation has a large role in atmospheric stability. During the day where there is strong solar radiation, the ground warms and warms the low-lying air; the warm air rises generating eddies and a high level of turbulence.

Pasquill (1961) defined six atmospheric stability classes which is now usually called the Pasquill-Gifford-Turner stability classes. The classes range from A to F with each represent a different degree of atmospheric turbulence. On the neutral stability condition is represented by stability class D. Classes A, B, and C, are where the unstable conditions are at; with respect to atmospheric stability where A is extremely unstable, B is moderately unstable, and C is slightly unstable. The stability classes E and F represent increasingly stable atmospheric conditions. Below is Figure 1 which demonsrates the Pasquill-Gifford-Turner stability classes.

Table 2.3: The Pasquill-Turner stability classes against Solar Insolation (Jones et al.,2013)

Wind Speed	**Day**			**Night**	
At 10 meters (m/s)	**Solar Insolation**			**Cloud Cover**	
	Strong	**Moderate**	**Slight**	**>50%**	**<50%**
<2	A	A-B	B	E	F
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
>6	C	D	D	D	D

2.3.3 Surface Roughness

Surface roughness otherwise known as terrain/layout affect the vertical wind profile, but also generate turbulence within the wind field as defined by Jones, Lehr, Simecek-Beatty and Reynolds (2013). Topography and large structures also affect the velocity field and turbulence as the wind moves around and over these features.

In the case of determination of dispersion parameters surface roughness is used. Briggs employed only two surface roughness category. The first is urban which directly corresponds to large ground roughness and he rural which corresponds to small surface roughness. The ALOHA software would choose by default rural classification if the ground roughness is less than 20cm.

2.3.4 Level of Concerns

Level of Concern or Threat zone is defined NOAA (2016) as a threshold value for a hazard (toxicity, flammability, thermal radiation, or overpressure)as in this study it focuses on toxic release; the LOC is usually the value above which a threat to people or property may exist. as ALOHA uses three tiered scenarios for LOCs as stated by the ALOHA Example Scenarios (2015). The three levels or areas are red, orange and yellow zone which indicate areas where the LOCs exceeded at same point after chemical release began in descending order respectively. The guidelines used by ALOHA are Acute Exposure Guideline Levels (AEGLs), Emergency Response Planning Guidelines (ERPGs), Protective Action Criteria for Chemicals (PACs) and

Immediately Dangerous to Life and Health (IDLH) to indicate the LOC. By default AEGLs is used but it changes according to local authority.

2.4 Emergency Evacuation

In the actual occurrence of hazard or any emergency, Emergency evacuations are conducted immediately to relocate of people away from the threat. Examples includes but does not limit to the small scale evacuation of a building due to a storm or fire and to the large scale evacuation of a district because of a flood, bombardment or approaching weather system like a hurricane, typhoon or tornado. In situations involving hazardous materials or possible contamination, evacuees may be decontaminated prior to being transported out of the contaminated area.

Chao and Henshaw (2001) states that when developing an emergency plan, to avoid confusion, injury, and property damage it is imperative that a clear chain of command exists. Furthermore, specific evacuation routes, procedures and exits be established and the installation designated people for the shutdown of critical operations during an evacuation.

The effectiveness of the egress systems of a building or facility relies on its size, complexity and use as well as the condition of its occupants can as stated by Tubbs and Meacham (2007). Speaking of occupants Künzer (2016) seeks to demystify myths on evacuation in her Myths of Evacuation article like people do not run into smoke yet in actuality they are not discouraged by the hazard and run through it none the same. Or that the myth of people panic usually in an evacuation, though studies have shown that this occurs rarely.

2.4.1 Escape Route

Emergency escape route or as defined in the OSHA (2002) simply termed route is the " means the route that employees are directed to follow in the event they are required to evacuate the workplace or seek a designated refuge area.

To permit prompt evacuation of employees and other building occupants during an emergency, at least two routes are needed. The route must also permit maximum occupant load for each floor served. Moreover, exit doors or discharges must go on beyond where the exit is located and must be blocked at that level by doors, partitions or other effective means that clearly indicate the direction of travel leading to the exit discharge.

Wind direction or air circulation is the essential factor that may affect the toxic gas release direction. The circular shape of the Earth is responsible for the uneven absorption of solar energy from the surface of atmosphere as stated by Assael and Kakosimos (2010). The wind direction might also induce cross flows of toxic release which may hinder egress along the escape as such facility layout must take into consideration of wind direction and placement of storage tanks that house these toxic substances into account.

2.4.2 Incident Post Command

The Incident Command System (ICS) is a standardized approach to the command, control and coordination of emergency response providing a common hierarchy within which responders from multiple agencies can be effective. The Incident Post Command itself is the location on scene from which all incident planning and tactical operations are directed. In an emergency incident there should only be one to keep all distraction and misinformation away according to Cole and St Helena (2001).

However, there may be other support areas such as staging area for emergency personnel the Emergency Operation Center (EOC) or its equivalent at which the Emergency Response Team may reside to wait for further information in response of the incident.

The Incident Commander is the person is ultimately responsible for all activities that take place at an incident, including the development and implementation of strategic decisions and the ordering and releasing of resources as stated (Roberts, 2001) and is the one responsible and is stationary at the post.

Gas dispersion as stated can move sporadically due to wind direction and surface roughness according to Jones, Lehr, Simecek-Beatty and Reynolds (2013). It is only logical that there is a possibility that it might reach the command post if it is unfortunate enough. The effect would catastrophic as the chain of command will be disrupted as they themselves succumbed to the effects of the toxic release and therefore incapable of directing and coordinating the emergency efforts whether in deploying search and rescue operations or handling communications. This possibility could be negated with proper facility layout analysis which is done in this study whereby the command post is placed strategically away from danger yet accessible to personnel.

2.4.3 First Aid Station

The station is established in order to provide supplies or its major component is to give medical aid during major emergency events, disaster response situations, or military operations. The personnel includes medical practitioner like physicians, general doctor, nurse, technician and others. It often places emergency medical equipment such scalpel, bandages, anesthetics, medical drugs and others.

First Aid Courses should be given to specific person in charge in order to facilitate quick first aid emergency within the facility as they can lead the firs aid station. Training for first aid is offered by the nationally recognized and private educational organizations like The Red Crescent and NIOSH. First-aid courses should be individualized to the needs of the workplace. Some of the noted program elements may be optional for a particular plant or facility as stated (OSHA, 2006).

The First Aid station is a vital key in the emergency and response operations, without it victims of the accident cannot receive treatment which they are in need of. Should there be gas release near it, the personnel and victims would suffer the consequences. Thus, the first aid station needs to be shielded of, or partitioned or even conducted in an enclosed room separate devoid of possibility of being affected by toxic release.

2.4.4 Assembly Area

Usually referring to an area outside the facility or near it which is adequately far away from the source of incident, dangerous occurrences, explosions, fire and so on designated beforehand by the HSE Manager or Incident Post Commander. This area is the neutral zone whereby workers affected can be safe from danger and can also as a place of refuge awaiting rescue personnel if it is in the building.

Accounting for all employees following an evacuation is critical. Confusion in the assembly areas are inevitable is incorrectly handled and can lead to delays in rescuing anyone trapped in the building, or lead to unnecessary and dangerous search-and-rescue operations. Thus, a head count must be taken after evacuation and establish a method for accounting non-employees like suppliers and customers. Therefore, wait for rescue or plan for further evacuations should the accident escalates as stated by Chao and Henshaw (2001)

The assembly area must be filled with people when the toxic plumes reaches it, it could very well cause hundreds of fatalities due to exposure. Such a thing can be averted by the right placement of the assembly. Position it in an open and large area away from the source.

2.5 Safe Evacuation Route

Nobody expects an emergency or disaster – especially one that affects them, their employees, and their business personally. Yet the simple truth is that emergencies and disasters can strike anyone, anytime, and anywhere as stated by Chao and Henshaw (2001). Thus, this is where this study comes in whereby the assessment of evacuation on the facility which includes the facility layout analysis, past accidents investigation, dispersion of toxic release and at the end the safe emergency evacuation of all personnel of the facility.

CHAPTER 3

METHODOLOGY

3.1 Introduction To Material

The study of the toxic release dispersion from the storage tank in a chemical plant involves one type of substances only which is sulphuric acid. Observation around the chemical plant and the interview session also have been conducted at the study area to collect the data needed for the study. Table 3.1 and Table 3.2 show the details of the storage tank and the material properties respectively.

Table 3.1: Storage Tank Information

Material	Tank Volume	Orientation	Number
Sulfuric Acid	10,000m^3	Vertical	1

Table 3.2: Material Properties

Properties	Sulfuric Acid
Molecular Weight (g/mol)	98.08
Freezing Point (°C)	-3
Boiling Point (°C)	158.54
Critical Pressure (kPa)	12942.62
Critical Temperature (°C)	317.76
Heat Capacity, Cp_{gas} (J/kg.K)	949
Heat Capacity, Cp_{liq} (J/kg.K)	5.2
AEGL-1 (mg/m^3)	0.2
AEGL-2 (mg/m^3)	8.7
AEGL-3 (mg/m^3)	160
ERPG-1 (mg/m^3)	2
ERPG-2 (mg/m^3)	10
ERPG-1 (mg/m^3)	120

3.2 Workflow

In order to predict the consequences of the sulfuric acid dispersion to the carried out at the plant site to get the overview of the plant. The location of the storage tank containing sulfuric acid has been identified and data was collected. At the same time, the atmospheric data has been retrieved from meteorology department for January until December 2016. For Teluk Kalong Industrial Area, the wind speed and wind direction is measured from Kuala Terengganu station.

Hence, the atmospheric data that has been using in the simulation is based on measurement from Kuala Terengganu station. The atmospheric information can be reviewed in Appendix A. Then, all data collected has been used in the simulation by using Areal Location of Hazardous Atmosphere software version 5.4.7. 12 results of simulation has been produced. Out of 12, only 1 result has been chosen which indicates the worst case of sulfuric acid dispersion.

Worst case result is indicated by the highest concentration of toxic gas being dispersed. But as for this cases, all the simulations has the same maximum concentration which is 0.2mg/m^3. Hence, the worst case was considered for the highest concentration that affect the workers, residents and public facility such as road (Daniel and Joseph, 2002). Based on the result of worst case, the affected area by the sulfuric acid dispersion has been identified and evacuation routes has been developed. The figure below shows the overall steps taken for this study from the beginning.

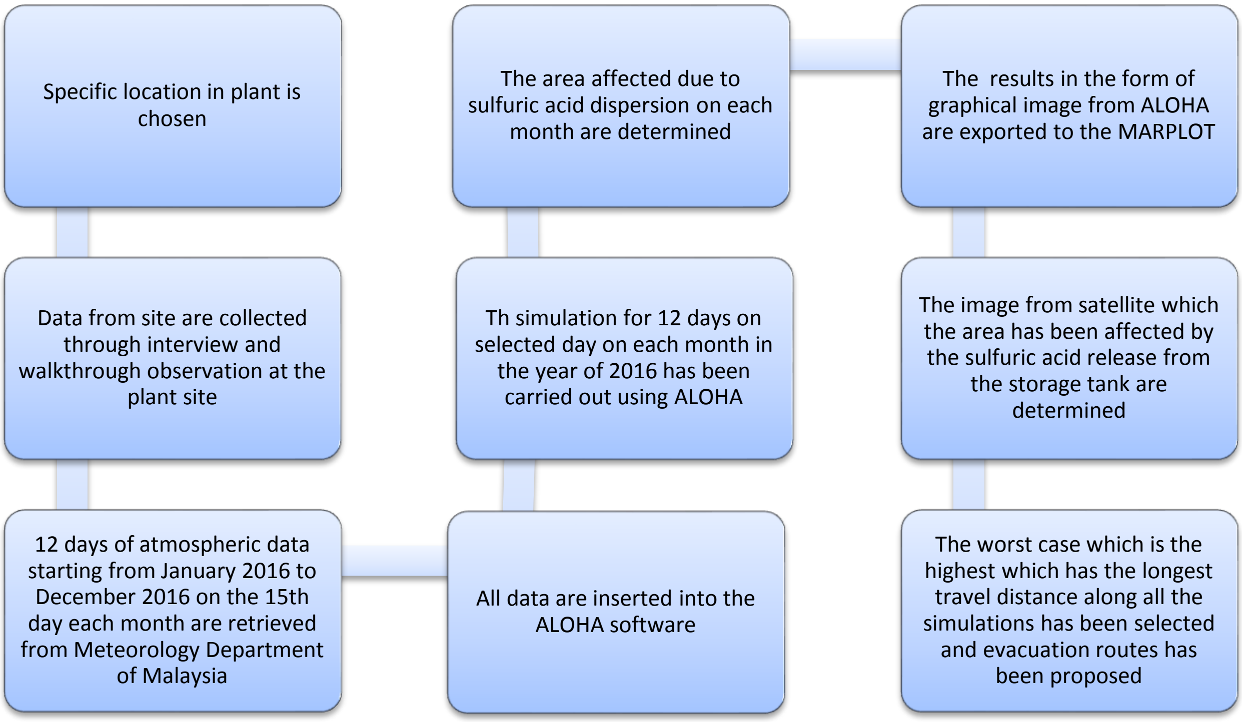


Figure 3.1: The overall steps

3.3 Areal Locations of Hazardous Atmospheres (ALOHA) version 5.4.6

ALOHA otherwise known as the Areal Locations of Hazardous was jointly developed by the Office of Emergency Management of the United Stated Environmental Protection Agency (EPA) and Emergency Response Division of National Oceanic and Atmospheric Administration (NOAA) and ALOHA 5.4.6 is the most recent version. It is a computer modelling software which deals with estimating the movement and dispersion of hazardous chemical gases. Through ALOHA, the rates at which the gases may escape into the atmosphere for example from leaking gas pipes, storage tanks and silos can be predicted. Hence, after an accidental chemical release, ALOHA can predict the dispersion of a hazardous chemical gas cloud formed from it (Thoman et al., 2006).

Typically, it is often used by Process Safety Managers to measure the risk associated with thermal radiation from fires, toxic air hazards from toxic gas release and blast effects from explosions to human population. The software is able to predict the area within which a person might experience serious health risks from coming in contact with certain concentrations of a toxic gas. Hence, it is called the level of concern, or LOC or in other studies can be equivalent to exposure limit. ALOHA can also be used to predict the area where a flammable gas may explode. Through ALOHA the researcher can predict the dispersion of a hazardous gas cloud using the physical characteristics of the released chemical and the real-time circumstances of the release scenario. Therefore, using its extensive chemical library and release equations, the software proceeds to solve the release problem and provides the graphical results in an easy-to-use form (Tseng et al., 2012).

Figure 3.2 below displays the simplest forms of the steps needed to run the ALOHA software. To run the software, the user may need to estimate some inputs as they will not have all the input information and will have to. Within ALOHA itself are checks to make sure that some of these inputs are reasonable or consistent with other inputs. Moreover, ALOHA also has an extensive help system.

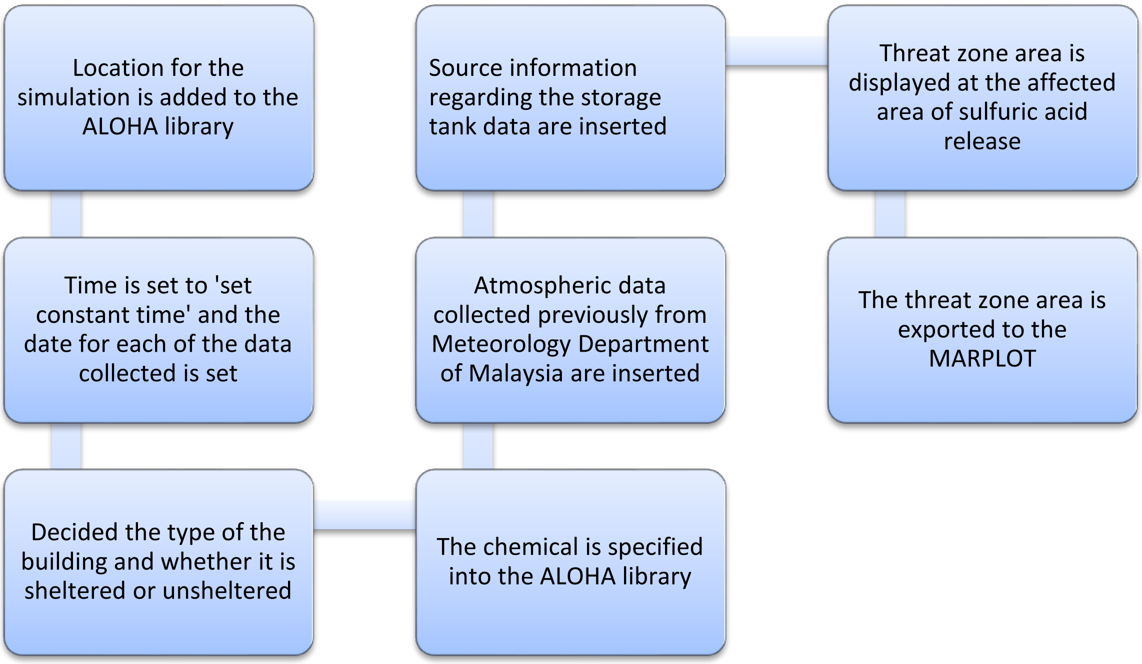


Figure 3.2: Steps for running ALOHA software

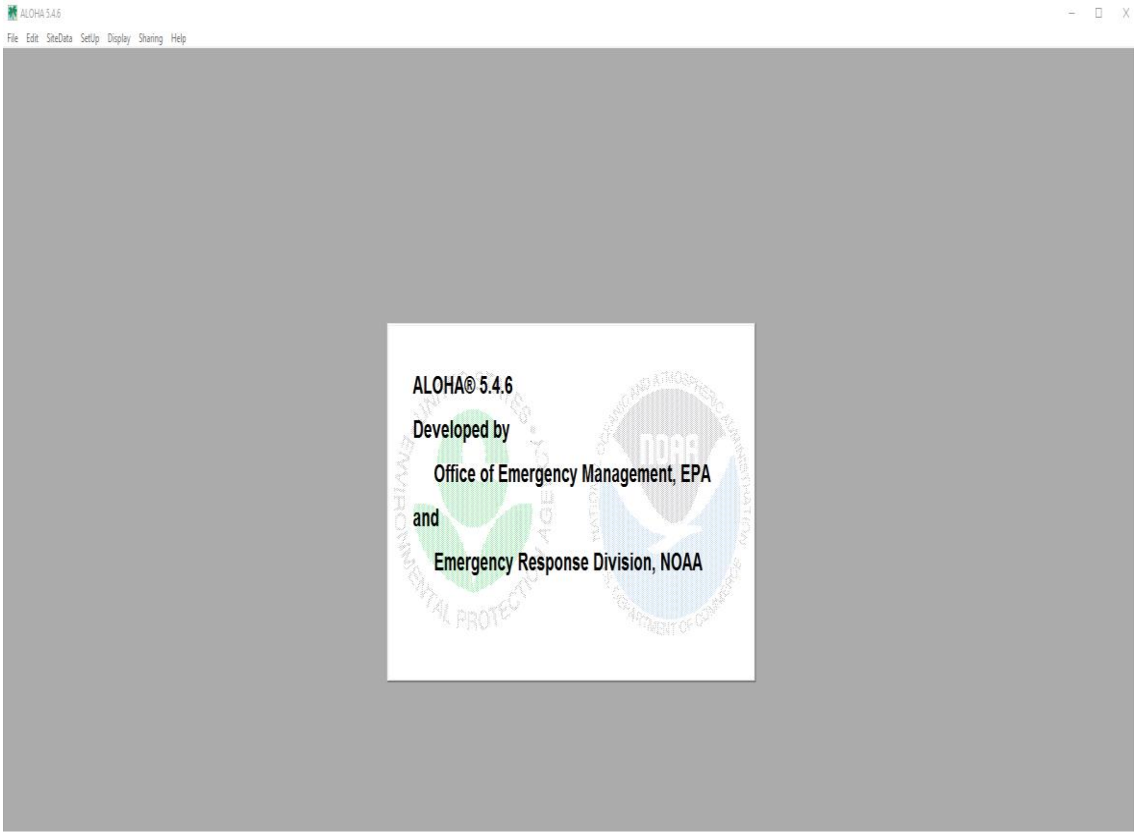


Figure 3.3: Interface of ALOHA 5.4.7 for Windows

3.3.1 Choosing a Location, Date & Time and a Chemical

Figure 3.3 is the main window for ALOHA 5.4.6 modelling software known as the Text Summary, all information that will be entered into the ALOHA 5.4.6 will appear in this window as a summary. First, location will be selected from the Site Data menu. A Location Information (Figure 3.4) dialog will appear with a list of the names of cities included in ALOHA's location library. All location within ALOHA's location library is within the territory of the USA, to add other country information, a few data should be added in the Location Input (Figure 3.5).

From SiteData, Date & Time will be selected and a Date and Time Options dialog box appears (Figure 3.6). Either use a constant time or use the default Internal Clock. The source of all figures come from the ALOHA software itself.

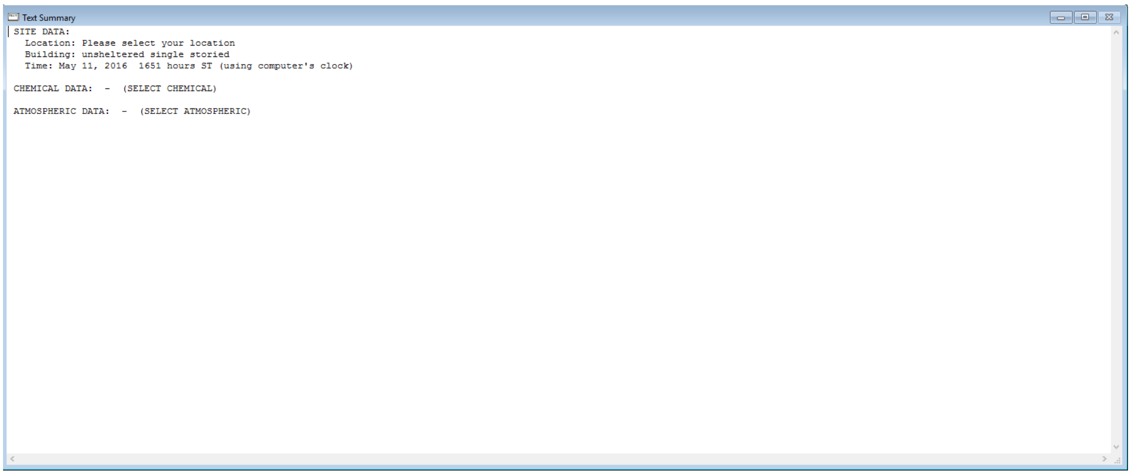


Figure 3.4: Main Window of ALOHA 5.4.7

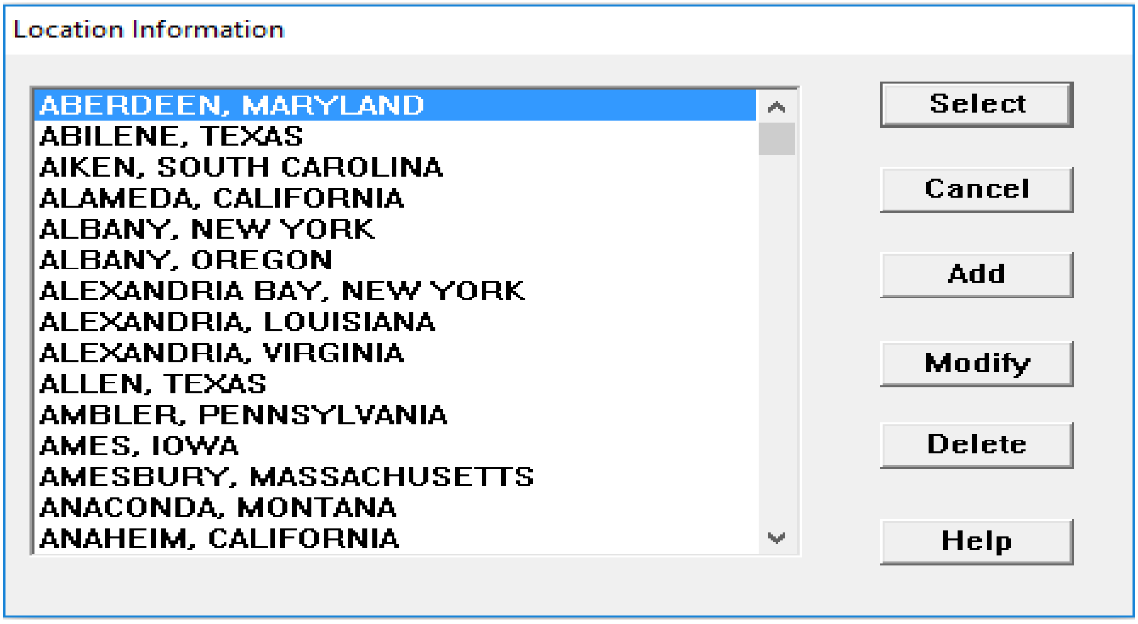


Figure 3.5: Location Information

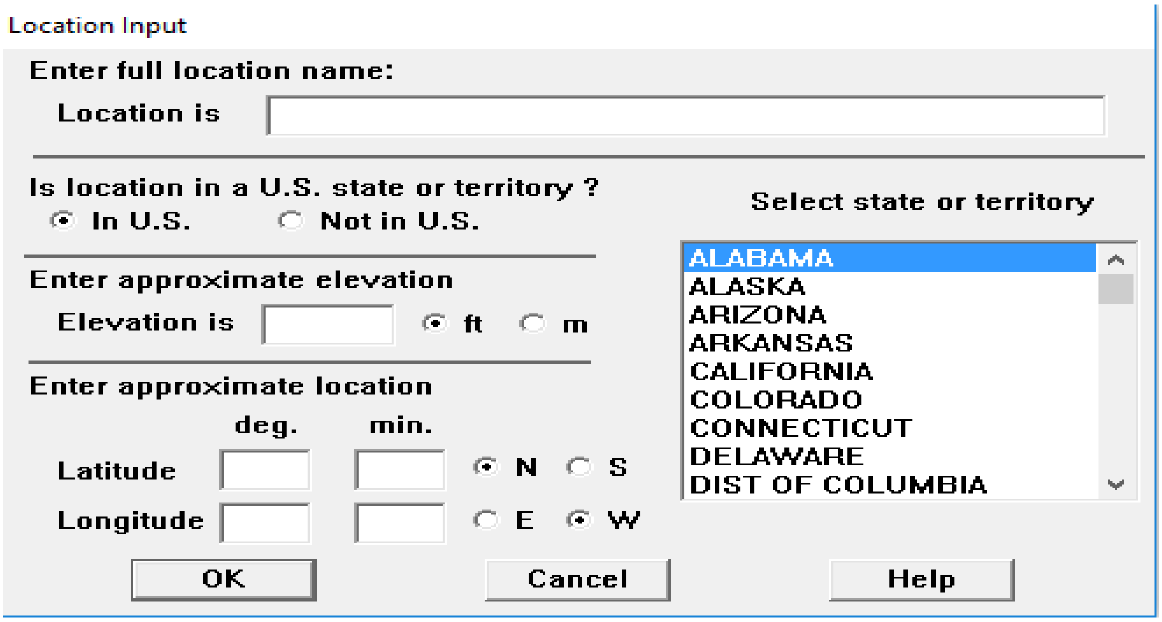


Figure 3.6: Location Input

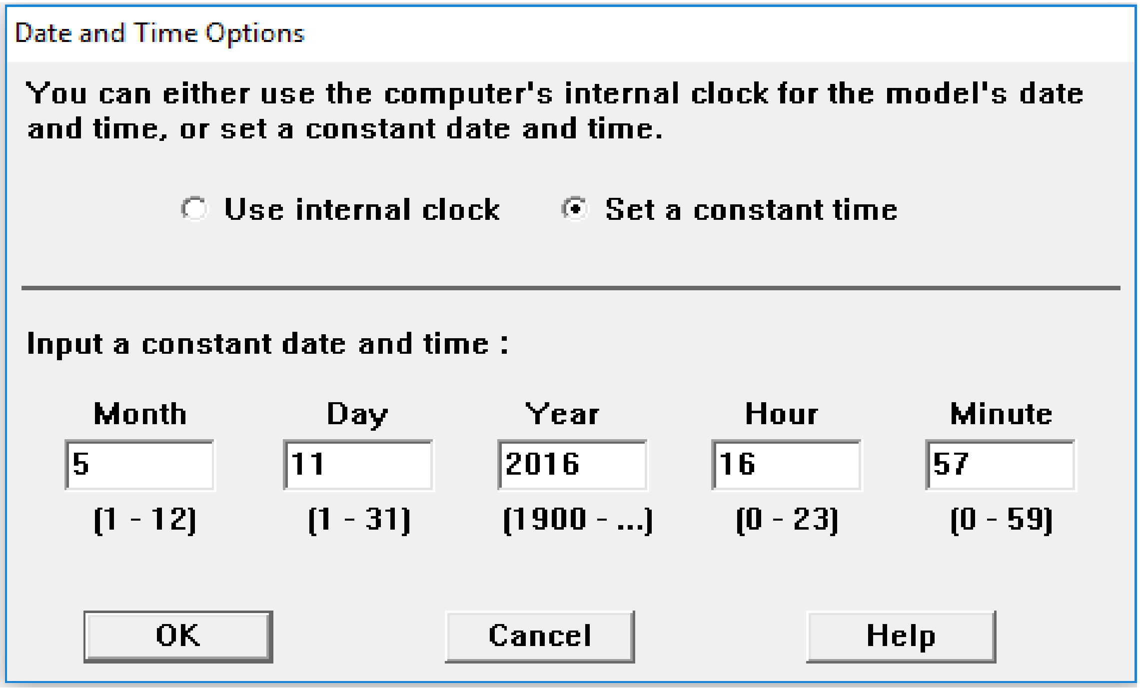


Figure 3.7: Date and Time Option

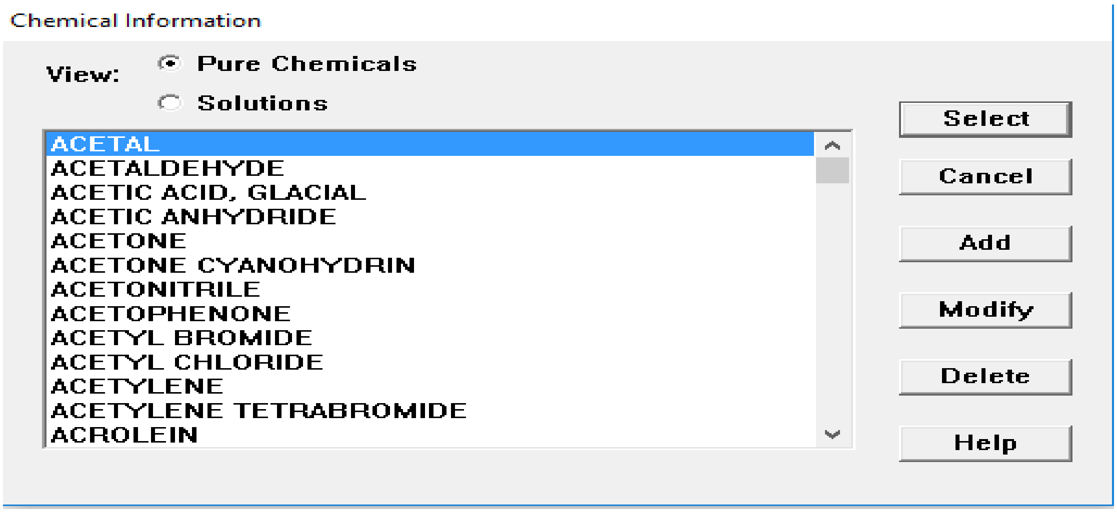


Figure 3.8: Chemical Information (Pure Chemicals)

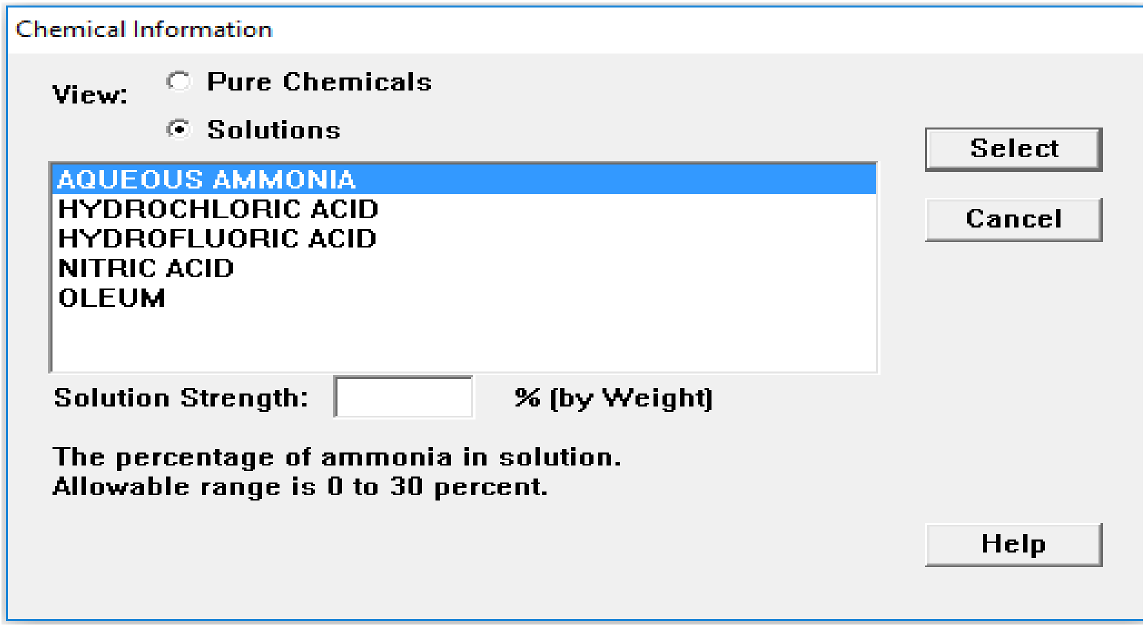


Figure 3.9: Chemical Information (Solutions)

The month, day, year, hour and minute for the scenario is entered if a set of constant time is chosen. The time must be entered in the form of the 24-hour time system.

Select Chemical from the SetUp menu to choose the chemical which is to be released. The dialog box of chemical information appears with a list of chemicals in ALOHA's chemical library. Pure Chemicals (Figure 3.7) or Solutions (Figure 3.8) is chosen for either category. Click on the name of the chemicals to be chosen after the chemical category, and then Select is clicked.

3.2.2 Entering Weather Information and Ground Roughness

In the SetUp menu, Atmospheric option is chosen and then User Input is selected. The first Atmospheric Options dialog box appears (Figure 3.9). Wind Speed, Wind direction, Measurement Height above ground, Ground roughness and Cloud Cover data need to be filled or selected. After clicking OK for the first Atmospheric Options dialog box, the second Atmospheric Options dialog box (Figure 3.10) appears and the data needs to be filled or to be choosed are air temperature, Stability Class, Inversion Height Options and Humidity, then click OK. The source of all figures come from the ALOHA software itself.

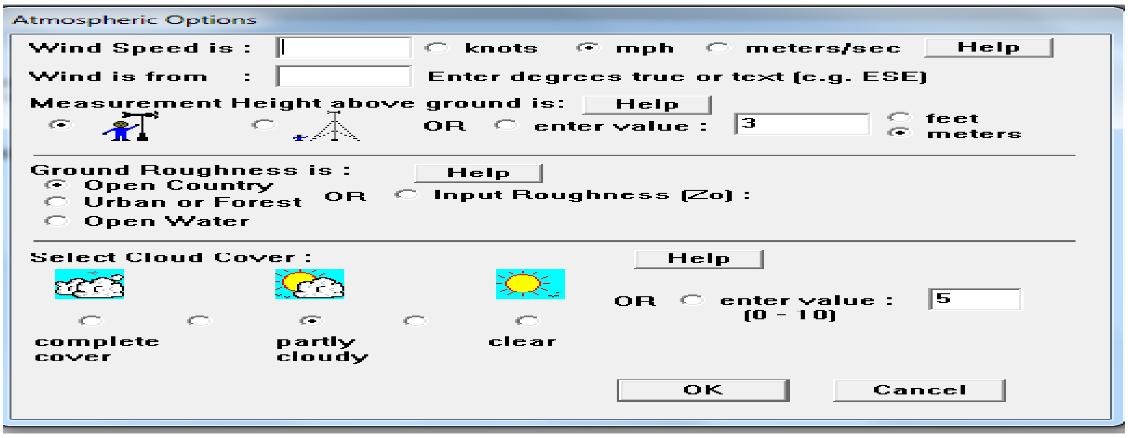


Figure 3.10: Atmospheric Options (First)

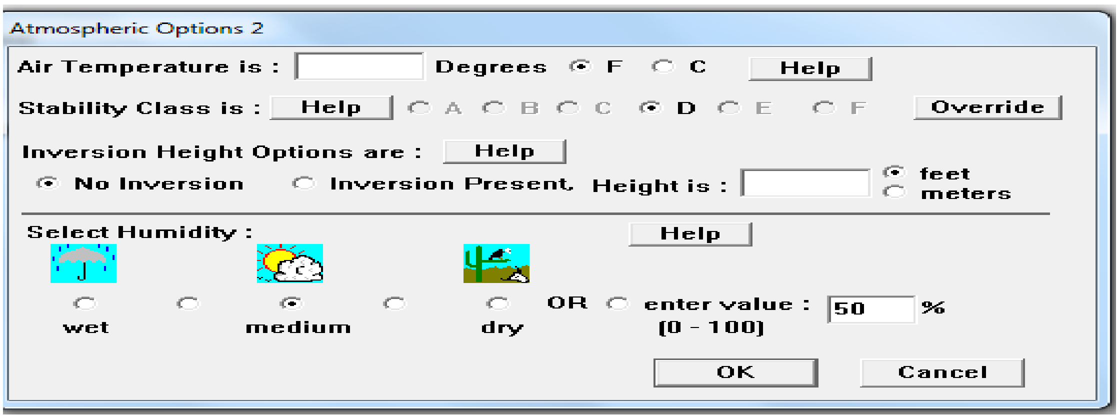


Figure 3.11: Atmospheric Options (Second)

3.2.3 Describing the Release

In the **SetUp** menu, point to Source, then select one from the four scenarios; Direct (Figure 3.11), Puddle (Figure 3.12, Figure 3.12 and Figure 3.14), Tank (Figure 3.15, Figure 3.16, Figure 3.17, Figure 3.18 and Figure 3.19) or Gas pipeline (Figure 3.20, Figure 3.21, and Figure 3.22). All the data needed in all scenarios must completed, otherwise a warning dialog box will appear.

The source strength information entered and the results of ALOHA's source strength calculation will appear in **Text Summary**. ALOHA 5.4.6 will estimate the Evaporation Rate or Burn Rate. **Source Strength** is chosen from the **Display** menu to see the Source Strength graph (Figure 3.23) for scenarios that had been chosen. The source of all figures come from the ALOHA software itself.

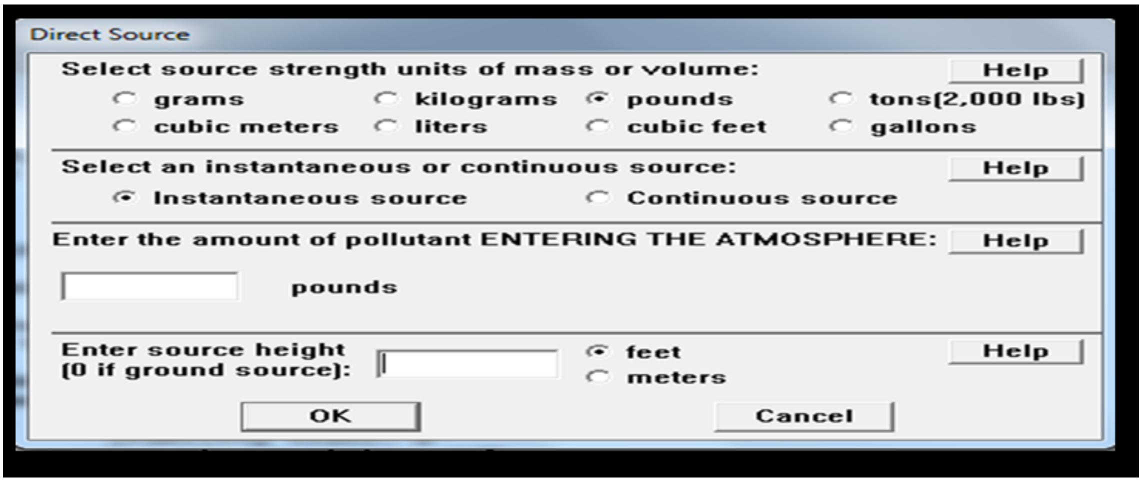


Figure 3.12: Direct Source

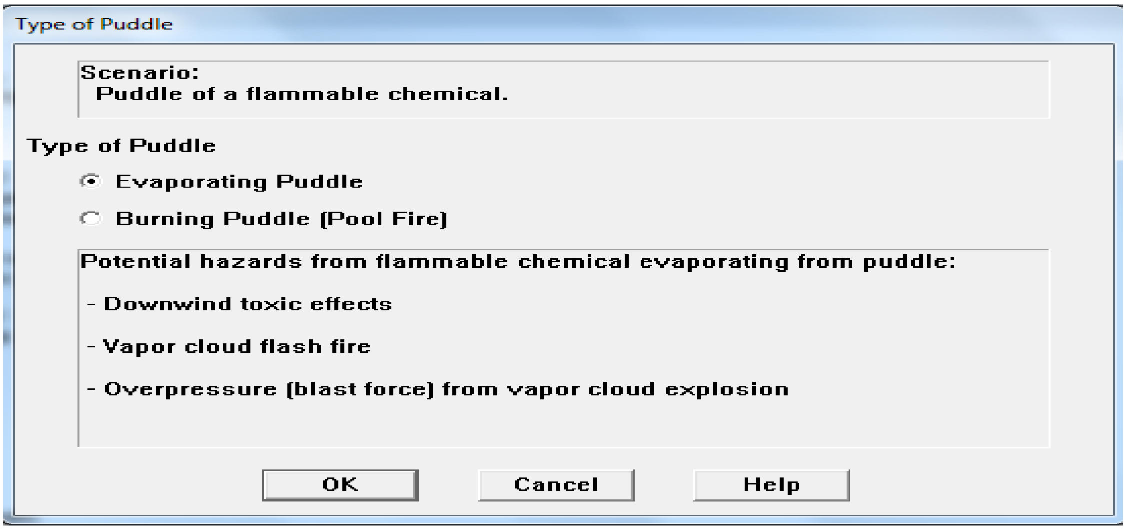


Figure 3.13: Puddle Input (First)

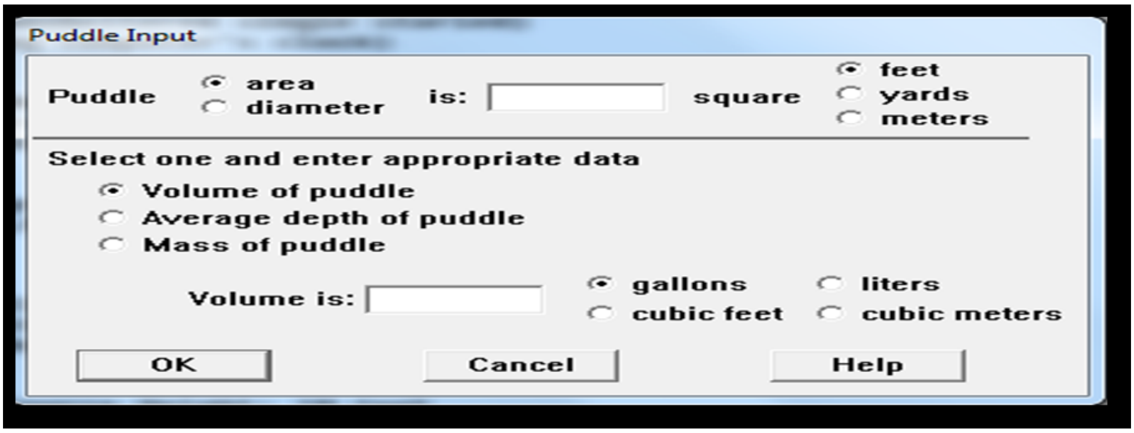


Figure 3.14: Puddle Input (Second)

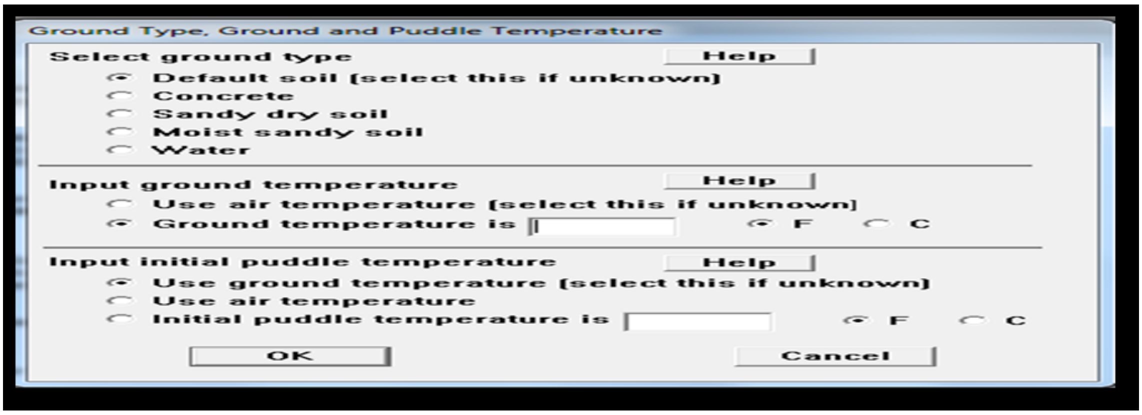


Figure 3.15: Ground Type, Ground and Puddle Temperature

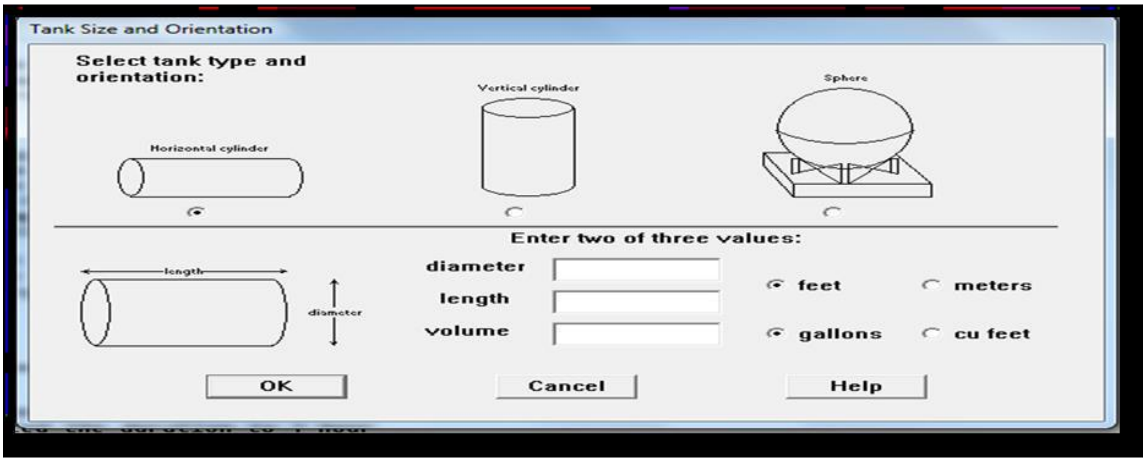


Figure 3.16: Tank Size and Orientation

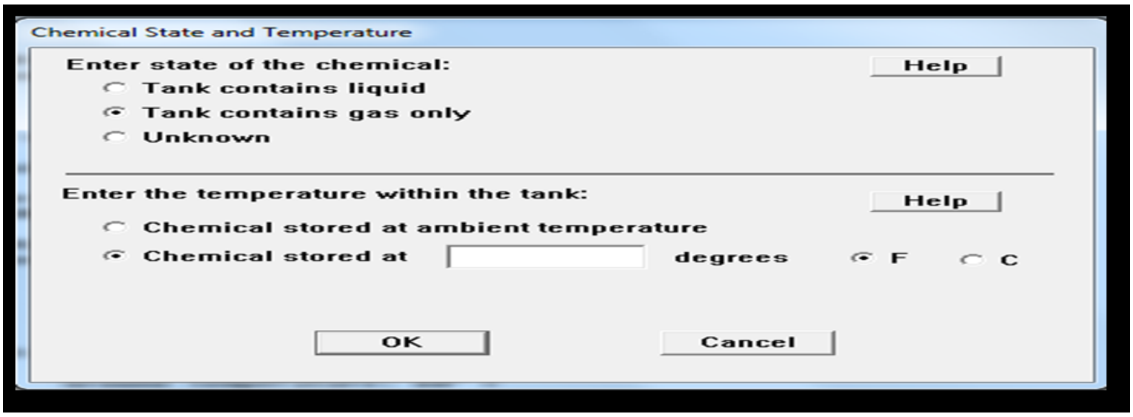


Figure 3.17: Chemical State and Temperature

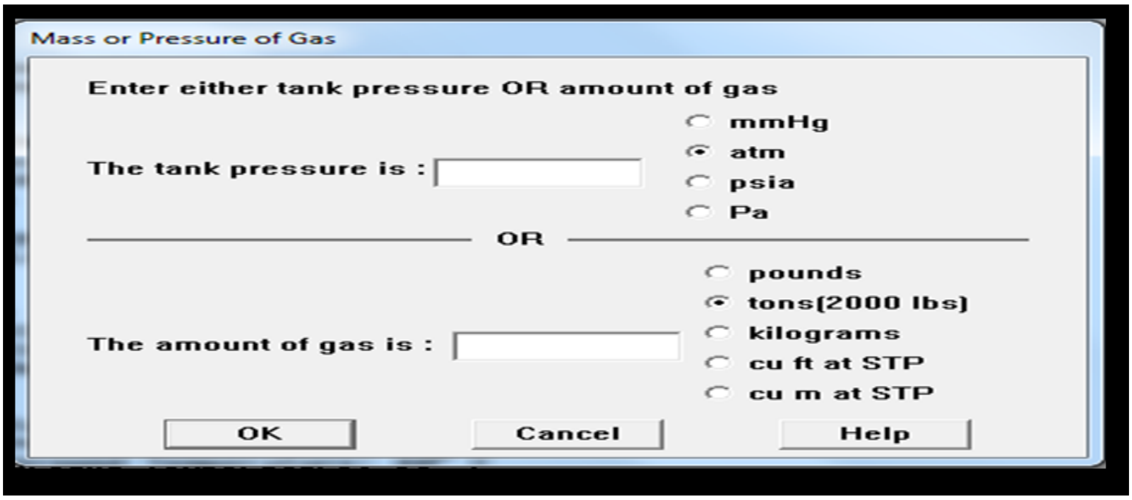


Figure 3.18: Mass or Pressure of Gas

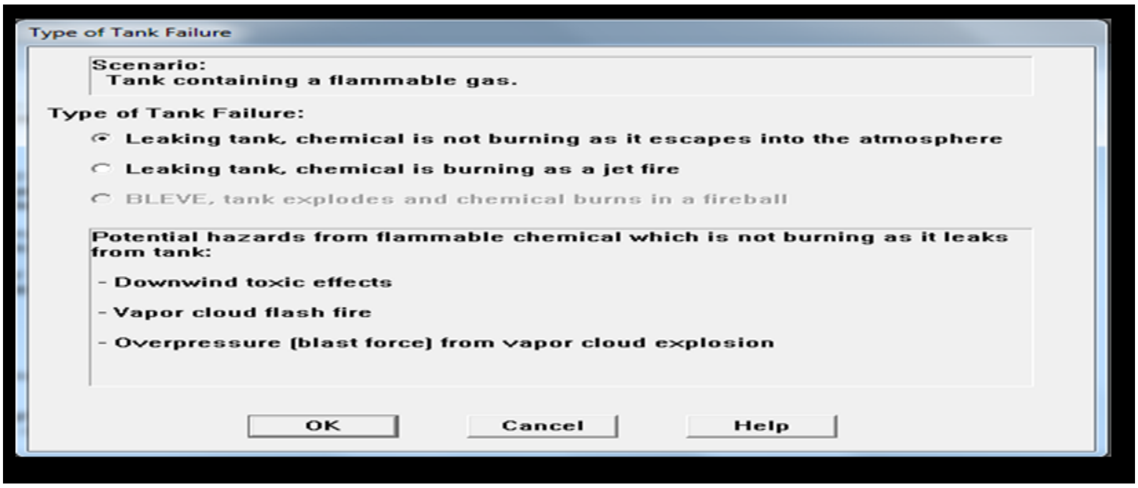


Figure 3.19: Type of Tank Failure

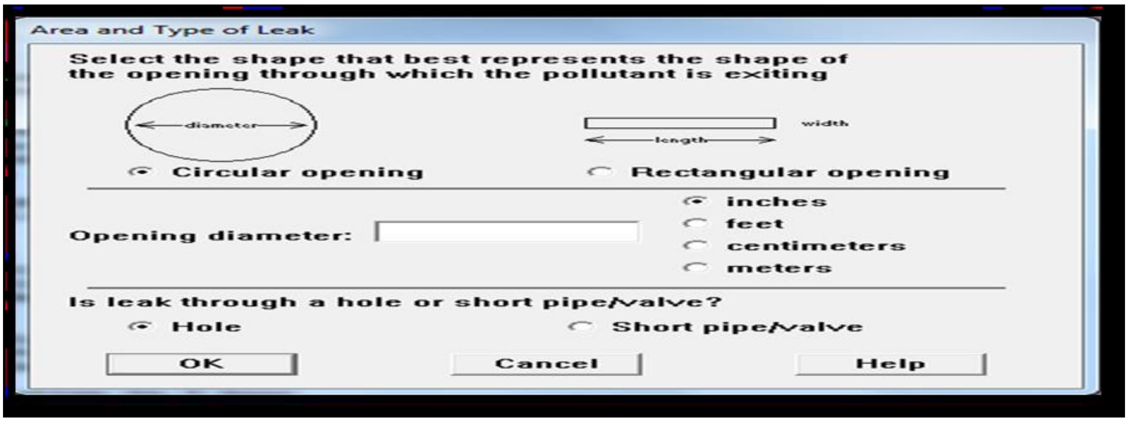


Figure 3.20: Area and Type of Leak

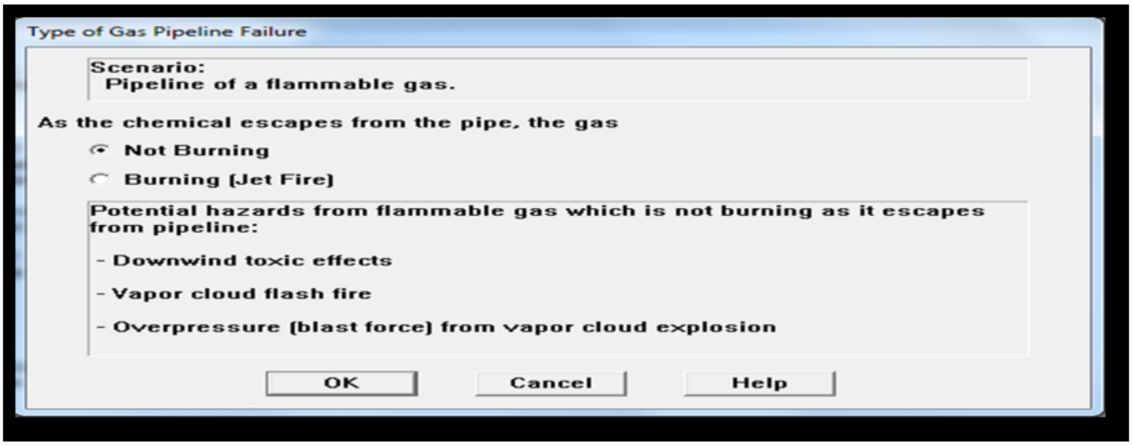


Figure 3.21: Type of Gas Pipeline Failure

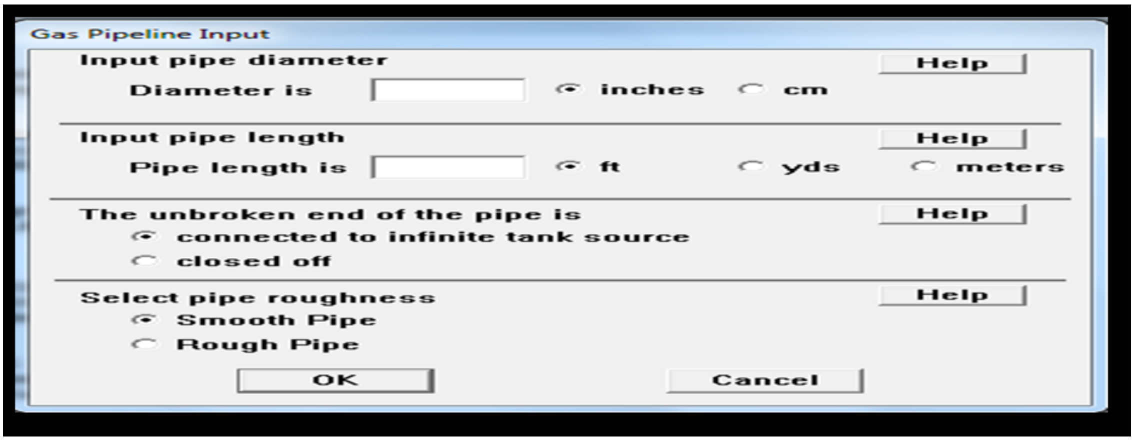


Figure 3.22: Gas Pipeline Input

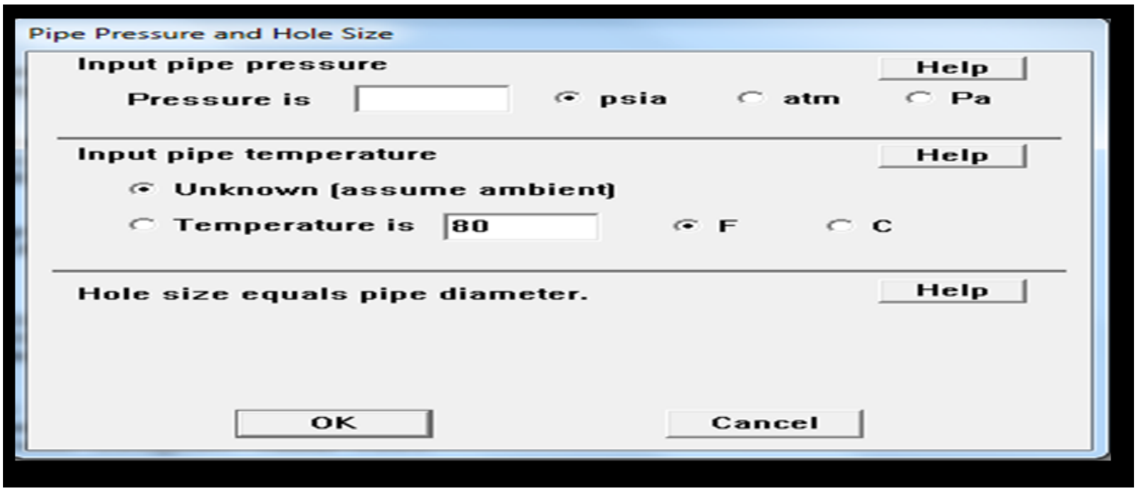


Figure 3.23: Pipe Pressure and Hole Size

3.2.4 Checking the Model Settings

To choose whether to make Gaussian or heavy gas dispersion computation, information about the properties of the chemicals and the amount of chemical released is used. The Calculation Option is selected from the SetUp menu and the dialog box of Calculation Options (Figure 3.24) appears. Choose either one of the three options and click OK. From the Display menu, Display Options is to be selected and Display Options dialog box appears (Figure 3.25). Output Units may be chosen either in English units or Metric units.

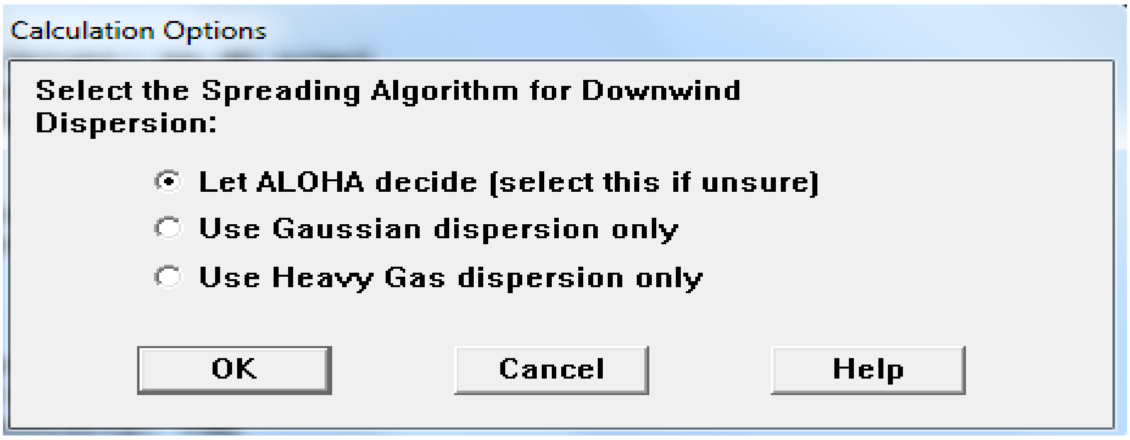


Figure 3.24: Calculation Options

.

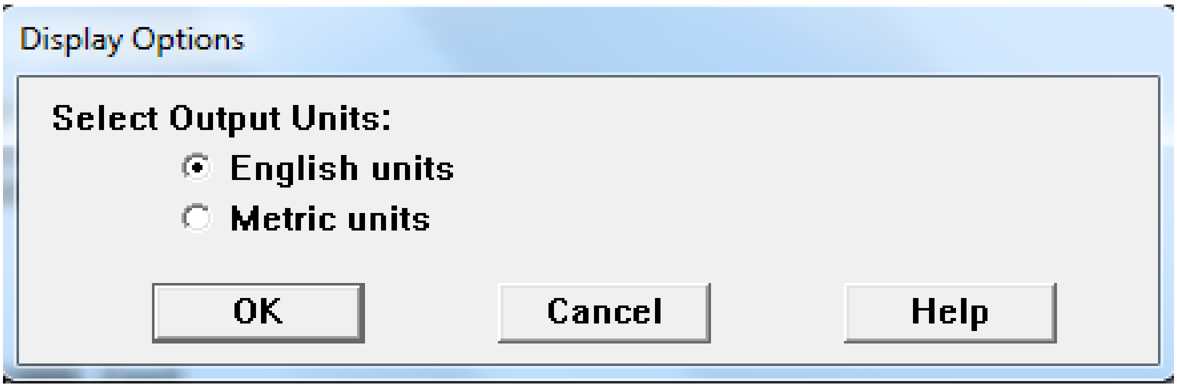


Figure 3.25: Display Options

3.2.5 Choosing LOCs and Creating a Threat Zone Estimate

Threat Zone is to be chosen from the Display menu and a Hazard to Analyze dialog box appears. ALOHA 5.4.6 can help to model three possible hazardous scenarios which are either toxic area, blast area or flammable area. The three scenarios needs to be chosen in the Hazard to Analyze dialog box (Figure 3.26).

ALOHA uses AEGL (Acute Exposure Guideline Level), ERPG (Emergency Response Planning Guideline), PAC (Protective Action Criteria) and IDLH (Immediately Dangerous to Life or Health) or the user himself can specify the Level of Concern (LOC) of the scenario. There are three LOC in the Toxic Level of Concern dialog box (Figure 3.27), which are Red Threat Zone, Orange Threat Zone and Yellow Threat Zone. Show wind direction confidence lines can be chosen either only for longest threat zone or for each threat zone. OK is clicked and ALOHA will display a threat zone (Figure 3.28, Figure 3.29, Figure 3.30 and Figure 3.31) estimate for the specific scenario entered.

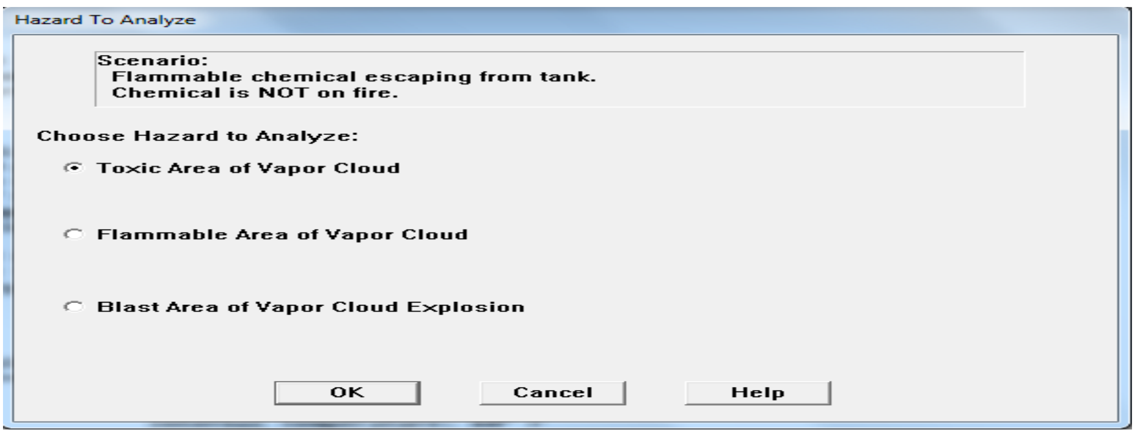


Figure 3.26: Hazard to Analyze

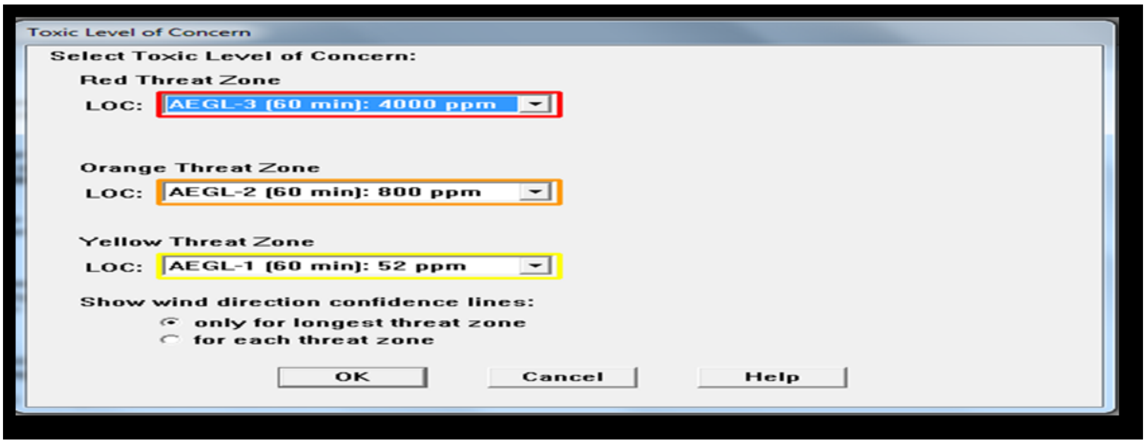
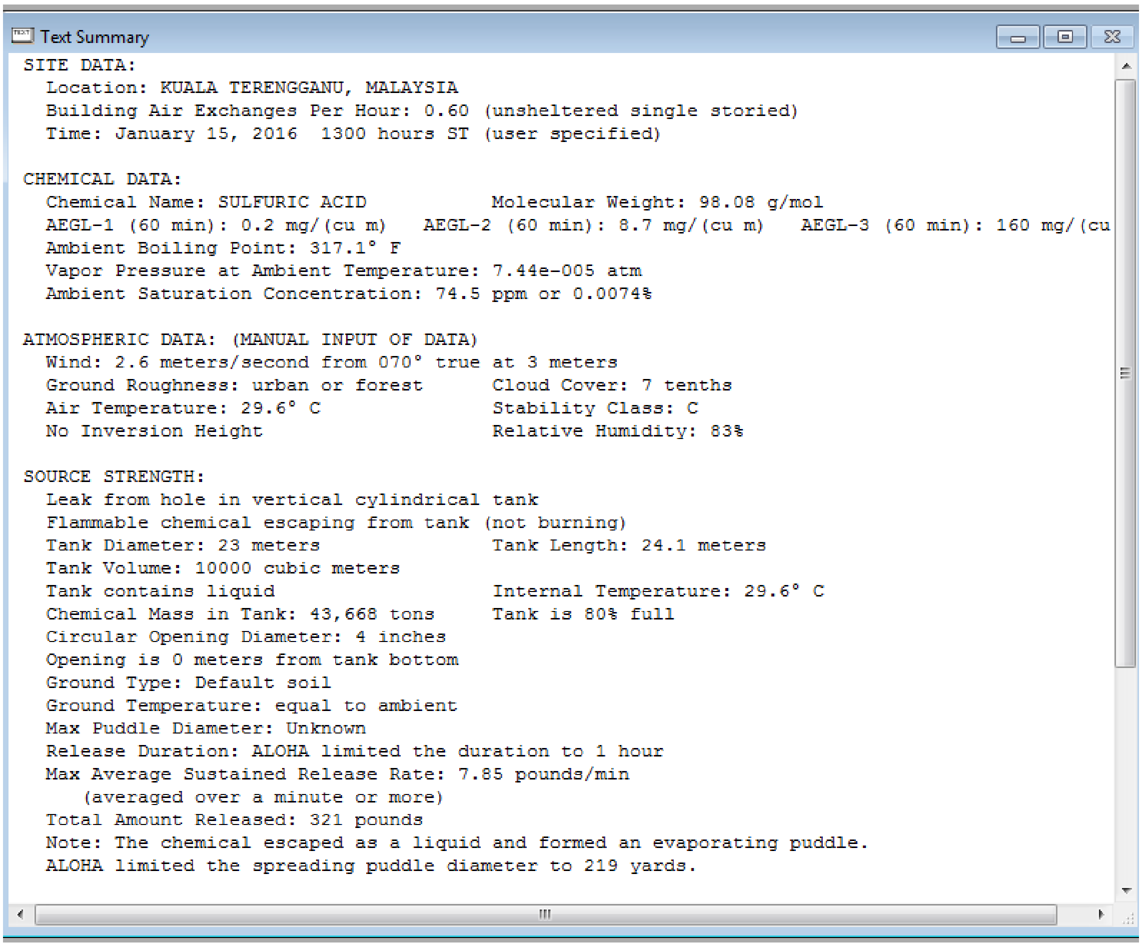


Figure 3.27: Toxic Level of Concern

3.4 Data

The figure 3.28 until figure 3.51 show the text summary for January, February, March, April, May, June, July, August, September, October, November and December which will be shown after the data has been put to run the ALOHA.



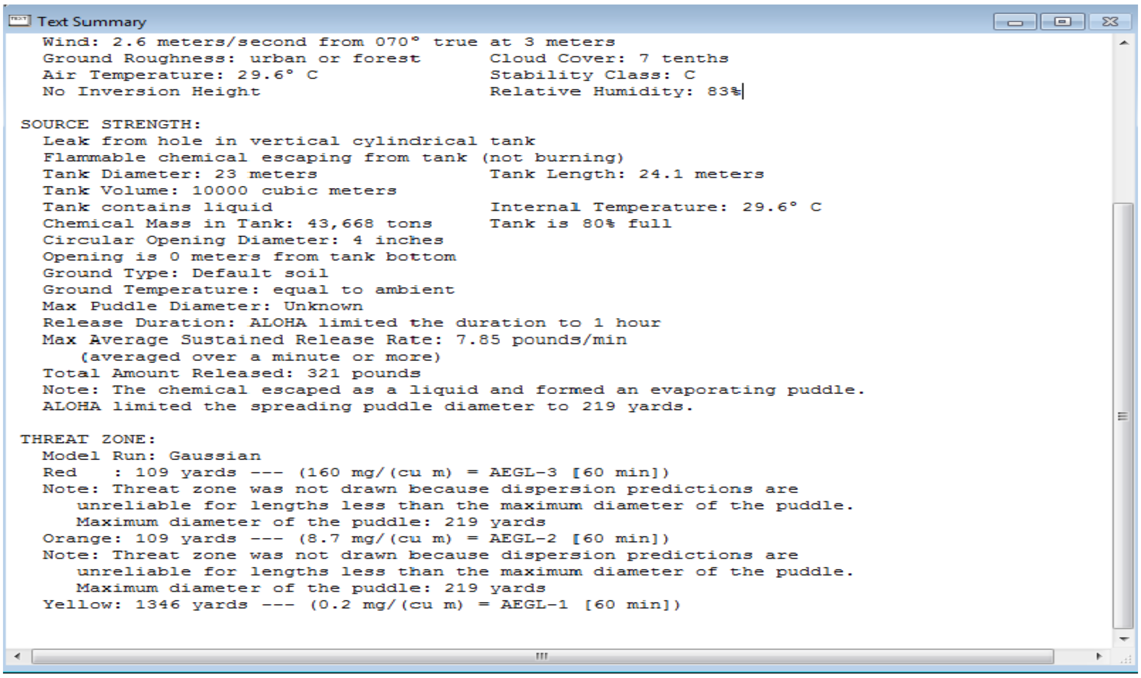
```
Text Summary
SITE DATA:
  Location: KUALA TERENGGANU, MALAYSIA
  Building Air Exchanges Per Hour: 0.60 (unsheltered single storied)
  Time: January 15, 2016  1300 hours ST (user specified)

CHEMICAL DATA:
  Chemical Name: SULFURIC ACID           Molecular Weight: 98.08 g/mol
  AEGL-1 (60 min): 0.2 mg/(cu m)    AEGL-2 (60 min): 8.7 mg/(cu m)    AEGL-3 (60 min): 160 mg/(cu
  Ambient Boiling Point: 317.1° F
  Vapor Pressure at Ambient Temperature: 7.44e-005 atm
  Ambient Saturation Concentration: 74.5 ppm or 0.0074%

ATMOSPHERIC DATA: (MANUAL INPUT OF DATA)
  Wind: 2.6 meters/second from 070° true at 3 meters
  Ground Roughness: urban or forest      Cloud Cover: 7 tenths
  Air Temperature: 29.6° C               Stability Class: C
  No Inversion Height                    Relative Humidity: 83%

SOURCE STRENGTH:
  Leak from hole in vertical cylindrical tank
  Flammable chemical escaping from tank (not burning)
  Tank Diameter: 23 meters               Tank Length: 24.1 meters
  Tank Volume: 10000 cubic meters
  Tank contains liquid                   Internal Temperature: 29.6° C
  Chemical Mass in Tank: 43,668 tons     Tank is 80% full
  Circular Opening Diameter: 4 inches
  Opening is 0 meters from tank bottom
  Ground Type: Default soil
  Ground Temperature: equal to ambient
  Max Puddle Diameter: Unknown
  Release Duration: ALOHA limited the duration to 1 hour
  Max Average Sustained Release Rate: 7.85 pounds/min
     (averaged over a minute or more)
  Total Amount Released: 321 pounds
  Note: The chemical escaped as a liquid and formed an evaporating puddle.
  ALOHA limited the spreading puddle diameter to 219 yards.
```

Figure 3.28: Text Summary for January (Site Data, Chemical Data, Atmospheric Data)

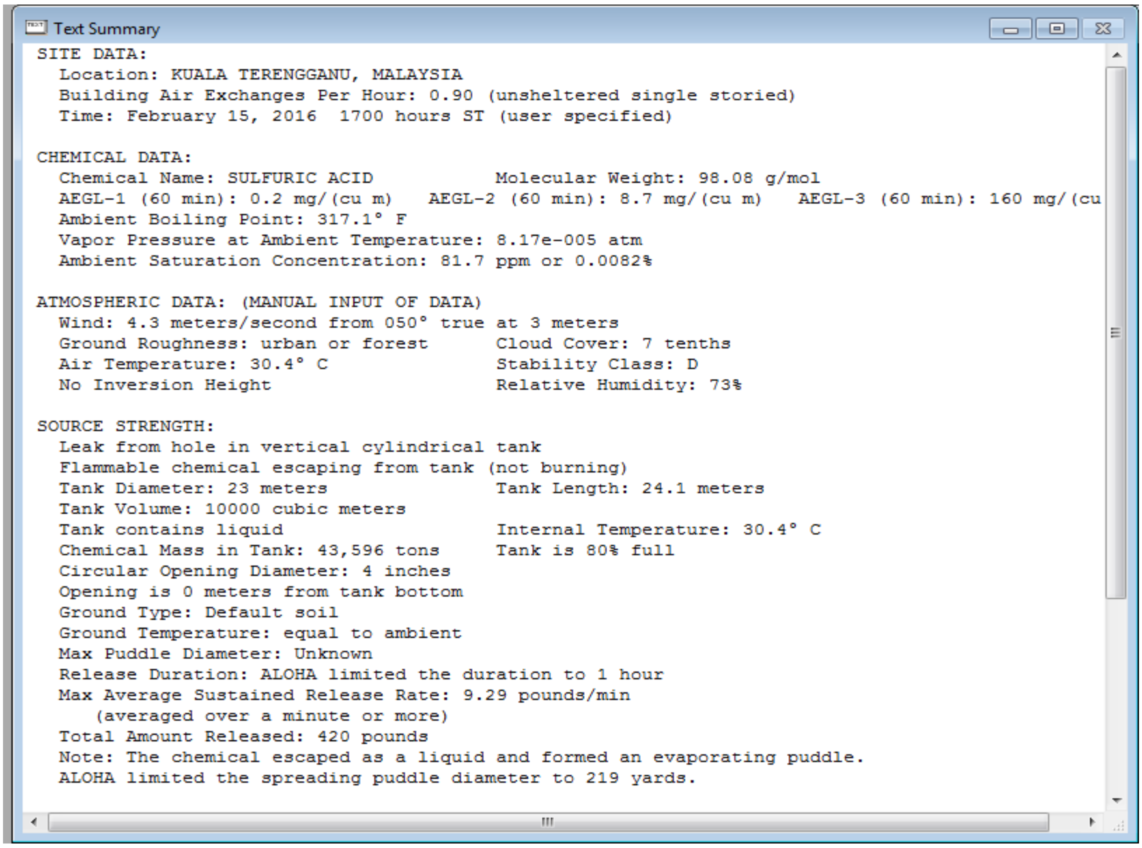


```
Text Summary
   Wind: 2.6 meters/second from 070° true at 3 meters
   Ground Roughness: urban or forest       Cloud Cover: 7 tenths
   Air Temperature: 29.6° C                Stability Class: C
   No Inversion Height                     Relative Humidity: 83%

 SOURCE STRENGTH:
   Leak from hole in vertical cylindrical tank
   Flammable chemical escaping from tank (not burning)
   Tank Diameter: 23 meters                Tank Length: 24.1 meters
   Tank Volume: 10000 cubic meters
   Tank contains liquid                    Internal Temperature: 29.6° C
   Chemical Mass in Tank: 43,668 tons      Tank is 80% full
   Circular Opening Diameter: 4 inches
   Opening is 0 meters from tank bottom
   Ground Type: Default soil
   Ground Temperature: equal to ambient
   Max Puddle Diameter: Unknown
   Release Duration: ALOHA limited the duration to 1 hour
   Max Average Sustained Release Rate: 7.85 pounds/min
      (averaged over a minute or more)
   Total Amount Released: 321 pounds
   Note: The chemical escaped as a liquid and formed an evaporating puddle.
   ALOHA limited the spreading puddle diameter to 219 yards.

 THREAT ZONE:
   Model Run: Gaussian
   Red    : 109 yards --- (160 mg/(cu m) = AEGL-3 [60 min])
   Note: Threat zone was not drawn because dispersion predictions are
      unreliable for lengths less than the maximum diameter of the puddle.
      Maximum diameter of the puddle: 219 yards
   Orange: 109 yards --- (8.7 mg/(cu m) = AEGL-2 [60 min])
   Note: Threat zone was not drawn because dispersion predictions are
      unreliable for lengths less than the maximum diameter of the puddle.
      Maximum diameter of the puddle: 219 yards
   Yellow: 1346 yards --- (0.2 mg/(cu m) = AEGL-1 [60 min])
```

Figure 3.29: Text Summary for January (Source Strength and Threat Zone)



```
Text Summary
 SITE DATA:
   Location: KUALA TERENGGANU, MALAYSIA
   Building Air Exchanges Per Hour: 0.90 (unsheltered single storied)
   Time: February 15, 2016  1700 hours ST (user specified)

 CHEMICAL DATA:
   Chemical Name: SULFURIC ACID            Molecular Weight: 98.08 g/mol
   AEGL-1 (60 min): 0.2 mg/(cu m)    AEGL-2 (60 min): 8.7 mg/(cu m)    AEGL-3 (60 min): 160 mg/(cu
   Ambient Boiling Point: 317.1° F
   Vapor Pressure at Ambient Temperature: 8.17e-005 atm
   Ambient Saturation Concentration: 81.7 ppm or 0.0082%

 ATMOSPHERIC DATA: (MANUAL INPUT OF DATA)
   Wind: 4.3 meters/second from 050° true at 3 meters
   Ground Roughness: urban or forest       Cloud Cover: 7 tenths
   Air Temperature: 30.4° C                Stability Class: D
   No Inversion Height                     Relative Humidity: 73%

 SOURCE STRENGTH:
   Leak from hole in vertical cylindrical tank
   Flammable chemical escaping from tank (not burning)
   Tank Diameter: 23 meters                Tank Length: 24.1 meters
   Tank Volume: 10000 cubic meters
   Tank contains liquid                    Internal Temperature: 30.4° C
   Chemical Mass in Tank: 43,596 tons      Tank is 80% full
   Circular Opening Diameter: 4 inches
   Opening is 0 meters from tank bottom
   Ground Type: Default soil
   Ground Temperature: equal to ambient
   Max Puddle Diameter: Unknown
   Release Duration: ALOHA limited the duration to 1 hour
   Max Average Sustained Release Rate: 9.29 pounds/min
      (averaged over a minute or more)
   Total Amount Released: 420 pounds
   Note: The chemical escaped as a liquid and formed an evaporating puddle.
   ALOHA limited the spreading puddle diameter to 219 yards.
```

Figure 3.30: Text Summary for February (Site Data, Chemical Data, Atmospheric Data)

```
Text Summary
  Wind: 4.3 meters/second from 050° true at 3 meters
  Ground Roughness: urban or forest       Cloud Cover: 7 tenths
  Air Temperature: 30.4° C                Stability Class: D
  No Inversion Height                     Relative Humidity: 73%

SOURCE STRENGTH:
  Leak from hole in vertical cylindrical tank
  Flammable chemical escaping from tank (not burning)
  Tank Diameter: 23 meters                Tank Length: 24.1 meters
  Tank Volume: 10000 cubic meters
  Tank contains liquid                    Internal Temperature: 30.4° C
  Chemical Mass in Tank: 43,596 tons      Tank is 80% full
  Circular Opening Diameter: 4 inches
  Opening is 0 meters from tank bottom
  Ground Type: Default soil
  Ground Temperature: equal to ambient
  Max Puddle Diameter: Unknown
  Release Duration: ALOHA limited the duration to 1 hour
  Max Average Sustained Release Rate: 9.29 pounds/min
     (averaged over a minute or more)
  Total Amount Released: 420 pounds
  Note: The chemical escaped as a liquid and formed an evaporating puddle.
  ALOHA limited the spreading puddle diameter to 219 yards.

THREAT ZONE:
  Model Run: Gaussian
  Red   : 109 yards --- (160 mg/(cu m) = AEGL-3 [60 min])
  Note: Threat zone was not drawn because dispersion predictions are
     unreliable for lengths less than the maximum diameter of the puddle.
     Maximum diameter of the puddle: 219 yards
  Orange: 114 yards --- (8.7 mg/(cu m) = AEGL-2 [60 min])
  Note: Threat zone was not drawn because dispersion predictions are
     unreliable for lengths less than the maximum diameter of the puddle.
     Maximum diameter of the puddle: 219 yards
  Yellow: 1757 yards --- (0.2 mg/(cu m) = AEGL-1 [60 min])
```

Figure 3.31: Text Summary for February (Source Strength and Threat Zone)

```
Text Summary
SITE DATA:
  Location: KUALA TERENGGANU, MALAYSIA
  Building Air Exchanges Per Hour: 0.80 (unsheltered single storied)
  Time: March 15, 2016  0100 hours ST (user specified)

CHEMICAL DATA:
  Chemical Name: SULFURIC ACID            Molecular Weight: 98.08 g/mol
  AEGL-1 (60 min): 0.2 mg/(cu m)    AEGL-2 (60 min): 8.7 mg/(cu m)    AEGL-3 (60 min): 160 mg/(cu
  Ambient Boiling Point: 317.1° F
  Vapor Pressure at Ambient Temperature: 9.27e-005 atm
  Ambient Saturation Concentration: 92.8 ppm or 0.0093%

ATMOSPHERIC DATA: (MANUAL INPUT OF DATA)
  Wind: 3.7 meters/second from 060° true at 3 meters
  Ground Roughness: urban or forest       Cloud Cover: 7 tenths
  Air Temperature: 31.5° C                Stability Class: D
  No Inversion Height                     Relative Humidity: 58%

SOURCE STRENGTH:
  Leak from hole in vertical cylindrical tank
  Flammable chemical escaping from tank (not burning)
  Tank Diameter: 23 meters                Tank Length: 24.1 meters
  Tank Volume: 10000 cubic meters
  Tank contains liquid                    Internal Temperature: 31.5° C
  Chemical Mass in Tank: 43,497 tons      Tank is 80% full
  Circular Opening Diameter: 4 inches
  Opening is 0 meters from tank bottom
  Ground Type: Default soil
  Ground Temperature: equal to ambient
  Max Puddle Diameter: Unknown
  Release Duration: ALOHA limited the duration to 1 hour
  Max Average Sustained Release Rate: 7.76 pounds/min
     (averaged over a minute or more)
  Total Amount Released: 357 pounds
  Note: The chemical escaped as a liquid and formed an evaporating puddle.
  ALOHA limited the spreading puddle diameter to 219 yards.
```

Figure 3.32: Text Summary for March (Site Data, Chemical Data, Atmospheric Data)

Text Summary

```
  Leak from hole in vertical cylindrical tank
  Flammable chemical escaping from tank (not burning)
  Tank Diameter: 23 meters              Tank Length: 24.1 meters
  Tank Volume: 10000 cubic meters
  Tank contains liquid                  Internal Temperature: 31.5° C
  Chemical Mass in Tank: 43,497 tons    Tank is 80% full
  Circular Opening Diameter: 4 inches
  Opening is 0 meters from tank bottom
  Ground Type: Default soil
  Ground Temperature: equal to ambient
  Max Puddle Diameter: Unknown
  Release Duration: ALOHA limited the duration to 1 hour
  Max Average Sustained Release Rate: 7.76 pounds/min
     (averaged over a minute or more)
  Total Amount Released: 357 pounds
  Note: The chemical escaped as a liquid and formed an evaporating puddle.
  ALOHA limited the spreading puddle diameter to 219 yards.

THREAT ZONE:
  Model Run: Gaussian
  Red   : 109 yards --- (160 mg/(cu m) = AEGL-3 [60 min])
  Note: Threat zone was not drawn because dispersion predictions are
     unreliable for lengths less than the maximum diameter of the puddle.
     Maximum diameter of the puddle: 219 yards
  Orange: 112 yards --- (8.7 mg/(cu m) = AEGL-2 [60 min])
  Note: Threat zone was not drawn because dispersion predictions are
     unreliable for lengths less than the maximum diameter of the puddle.
     Maximum diameter of the puddle: 219 yards
  Yellow: 1722 yards --- (0.2 mg/(cu m) = AEGL-1 [60 min])

THREAT AT POINT:
  Concentration Estimates at the point:
  East: 10,596 miles                    South: 2,392 miles
  The point selected is upwind of the source.
  The concentration is zero.
```

Figure 3.33: Text Summary for March (Source Strength and Threat Zone)

Text Summary

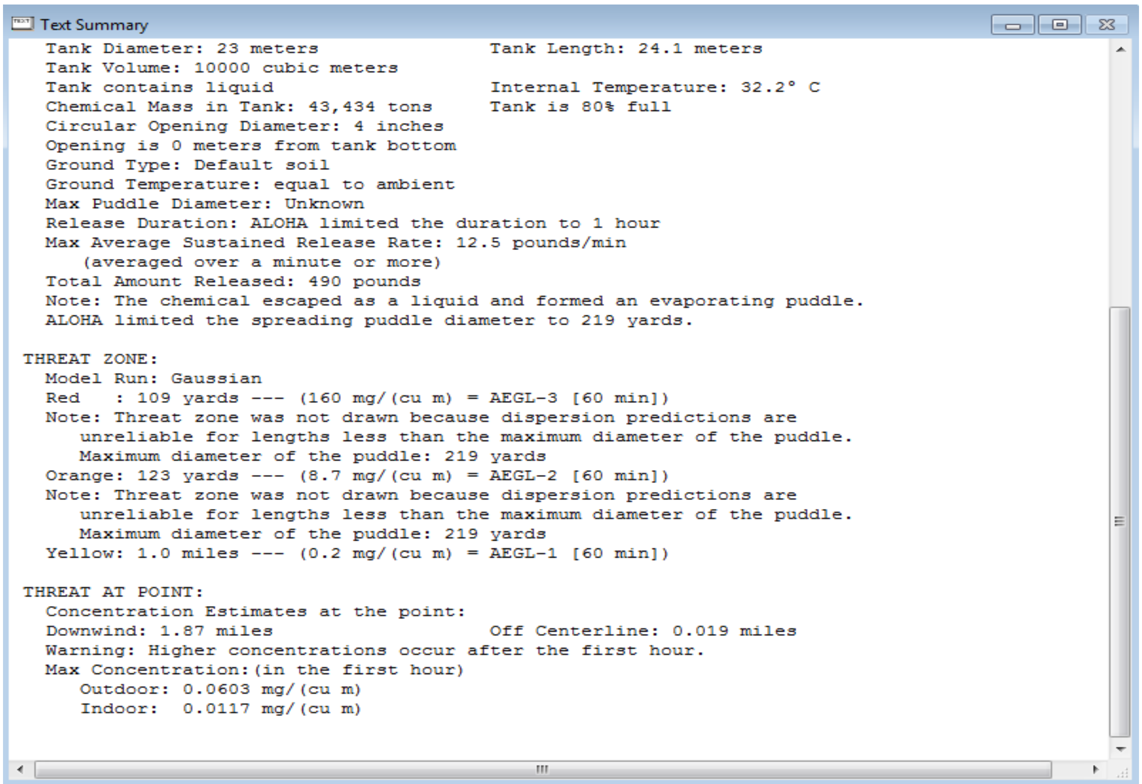
```
SITE DATA:
  Location: KUALA TERENGGANU, MALAYSIA
  Building Air Exchanges Per Hour: 0.61 (unsheltered single storied)
  Time: April 15, 2016  1300 hours ST (user specified)

CHEMICAL DATA:
  Chemical Name: SULFURIC ACID          Molecular Weight: 98.08 g/mol
  AEGL-1 (60 min): 0.2 mg/(cu m)   AEGL-2 (60 min): 8.7 mg/(cu m)   AEGL-3 (60 min): 160 mg/(cu
  Ambient Boiling Point: 317.1° F
  Vapor Pressure at Ambient Temperature: 1.00e-004 atm
  Ambient Saturation Concentration: 101 ppm or 0.010%

ATMOSPHERIC DATA: (MANUAL INPUT OF DATA)
  Wind: 2.5 meters/second from 060° true at 3 meters
  Ground Roughness: urban or forest     Cloud Cover: 5 tenths
  Air Temperature: 32.2° C              Stability Class: C
  No Inversion Height                   Relative Humidity: 73%

SOURCE STRENGTH:
  Leak from hole in vertical cylindrical tank
  Flammable chemical escaping from tank (not burning)
  Tank Diameter: 23 meters              Tank Length: 24.1 meters
  Tank Volume: 10000 cubic meters
  Tank contains liquid                  Internal Temperature: 32.2° C
  Chemical Mass in Tank: 43,434 tons    Tank is 80% full
  Circular Opening Diameter: 4 inches
  Opening is 0 meters from tank bottom
  Ground Type: Default soil
  Ground Temperature: equal to ambient
  Max Puddle Diameter: Unknown
  Release Duration: ALOHA limited the duration to 1 hour
  Max Average Sustained Release Rate: 12.5 pounds/min
     (averaged over a minute or more)
  Total Amount Released: 490 pounds
  Note: The chemical escaped as a liquid and formed an evaporating puddle.
  ALOHA limited the spreading puddle diameter to 219 yards.
```

Figure 3.34: Text Summary for April (Site Data, Chemical Data, Atmospheric Data)

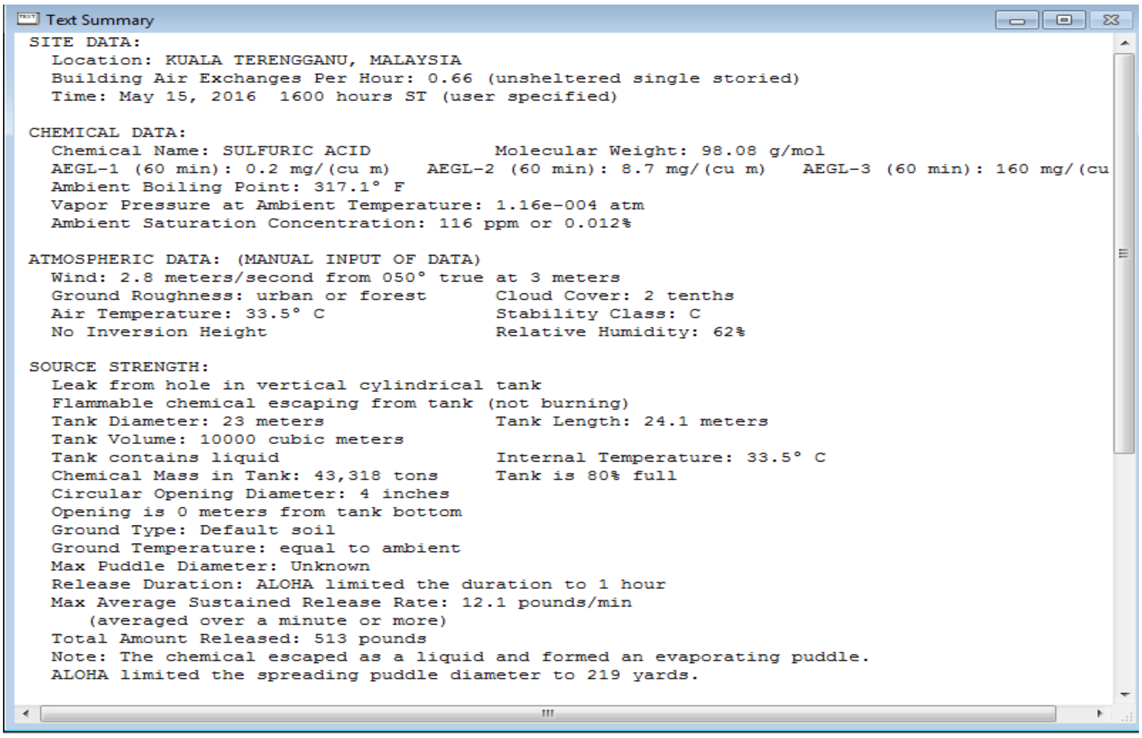


```
Text Summary
  Tank Diameter: 23 meters                Tank Length: 24.1 meters
  Tank Volume: 10000 cubic meters
  Tank contains liquid                    Internal Temperature: 32.2° C
  Chemical Mass in Tank: 43,434 tons      Tank is 80% full
  Circular Opening Diameter: 4 inches
  Opening is 0 meters from tank bottom
  Ground Type: Default soil
  Ground Temperature: equal to ambient
  Max Puddle Diameter: Unknown
  Release Duration: ALOHA limited the duration to 1 hour
  Max Average Sustained Release Rate: 12.5 pounds/min
     (averaged over a minute or more)
  Total Amount Released: 490 pounds
  Note: The chemical escaped as a liquid and formed an evaporating puddle.
  ALOHA limited the spreading puddle diameter to 219 yards.

THREAT ZONE:
  Model Run: Gaussian
  Red   : 109 yards --- (160 mg/(cu m) = AEGL-3 [60 min])
  Note: Threat zone was not drawn because dispersion predictions are
     unreliable for lengths less than the maximum diameter of the puddle.
     Maximum diameter of the puddle: 219 yards
  Orange: 123 yards --- (8.7 mg/(cu m) = AEGL-2 [60 min])
  Note: Threat zone was not drawn because dispersion predictions are
     unreliable for lengths less than the maximum diameter of the puddle.
     Maximum diameter of the puddle: 219 yards
  Yellow: 1.0 miles --- (0.2 mg/(cu m) = AEGL-1 [60 min])

THREAT AT POINT:
  Concentration Estimates at the point:
  Downwind: 1.87 miles                    Off Centerline: 0.019 miles
  Warning: Higher concentrations occur after the first hour.
  Max Concentration:(in the first hour)
     Outdoor: 0.0603 mg/(cu m)
     Indoor:  0.0117 mg/(cu m)
```

Figure 3.35: Text Summary for April (Source Strength and Threat Zone)



```
Text Summary
SITE DATA:
  Location: KUALA TERENGGANU, MALAYSIA
  Building Air Exchanges Per Hour: 0.66 (unsheltered single storied)
  Time: May 15, 2016  1600 hours ST (user specified)

CHEMICAL DATA:
  Chemical Name: SULFURIC ACID            Molecular Weight: 98.08 g/mol
  AEGL-1 (60 min): 0.2 mg/(cu m)    AEGL-2 (60 min): 8.7 mg/(cu m)    AEGL-3 (60 min): 160 mg/(cu
  Ambient Boiling Point: 317.1° F
  Vapor Pressure at Ambient Temperature: 1.16e-004 atm
  Ambient Saturation Concentration: 116 ppm or 0.012%

ATMOSPHERIC DATA: (MANUAL INPUT OF DATA)
  Wind: 2.8 meters/second from 050° true at 3 meters
  Ground Roughness: urban or forest       Cloud Cover: 2 tenths
  Air Temperature: 33.5° C                Stability Class: C
  No Inversion Height                     Relative Humidity: 62%

SOURCE STRENGTH:
  Leak from hole in vertical cylindrical tank
  Flammable chemical escaping from tank (not burning)
  Tank Diameter: 23 meters                Tank Length: 24.1 meters
  Tank Volume: 10000 cubic meters
  Tank contains liquid                    Internal Temperature: 33.5° C
  Chemical Mass in Tank: 43,318 tons      Tank is 80% full
  Circular Opening Diameter: 4 inches
  Opening is 0 meters from tank bottom
  Ground Type: Default soil
  Ground Temperature: equal to ambient
  Max Puddle Diameter: Unknown
  Release Duration: ALOHA limited the duration to 1 hour
  Max Average Sustained Release Rate: 12.1 pounds/min
     (averaged over a minute or more)
  Total Amount Released: 513 pounds
  Note: The chemical escaped as a liquid and formed an evaporating puddle.
  ALOHA limited the spreading puddle diameter to 219 yards.
```

Figure 3.36: Text Summary for May (Site Data, Chemical Data, Atmospheric Data)

Text Summary

```
  Tank Diameter: 23 meters              Tank Length: 24.1 meters
  Tank Volume: 10000 cubic meters
  Tank contains liquid                  Internal Temperature: 33.5° C
  Chemical Mass in Tank: 43,318 tons    Tank is 80% full
  Circular Opening Diameter: 4 inches
  Opening is 0 meters from tank bottom
  Ground Type: Default soil
  Ground Temperature: equal to ambient
  Max Puddle Diameter: Unknown
  Release Duration: ALOHA limited the duration to 1 hour
  Max Average Sustained Release Rate: 12.1 pounds/min
     (averaged over a minute or more)
  Total Amount Released: 513 pounds
  Note: The chemical escaped as a liquid and formed an evaporating puddle.
  ALOHA limited the spreading puddle diameter to 219 yards.

THREAT ZONE:
  Model Run: Gaussian
  Red   : 109 yards --- (160 mg/(cu m) = AEGL-3 [60 min])
  Note: Threat zone was not drawn because dispersion predictions are
     unreliable for lengths less than the maximum diameter of the puddle.
     Maximum diameter of the puddle: 219 yards
  Orange: 114 yards --- (8.7 mg/(cu m) = AEGL-2 [60 min])
  Note: Threat zone was not drawn because dispersion predictions are
     unreliable for lengths less than the maximum diameter of the puddle.
     Maximum diameter of the puddle: 219 yards
  Yellow: 1659 yards --- (0.2 mg/(cu m) = AEGL-1 [60 min])

THREAT AT POINT:
  Concentration Estimates at the point:
  Downwind: 1.02 miles                  Off Centerline: 0.0035 miles
  Warning: Higher concentrations occur after the first hour.
  Max Concentration:(in the first hour)
     Outdoor: 0.175 mg/(cu m)
     Indoor:  0.0517 mg/(cu m)
```

Figure 3.37: Text Summary for May (Source Strength and Threat Zone)

Text Summary

```
  Location: KUALA TERENGGANU, MALAYSIA
  Building Air Exchanges Per Hour: 0.77 (unsheltered single storied)
  Time: June 15, 2016  0500 hours ST (user specified)

CHEMICAL DATA:
  Chemical Name: SULFURIC ACID          Molecular Weight: 98.08 g/mol
  AEGL-1 (60 min): 0.2 mg/(cu m)   AEGL-2 (60 min): 8.7 mg/(cu m)   AEGL-3 (60 min): 160 mg/(cu
  Ambient Boiling Point: 317.1° F
  Vapor Pressure at Ambient Temperature: 5.41e-005 atm
  Ambient Saturation Concentration: 54.2 ppm or 0.0054%

ATMOSPHERIC DATA: (MANUAL INPUT OF DATA)
  Wind: 3.7 meters/second from 330° true at 3 meters
  Ground Roughness: urban or forest     Cloud Cover: 7 tenths
  Air Temperature: 26.9° C              Stability Class: D
  No Inversion Height                   Relative Humidity: 85%

SOURCE STRENGTH:
  Leak from hole in vertical cylindrical tank
  Flammable chemical escaping from tank (not burning)
  Tank Diameter: 23 meters              Tank Length: 24.1 meters
  Tank Volume: 10000 cubic meters
  Tank contains liquid                  Internal Temperature: 26.9° C
  Chemical Mass in Tank: 43,916 tons    Tank is 80% full
  Circular Opening Diameter: 4 inches
  Opening is 0 meters from tank bottom
  Ground Type: Default soil
  Ground Temperature: equal to ambient
  Max Puddle Diameter: Unknown
  Release Duration: ALOHA limited the duration to 1 hour
  Max Average Sustained Release Rate: 4.62 pounds/min
     (averaged over a minute or more)
  Total Amount Released: 212 pounds
  Note: The chemical escaped as a liquid and formed an evaporating puddle.
  ALOHA limited the spreading puddle diameter to 219 yards.
```

Figure 3.38: Text Summary for Jun (Site Data, Chemical Data, Atmospheric Data)

```
Text Summary
   Wind: 3.7 meters/second from 330° true at 3 meters
   Ground Roughness: urban or forest      Cloud Cover: 7 tenths
   Air Temperature: 26.9° C               Stability Class: D
   No Inversion Height                    Relative Humidity: 85%

 SOURCE STRENGTH:
   Leak from hole in vertical cylindrical tank
   Flammable chemical escaping from tank (not burning)
   Tank Diameter: 23 meters               Tank Length: 24.1 meters
   Tank Volume: 10000 cubic meters
   Tank contains liquid                   Internal Temperature: 26.9° C
   Chemical Mass in Tank: 43,916 tons     Tank is 80% full
   Circular Opening Diameter: 4 inches
   Opening is 0 meters from tank bottom
   Ground Type: Default soil
   Ground Temperature: equal to ambient
   Max Puddle Diameter: Unknown
   Release Duration: ALOHA limited the duration to 1 hour
   Max Average Sustained Release Rate: 4.62 pounds/min
      (averaged over a minute or more)
   Total Amount Released: 212 pounds
   Note: The chemical escaped as a liquid and formed an evaporating puddle.
   ALOHA limited the spreading puddle diameter to 219 yards.

 THREAT ZONE:
   Model Run: Gaussian
   Red   : 109 yards --- (160 mg/(cu m) = AEGL-3 [60 min])
   Note: Threat zone was not drawn because dispersion predictions are
      unreliable for lengths less than the maximum diameter of the puddle.
      Maximum diameter of the puddle: 219 yards
   Orange: 109 yards --- (8.7 mg/(cu m) = AEGL-2 [60 min])
   Note: Threat zone was not drawn because dispersion predictions are
      unreliable for lengths less than the maximum diameter of the puddle.
      Maximum diameter of the puddle: 219 yards
   Yellow: 1186 yards --- (0.2 mg/(cu m) = AEGL-1 [60 min])
```

Figure 3.39: Text Summary for Jun (Source Strength and Threat Zone)

```
Text Summary
 SITE DATA:
   Location: KUALA TERENGGANU, MALAYSIA
   Building Air Exchanges Per Hour: 0.84 (unsheltered single storied)
   Time: July 15, 2016  1300 hours ST (user specified)

 CHEMICAL DATA:
   Chemical Name: SULFURIC ACID           Molecular Weight: 98.08 g/mol
   AEGL-1 (60 min): 0.2 mg/(cu m)   AEGL-2 (60 min): 8.7 mg/(cu m)   AEGL-3 (60 min): 160 mg/(cu
   Ambient Boiling Point: 317.1° F
   Vapor Pressure at Ambient Temperature: 6.86e-005 atm
   Ambient Saturation Concentration: 68.6 ppm or 0.0069%

 ATMOSPHERIC DATA: (MANUAL INPUT OF DATA)
   Wind: 4 meters/second from 030° true at 3 meters
   Ground Roughness: urban or forest      Cloud Cover: 7 tenths
   Air Temperature: 28.9° C               Stability Class: D
   No Inversion Height                    Relative Humidity: 84%

 SOURCE STRENGTH:
   Leak from hole in vertical cylindrical tank
   Flammable chemical escaping from tank (not burning)
   Tank Diameter: 23 meters               Tank Length: 24.1 meters
   Tank Volume: 10000 cubic meters
   Tank contains liquid                   Internal Temperature: 28.9° C
   Chemical Mass in Tank: 43,732 tons     Tank is 80% full
   Circular Opening Diameter: 4 inches
   Opening is 0 meters from tank bottom
   Ground Type: Default soil
   Ground Temperature: equal to ambient
   Max Puddle Diameter: Unknown
   Release Duration: ALOHA limited the duration to 1 hour
   Max Average Sustained Release Rate: 11.2 pounds/min
      (averaged over a minute or more)
   Total Amount Released: 455 pounds
   Note: The chemical escaped as a liquid and formed an evaporating puddle.
   ALOHA limited the spreading puddle diameter to 219 yards.
```

Figure 3.40: Text Summary for July (Site Data, Chemical Data, Atmospheric Data)

Text Summary

```
  Tank Diameter: 23 meters                 Tank Length: 24.1 meters
  Tank Volume: 10000 cubic meters
  Tank contains liquid                     Internal Temperature: 28.9° C
  Chemical Mass in Tank: 43,732 tons       Tank is 80% full
  Circular Opening Diameter: 4 inches
  Opening is 0 meters from tank bottom
  Ground Type: Default soil
  Ground Temperature: equal to ambient
  Max Puddle Diameter: Unknown
  Release Duration: ALOHA limited the duration to 1 hour
  Max Average Sustained Release Rate: 11.2 pounds/min
     (averaged over a minute or more)
  Total Amount Released: 455 pounds
  Note: The chemical escaped as a liquid and formed an evaporating puddle.
  ALOHA limited the spreading puddle diameter to 219 yards.

THREAT ZONE:
  Model Run: Gaussian
  Red    : 109 yards --- (160 mg/(cu m) = AEGL-3 [60 min])
  Note: Threat zone was not drawn because dispersion predictions are
     unreliable for lengths less than the maximum diameter of the puddle.
     Maximum diameter of the puddle: 219 yards
  Orange: 130 yards --- (8.7 mg/(cu m) = AEGL-2 [60 min])
  Note: Threat zone was not drawn because dispersion predictions are
     unreliable for lengths less than the maximum diameter of the puddle.
     Maximum diameter of the puddle: 219 yards
  Yellow: 1.2 miles --- (0.2 mg/(cu m) = AEGL-1 [60 min])

THREAT AT POINT:
  Concentration Estimates at the point:
  Downwind: 1.18 miles                     Off Centerline: 0 miles
  Warning: Higher concentrations occur after the first hour.
  Max Concentration:(in the first hour)
     Outdoor: 0.201 mg/(cu m)
     Indoor:  0.0716 mg/(cu m)
```

Figure 3.41: Text Summary for July (Source Strength and Threat Zone)

Text Summary

```
SITE DATA:
  Location: KUALA TERENGGANU,TERENGGANU, MALAYSIA
  Building Air Exchanges Per Hour: 0.69 (unsheltered single storied)
  Time: August 15, 2016  1600 hours ST (user specified)

CHEMICAL DATA:
  Chemical Name: SULFURIC ACID          Molecular Weight: 98.10 g/mol
  Default LOC-1: 2 mg/(cu m)    Default LOC-2: 10 ppm    Default LOC-3: 120 mg/(cu m)
  AEGL-1 (60 min): 0.2 mg/(cu m)    AEGL-2 (60 min): 8.7 mg/(cu m)    AEGL-3 (60 min): 160 mg/(cu m)
  Ambient Boiling Point: 317.1° F
  Vapor Pressure at Ambient Temperature: 9.93e-005 atm
  Ambient Saturation Concentration: 99.3 ppm or 0.0099%

ATMOSPHERIC DATA: (MANUAL INPUT OF DATA)
  Wind: 3 meters/second from 090° true at 3 meters
  Ground Roughness: urban or forest      Cloud Cover: 7 tenths
  Air Temperature: 32.1° C               Stability Class: D
  No Inversion Height                    Relative Humidity: 73%

SOURCE STRENGTH:  -  (SELECT SOURCE)
```

Figure 3.42: Text Summary for August (Site Data, Chemical Data, Atmospheric Data)

```
Text Summary
   Tank Diameter: 23 meters                  Tank Length: 24.1 meters
   Tank Volume: 10000 cubic meters
   Tank contains liquid                      Internal Temperature: 32.1° C
   Chemical Mass in Tank: 43,443 tons        Tank is 80% full
   Circular Opening Diameter: 4 inches
   Opening is 0 meters from tank bottom
   Ground Type: Default soil
   Ground Temperature: equal to ambient
   Max Puddle Diameter: Unknown
   Release Duration: ALOHA limited the duration to 1 hour
   Max Average Sustained Release Rate: 9.85 pounds/min
      (averaged over a minute or more)
   Total Amount Released: 426 pounds
   Note: The chemical escaped as a liquid and formed an evaporating puddle.
   ALOHA limited the spreading puddle diameter to 219 yards.

 THREAT ZONE:
   Model Run: Gaussian
   Red    : 109 yards --- (160 mg/(cu m) = AEGL-3 [60 min])
   Note: Threat zone was not drawn because dispersion predictions are
      unreliable for lengths less than the maximum diameter of the puddle.
      Maximum diameter of the puddle: 219 yards
   Orange: 141 yards --- (8.7 mg/(cu m) = AEGL-2 [60 min])
   Note: Threat zone was not drawn because dispersion predictions are
      unreliable for lengths less than the maximum diameter of the puddle.
      Maximum diameter of the puddle: 219 yards
   Yellow: 1.3 miles --- (0.2 mg/(cu m) = AEGL-1 [60 min])

 THREAT AT POINT:
   Concentration Estimates at the point:
   Downwind: 1.18 miles                      Off Centerline: 0 miles
   Warning: Higher concentrations occur after the first hour.
   Max Concentration:(in the first hour)
      Outdoor: 0.235 mg/(cu m)
      Indoor:  0.072 mg/(cu m)
```

Figure 3.43: Text Summary for August (Source Strength and Threat Zone)

```
Text Summary
 SITE DATA:
   Location: KUALA TERENGGANU, MALAYSIA
   Building Air Exchanges Per Hour: 0.58 (unsheltered single storied)
   Time: September 15, 2016  1200 hours ST (user specified)

 CHEMICAL DATA:
   Chemical Name: SULFURIC ACID             Molecular Weight: 98.08 g/mol
   AEGL-1 (60 min): 0.2 mg/(cu m)   AEGL-2 (60 min): 8.7 mg/(cu m)   AEGL-3 (60 min): 160 mg/(cu
   Ambient Boiling Point: 317.1° F
   Vapor Pressure at Ambient Temperature: 9.17e-005 atm
   Ambient Saturation Concentration: 91.7 ppm or 0.0092%

 ATMOSPHERIC DATA: (MANUAL INPUT OF DATA)
   Wind: 2.4 meters/second from 080° true at 3 meters
   Ground Roughness: urban or forest        Cloud Cover: 7 tenths
   Air Temperature: 31.4° C                 Stability Class: C
   No Inversion Height                      Relative Humidity: 63%

 SOURCE STRENGTH:
   Leak from hole in vertical cylindrical tank
   Flammable chemical escaping from tank (not burning)
   Tank Diameter: 23 meters                 Tank Length: 24.1 meters
   Tank Volume: 10000 cubic meters
   Tank contains liquid                     Internal Temperature: 31.4° C
   Chemical Mass in Tank: 43,506 tons       Tank is 80% full
   Circular Opening Diameter: 4 inches
   Opening is 0 meters from tank bottom
   Ground Type: Default soil
   Ground Temperature: equal to ambient
   Max Puddle Diameter: Unknown
   Release Duration: ALOHA limited the duration to 1 hour
   Max Average Sustained Release Rate: 9.47 pounds/min
      (averaged over a minute or more)
   Total Amount Released: 380 pounds
   Note: The chemical escaped as a liquid and formed an evaporating puddle.
   ALOHA limited the spreading puddle diameter to 219 yards.
```

Figure 3.44: Text Summary for September (Source Strength and Threat Zone)

```
Text Summary
   Tank Diameter: 23 meters                   Tank Length: 24.1 meters
   Tank Volume: 10000 cubic meters
   Tank contains liquid                       Internal Temperature: 31.4° C
   Chemical Mass in Tank: 43,506 tons         Tank is 80% full
   Circular Opening Diameter: 4 inches
   Opening is 0 meters from tank bottom
   Ground Type: Default soil
   Ground Temperature: equal to ambient
   Max Puddle Diameter: Unknown
   Release Duration: ALOHA limited the duration to 1 hour
   Max Average Sustained Release Rate: 9.47 pounds/min
      (averaged over a minute or more)
   Total Amount Released: 380 pounds
   Note: The chemical escaped as a liquid and formed an evaporating puddle.
   ALOHA limited the spreading puddle diameter to 219 yards.

 THREAT ZONE:
   Model Run: Gaussian
   Red   : 109 yards --- (160 mg/(cu m) = AEGL-3 [60 min])
   Note: Threat zone was not drawn because dispersion predictions are
      unreliable for lengths less than the maximum diameter of the puddle.
      Maximum diameter of the puddle: 219 yards
   Orange: 109 yards --- (8.7 mg/(cu m) = AEGL-2 [60 min])
   Note: Threat zone was not drawn because dispersion predictions are
      unreliable for lengths less than the maximum diameter of the puddle.
      Maximum diameter of the puddle: 219 yards
   Yellow: 1572 yards --- (0.2 mg/(cu m) = AEGL-1 [60 min])

 THREAT AT POINT:
   Concentration Estimates at the point:
   Downwind: 1.33 miles                       Off Centerline: 0 miles
   Warning: Higher concentrations occur after the first hour.
   Max Concentration:(in the first hour)
      Outdoor: 0.0916 mg/(cu m)
      Indoor:  0.0211 mg/(cu m)
```

Figure 3.45: Text Summary for September (Source Strength and Threat Zone)

```
Text Summary
 SITE DATA:
   Location: KUALA TERENGGANU, MALAYSIA
   Building Air Exchanges Per Hour: 0.71 (unsheltered single storied)
   Time: October 15, 2016  1500 hours ST (user specified)

 CHEMICAL DATA:
   Chemical Name: SULFURIC ACID               Molecular Weight: 98.08 g/mol
   AEGL-1 (60 min): 0.2 mg/(cu m)    AEGL-2 (60 min): 8.7 mg/(cu m)    AEGL-3 (60 min): 160 mg/(cu
   Ambient Boiling Point: 317.1° F
   Vapor Pressure at Ambient Temperature: 8.56e-005 atm
   Ambient Saturation Concentration: 85.6 ppm or 0.0086%

 ATMOSPHERIC DATA: (MANUAL INPUT OF DATA)
   Wind: 3.2 meters/second from 060° true at 3 meters
   Ground Roughness: urban or forest          Cloud Cover: 7 tenths
   Air Temperature: 30.8° C                   Stability Class: C
   No Inversion Height                        Relative Humidity: 67%

 SOURCE STRENGTH:
   Leak from hole in vertical cylindrical tank
   Flammable chemical escaping from tank (not burning)
   Tank Diameter: 23 meters                   Tank Length: 24.1 meters
   Tank Volume: 10000 cubic meters
   Tank contains liquid                       Internal Temperature: 30.8° C
   Chemical Mass in Tank: 43,560 tons         Tank is 80% full
   Circular Opening Diameter: 4 inches
   Opening is 0 meters from tank bottom
   Ground Type: Default soil
   Ground Temperature: equal to ambient
   Max Puddle Diameter: Unknown
   Release Duration: ALOHA limited the duration to 1 hour
   Max Average Sustained Release Rate: 9.72 pounds/min
      (averaged over a minute or more)
   Total Amount Released: 410 pounds
   Note: The chemical escaped as a liquid and formed an evaporating puddle.
   ALOHA limited the spreading puddle diameter to 219 yards.
```

Figure 3.46: Text Summary for October (Source Strength and Threat Zone)

```
Text Summary
   Flammable chemical escaping from tank (not burning)
   Tank Diameter: 23 meters             Tank Length: 24.1 meters
   Tank Volume: 10000 cubic meters
   Tank contains liquid                 Internal Temperature: 30.8° C
   Chemical Mass in Tank: 43,560 tons   Tank is 80% full
   Circular Opening Diameter: 4 inches
   Opening is 0 meters from tank bottom
   Ground Type: Default soil
   Ground Temperature: equal to ambient
   Max Puddle Diameter: Unknown
   Release Duration: ALOHA limited the duration to 1 hour
   Max Average Sustained Release Rate: 9.72 pounds/min
      (averaged over a minute or more)
   Total Amount Released: 410 pounds
   Note: The chemical escaped as a liquid and formed an evaporating puddle.
   ALOHA limited the spreading puddle diameter to 219 yards.

 THREAT ZONE:
   Model Run: Gaussian
   Red    : 109 yards --- (160 mg/(cu m) = AEGL-3 [60 min])
   Note: Threat zone was not drawn because dispersion predictions are
      unreliable for lengths less than the maximum diameter of the puddle.
      Maximum diameter of the puddle: 219 yards
   Orange: 109 yards --- (8.7 mg/(cu m) = AEGL-2 [60 min])
   Note: Threat zone was not drawn because dispersion predictions are
      unreliable for lengths less than the maximum diameter of the puddle.
      Maximum diameter of the puddle: 219 yards
   Yellow: 1350 yards --- (0.2 mg/(cu m) = AEGL-1 [60 min])

 THREAT AT POINT:
   Concentration Estimates at the point:
   Downwind: 1,355 yards                Off Centerline: 4.67 yards
   Max Concentration:
      Outdoor: 0.199 mg/(cu m)
      Indoor:  0.0673 mg/(cu m)
```

Figure 3.47: Text Summary for October (Source Strength and Threat Zone)

```
Text Summary
 SITE DATA:
   Location: KUALA TERENGGANU, MALAYSIA
   Building Air Exchanges Per Hour: 0.85 (unsheltered single storied)
   Time: November 15, 2016  0100 hours ST (user specified)

 CHEMICAL DATA:
   Chemical Name: SULFURIC ACID         Molecular Weight: 98.08 g/mol
   AEGL-1 (60 min): 0.2 mg/(cu m)   AEGL-2 (60 min): 8.7 mg/(cu m)   AEGL-3 (60 min): 160 mg/(cu
   Ambient Boiling Point: 317.1° F
   Vapor Pressure at Ambient Temperature: 8.56e-005 atm
   Ambient Saturation Concentration: 85.6 ppm or 0.0086%

 ATMOSPHERIC DATA: (MANUAL INPUT OF DATA)
   Wind: 4 meters/second from 050° true at 3 meters
   Ground Roughness: urban or forest    Cloud Cover: 7 tenths
   Air Temperature: 30.8° C             Stability Class: D
   No Inversion Height                  Relative Humidity: 70%

 SOURCE STRENGTH:
   Leak from hole in vertical cylindrical tank
   Flammable chemical escaping from tank (not burning)
   Tank Diameter: 23 meters             Tank Length: 24.1 meters
   Tank Volume: 10000 cubic meters
   Tank contains liquid                 Internal Temperature: 30.8° C
   Chemical Mass in Tank: 43,560 tons   Tank is 80% full
   Circular Opening Diameter: 4 inches
   Opening is 0 meters from tank bottom
   Ground Type: Default soil
   Ground Temperature: equal to ambient
   Max Puddle Diameter: Unknown
   Release Duration: ALOHA limited the duration to 1 hour
   Max Average Sustained Release Rate: 7.74 pounds/min
      (averaged over a minute or more)
   Total Amount Released: 356 pounds
   Note: The chemical escaped as a liquid and formed an evaporating puddle.
   ALOHA limited the spreading puddle diameter to 219 yards.
```

Figure 3.48: Text Summary for November (Source Strength and Threat Zone)

```
Text Summary
   Wind: 4 meters/second from 050° true at 3 meters
   Ground Roughness: urban or forest        Cloud Cover: 7 tenths
   Air Temperature: 30.8° C                 Stability Class: D
   No Inversion Height                      Relative Humidity: 70%

 SOURCE STRENGTH:
   Leak from hole in vertical cylindrical tank
   Flammable chemical escaping from tank (not burning)
   Tank Diameter: 23 meters                 Tank Length: 24.1 meters
   Tank Volume: 10000 cubic meters
   Tank contains liquid                     Internal Temperature: 30.8° C
   Chemical Mass in Tank: 43,560 tons       Tank is 80% full
   Circular Opening Diameter: 4 inches
   Opening is 0 meters from tank bottom
   Ground Type: Default soil
   Ground Temperature: equal to ambient
   Max Puddle Diameter: Unknown
   Release Duration: ALOHA limited the duration to 1 hour
   Max Average Sustained Release Rate: 7.74 pounds/min
      (averaged over a minute or more)
   Total Amount Released: 356 pounds
   Note: The chemical escaped as a liquid and formed an evaporating puddle.
   ALOHA limited the spreading puddle diameter to 219 yards.

 THREAT ZONE:
   Model Run: Gaussian
   Red   : 109 yards --- (160 mg/(cu m) = AEGL-3 [60 min])
   Note: Threat zone was not drawn because dispersion predictions are
      unreliable for lengths less than the maximum diameter of the puddle.
      Maximum diameter of the puddle: 219 yards
   Orange: 109 yards --- (8.7 mg/(cu m) = AEGL-2 [60 min])
   Note: Threat zone was not drawn because dispersion predictions are
      unreliable for lengths less than the maximum diameter of the puddle.
      Maximum diameter of the puddle: 219 yards
   Yellow: 1630 yards --- (0.2 mg/(cu m) = AEGL-1 [60 min])
```

Figure 3.49: Text Summary for November (Source Strength and Threat Zone)

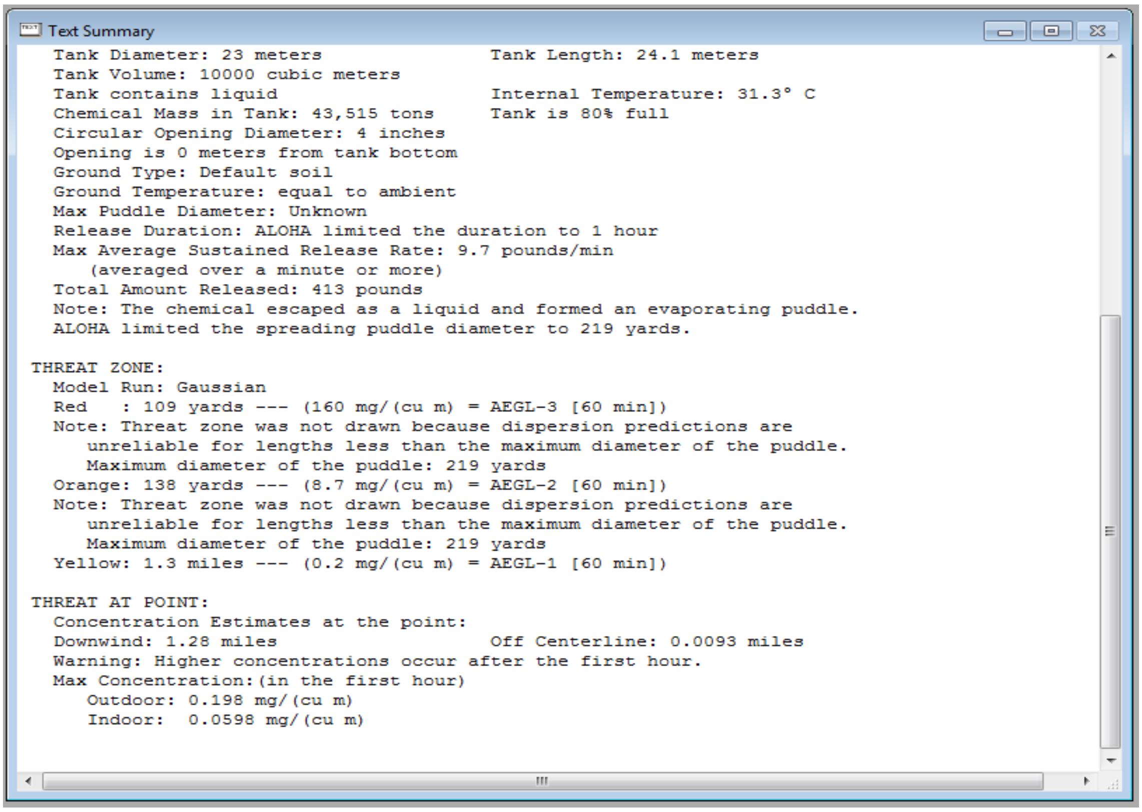
```
Text Summary
 SITE DATA:
   Location: KUALA TERENGGANU, MALAYSIA
   Building Air Exchanges Per Hour: 0.70 (unsheltered single storied)
   Time: December 15, 2016  1500 hours ST (user specified)

 CHEMICAL DATA:
   Chemical Name: SULFURIC ACID             Molecular Weight: 98.08 g/mol
   AEGL-1 (60 min): 0.2 mg/(cu m)    AEGL-2 (60 min): 8.7 mg/(cu m)    AEGL-3 (60 min): 160 mg/(cu
   Ambient Boiling Point: 317.1° F
   Vapor Pressure at Ambient Temperature: 9.06e-005 atm
   Ambient Saturation Concentration: 90.7 ppm or 0.0091%

 ATMOSPHERIC DATA: (MANUAL INPUT OF DATA)
   Wind: 3.1 meters/second from 060° true at 3 meters
   Ground Roughness: urban or forest        Cloud Cover: 7 tenths
   Air Temperature: 31.3° C                 Stability Class: D
   No Inversion Height                      Relative Humidity: 64%

 SOURCE STRENGTH:
   Leak from hole in vertical cylindrical tank
   Flammable chemical escaping from tank (not burning)
   Tank Diameter: 23 meters                 Tank Length: 24.1 meters
   Tank Volume: 10000 cubic meters
   Tank contains liquid                     Internal Temperature: 31.3° C
   Chemical Mass in Tank: 43,515 tons       Tank is 80% full
   Circular Opening Diameter: 4 inches
   Opening is 0 meters from tank bottom
   Ground Type: Default soil
   Ground Temperature: equal to ambient
   Max Puddle Diameter: Unknown
   Release Duration: ALOHA limited the duration to 1 hour
   Max Average Sustained Release Rate: 9.7 pounds/min
      (averaged over a minute or more)
   Total Amount Released: 413 pounds
   Note: The chemical escaped as a liquid and formed an evaporating puddle.
   ALOHA limited the spreading puddle diameter to 219 yards.
```

Figure 3.50: Text Summary for December (Source Strength and Threat Zone)



```
Text Summary
   Tank Diameter: 23 meters                Tank Length: 24.1 meters
   Tank Volume: 10000 cubic meters
   Tank contains liquid                    Internal Temperature: 31.3° C
   Chemical Mass in Tank: 43,515 tons      Tank is 80% full
   Circular Opening Diameter: 4 inches
   Opening is 0 meters from tank bottom
   Ground Type: Default soil
   Ground Temperature: equal to ambient
   Max Puddle Diameter: Unknown
   Release Duration: ALOHA limited the duration to 1 hour
   Max Average Sustained Release Rate: 9.7 pounds/min
      (averaged over a minute or more)
   Total Amount Released: 413 pounds
   Note: The chemical escaped as a liquid and formed an evaporating puddle.
   ALOHA limited the spreading puddle diameter to 219 yards.

 THREAT ZONE:
   Model Run: Gaussian
   Red   : 109 yards --- (160 mg/(cu m) = AEGL-3 [60 min])
   Note: Threat zone was not drawn because dispersion predictions are
      unreliable for lengths less than the maximum diameter of the puddle.
      Maximum diameter of the puddle: 219 yards
   Orange: 138 yards --- (8.7 mg/(cu m) = AEGL-2 [60 min])
   Note: Threat zone was not drawn because dispersion predictions are
      unreliable for lengths less than the maximum diameter of the puddle.
      Maximum diameter of the puddle: 219 yards
   Yellow: 1.3 miles --- (0.2 mg/(cu m) = AEGL-1 [60 min])

 THREAT AT POINT:
   Concentration Estimates at the point:
   Downwind: 1.28 miles                    Off Centerline: 0.0093 miles
   Warning: Higher concentrations occur after the first hour.
   Max Concentration:(in the first hour)
      Outdoor: 0.198 mg/(cu m)
      Indoor:  0.0598 mg/(cu m)
```

Figure 3.51: Text Summary for December (Source Strength and Threat Zone)

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this section, the result of simulation from ALOHA for January until December are shown. Toxic threat zone of the affected area from the source point has been determined and presented in satellite image.

4.2 Radius of Toxic Dispersion

4.2.1 January

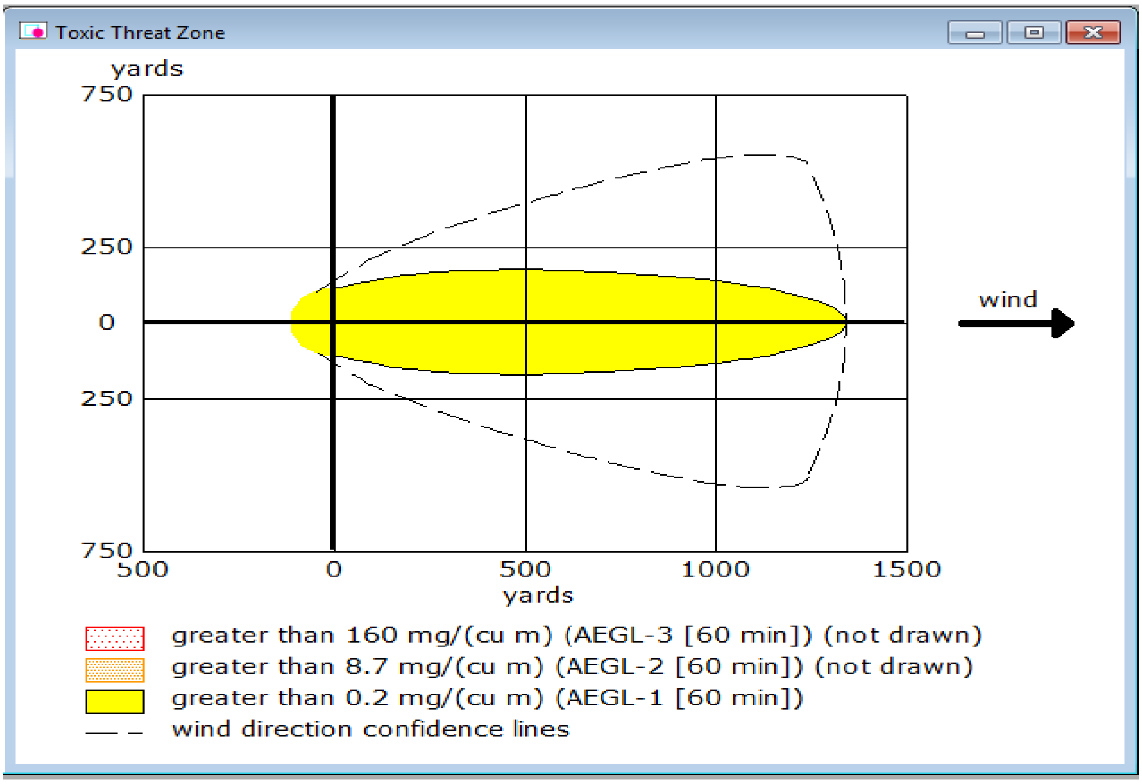


Figure 4.1: Toxic Threat Zone for January

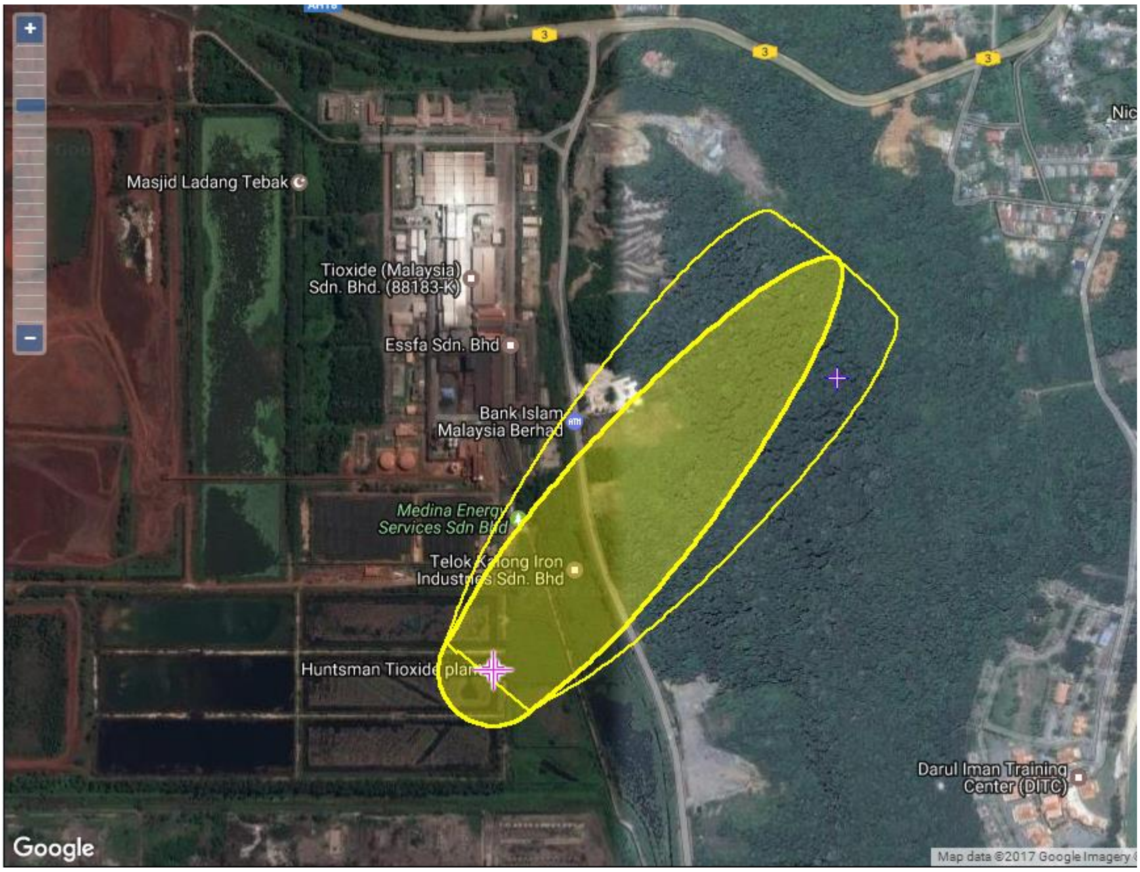


Figure 4.2: Toxic Dispersion Area for January

January 2016 has the wind speed with 2.8 m/s and the amount of the release was estimated for about 321 pounds. The highest distance for the toxic dispersion is 1346 yards. Figure 4.2 shows the toxic dispersion area indicated by the yellow zone. From the figure, the affected area are mostly covered by the forest and far from the residential area while only few area of the plant is affected. The other plants are totally safe from the toxic dispersion.

4.2.2 February

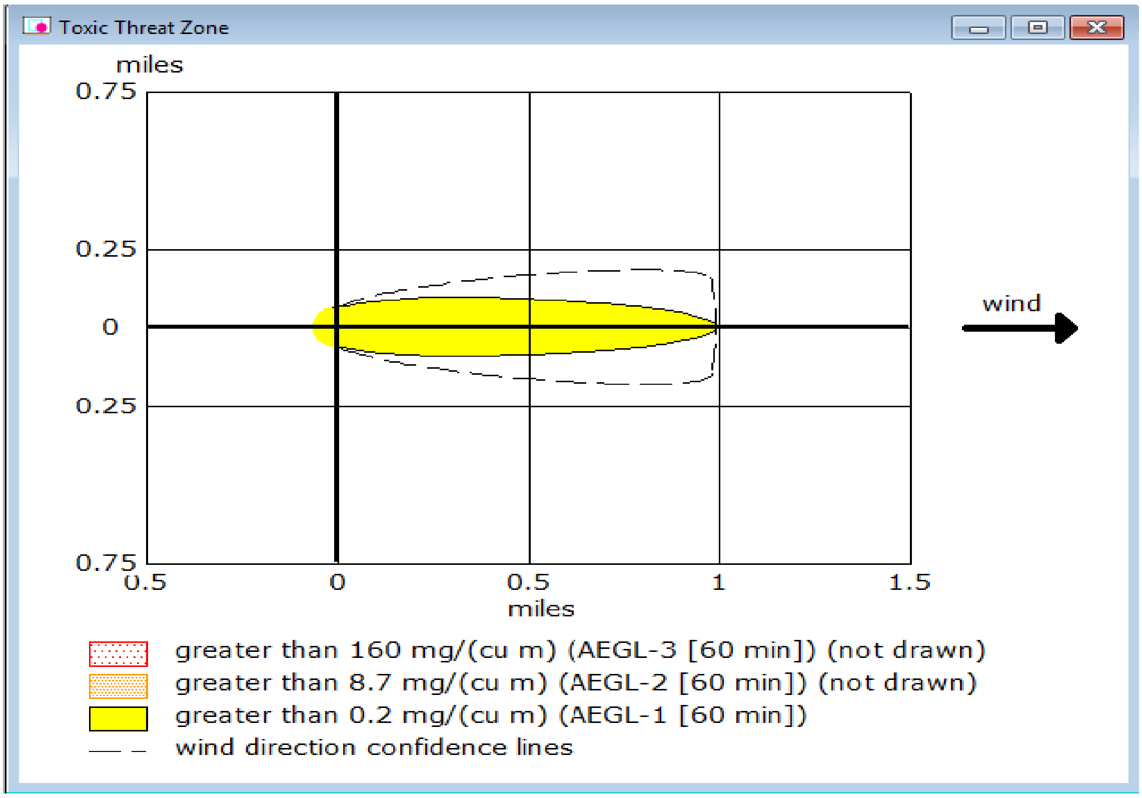


Figure 4.3: Toxic Threat Zone for February

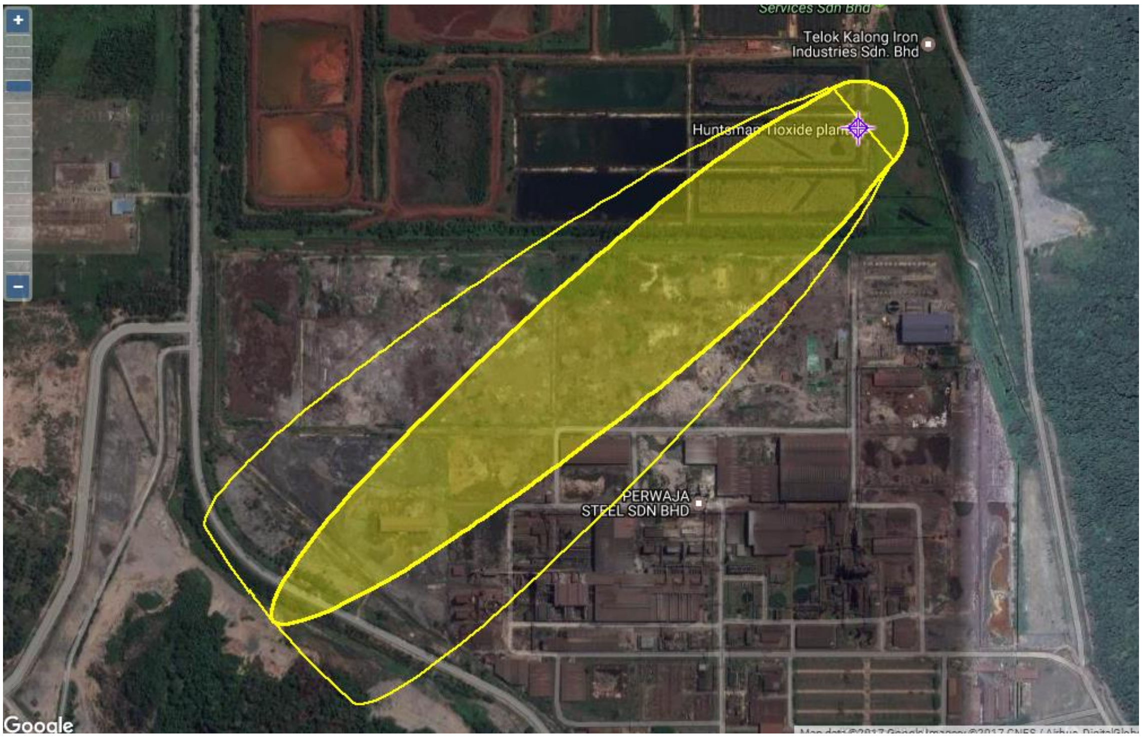


Figure 4.4: Toxic Dispersion Area for February

February 2016 has the highest wind speed with 4.3 m/s and the amount of the release was estimated for about 420 pounds. The highest distance for the toxic dispersion is 1757 yards. Figure 4.4 shows the toxic dispersion area indicated by the yellow zone. From the figure, the toxic dispersion from the storage tank affected almost whole area of the study area and the other plants which is Perwaja Steel plant and also the public road used to connect the Kemaman Supply Base (KSB) with the Teluk Kalong Industrial Area.

4.2.3 March

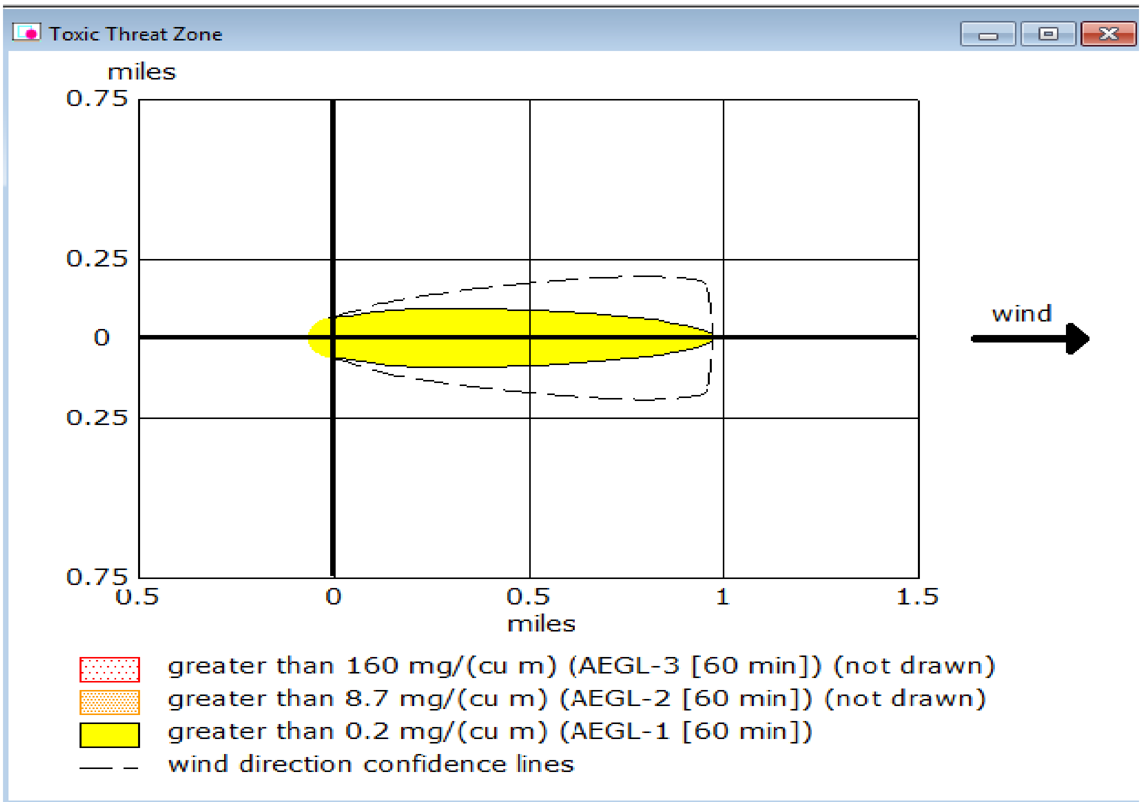


Figure 4.5: Toxic Threat Zone for March

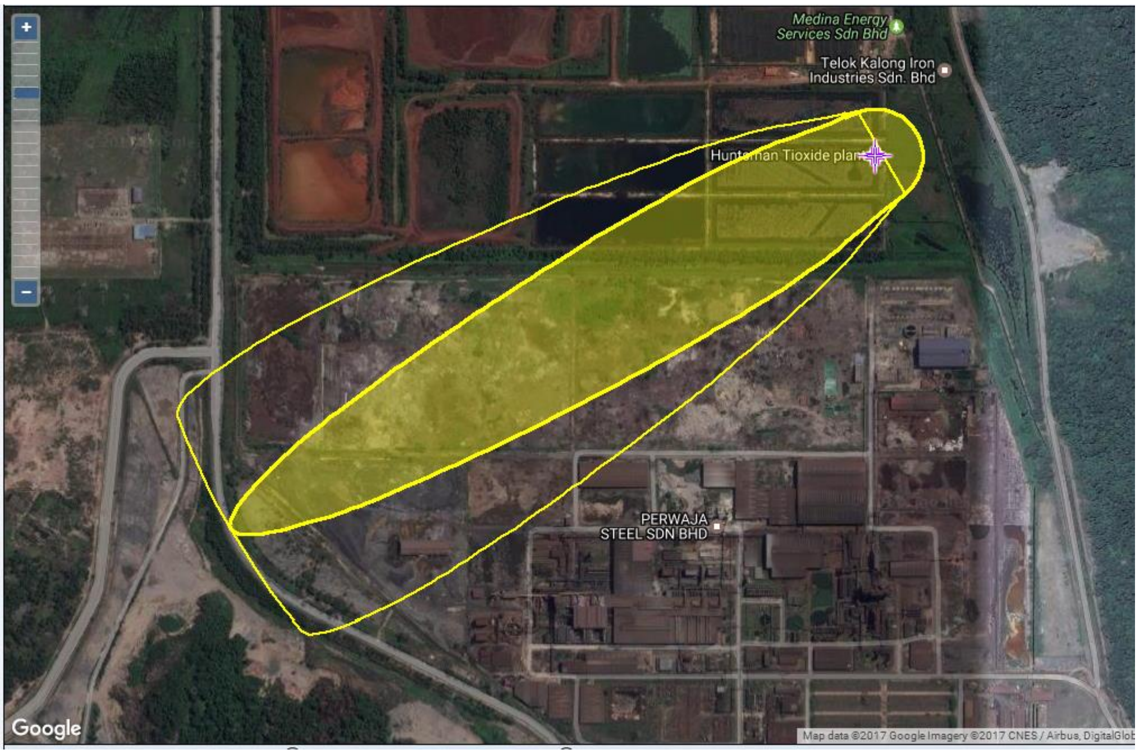


Figure 4.6: Toxic Dispersion Area for March

March 2016 has the wind speed with 3.7 m/s and the amount of the release was estimated for about 357 pounds. The highest distance for the toxic dispersion is 1722 yards. Figure 4.6 shows the toxic dispersion area indicated by the yellow zone. From the figure, the toxic dispersion affected all the area of our study area and also the public road used to connect the Kemaman Supply Base (KSB) with the Teluk Kalong Industrial Area.

4.2.4 April

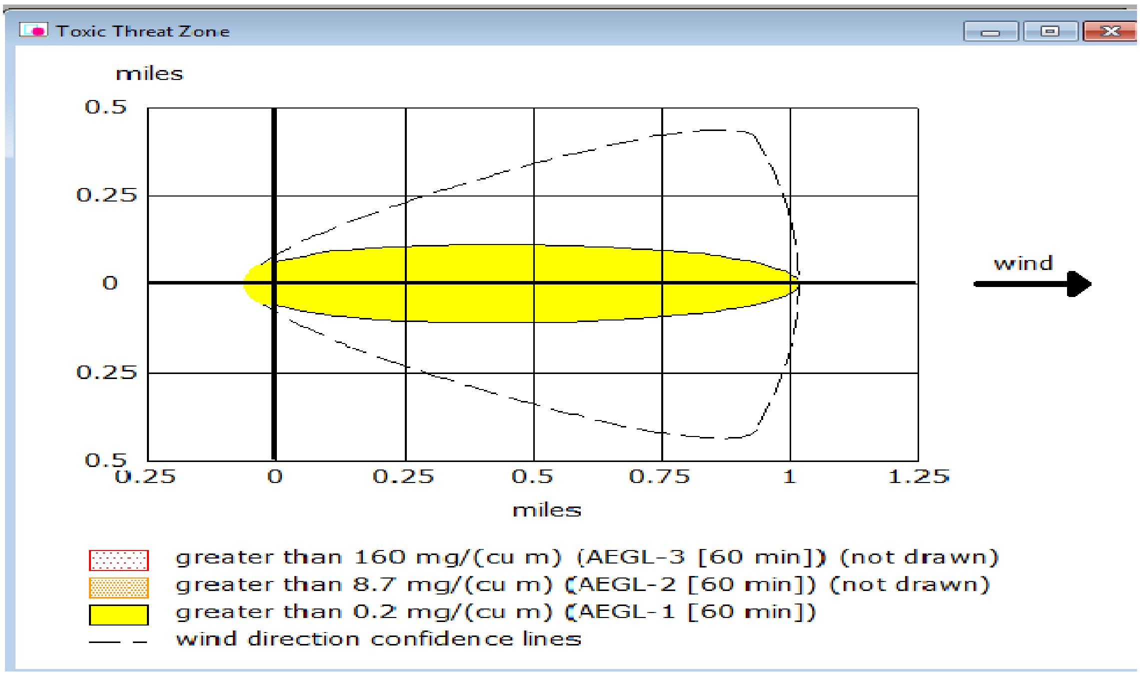


Figure 4.7: Toxic Threat Zone for April

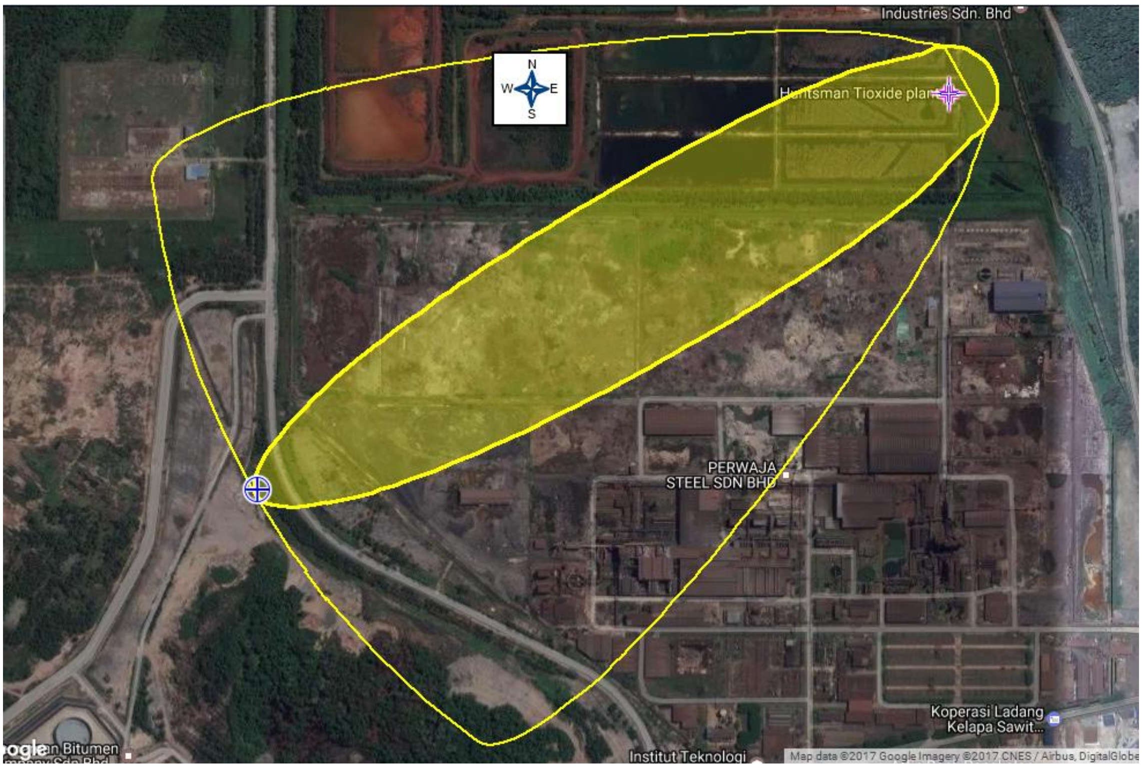


Figure 4.8: Toxic Dispersion Area for April

April 2016 has the wind speed with 2.5 m/s and the amount of the release was estimated for about 490 pounds. The highest distance for the toxic dispersion is 1 mile. Figure 4.8 shows the toxic dispersion area indicated by the yellow zone. From the figure, the toxic dispersion affected all the area of our study area and also the public road used to connect the Kemaman Supply Base (KSB) with the Teluk Kalong Industrial Area.

4.2.5 May

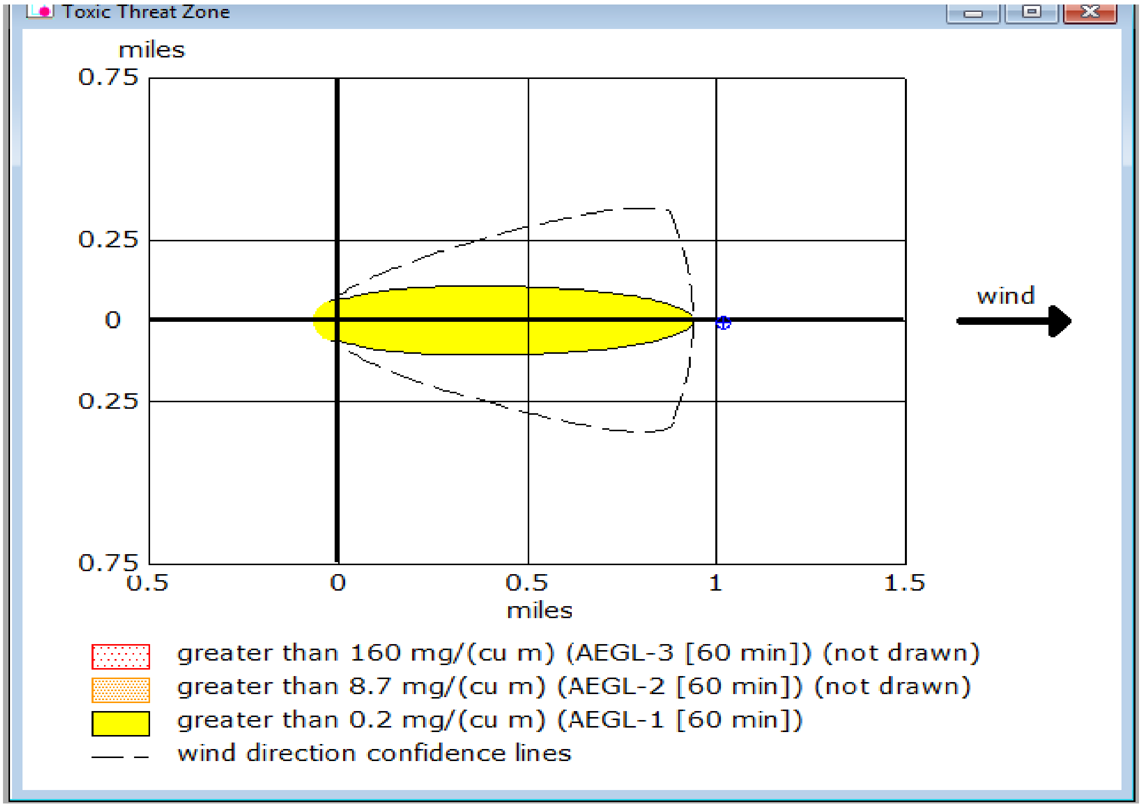


Figure 4.9: Toxic Threat Zone for May

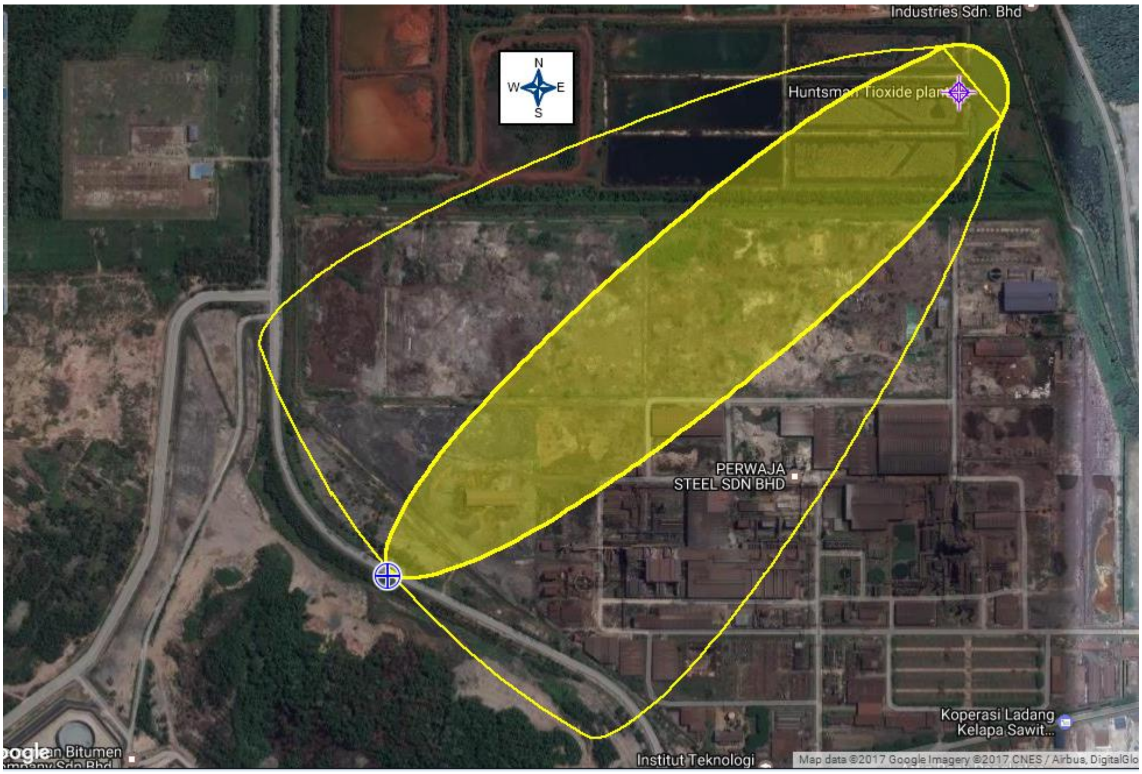


Figure 4.10: Toxic Dispersion Area for May

May 2016 has the wind speed with 2.8 m/s and the amount of the release was estimated for about 513 pounds. The highest distance for the toxic dispersion is 1659 yards. Figure 4.10 shows the toxic dispersion area indicated by the yellow zone. From the figure, the toxic dispersion affected all the area of our study area, small area of Perwaja Steel plant and also the public road used to connect the Kemaman Supply Base (KSB) with the Teluk Kalong Industrial Area.

4.2.6 June

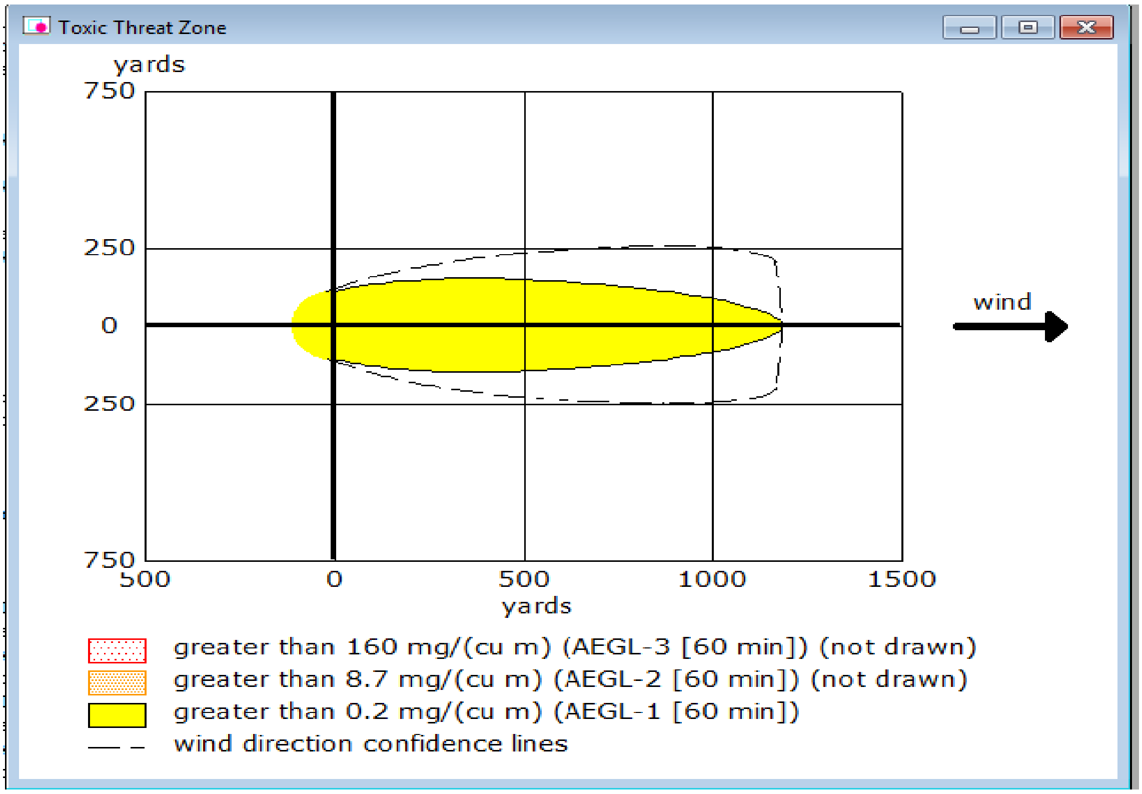


Figure 4.11: Toxic Threat Zone for June

Figure 4.12: Toxic Dispersion Area for June

June 2016 has the wind speed with 3.7 m/s and the amount of the release was estimated for about 212 pounds. The highest distance for the toxic dispersion is 1186 yards. Figure 4.12 shows the toxic dispersion area indicated by the yellow zone. From the figure, the toxic dispersion affected small area of our study area, and part of Perwaja Steel plant and also the public road used to connect the Kemaman Supply Base (KSB) with the Teluk Kalong Industrial Area.

4.2.7 July

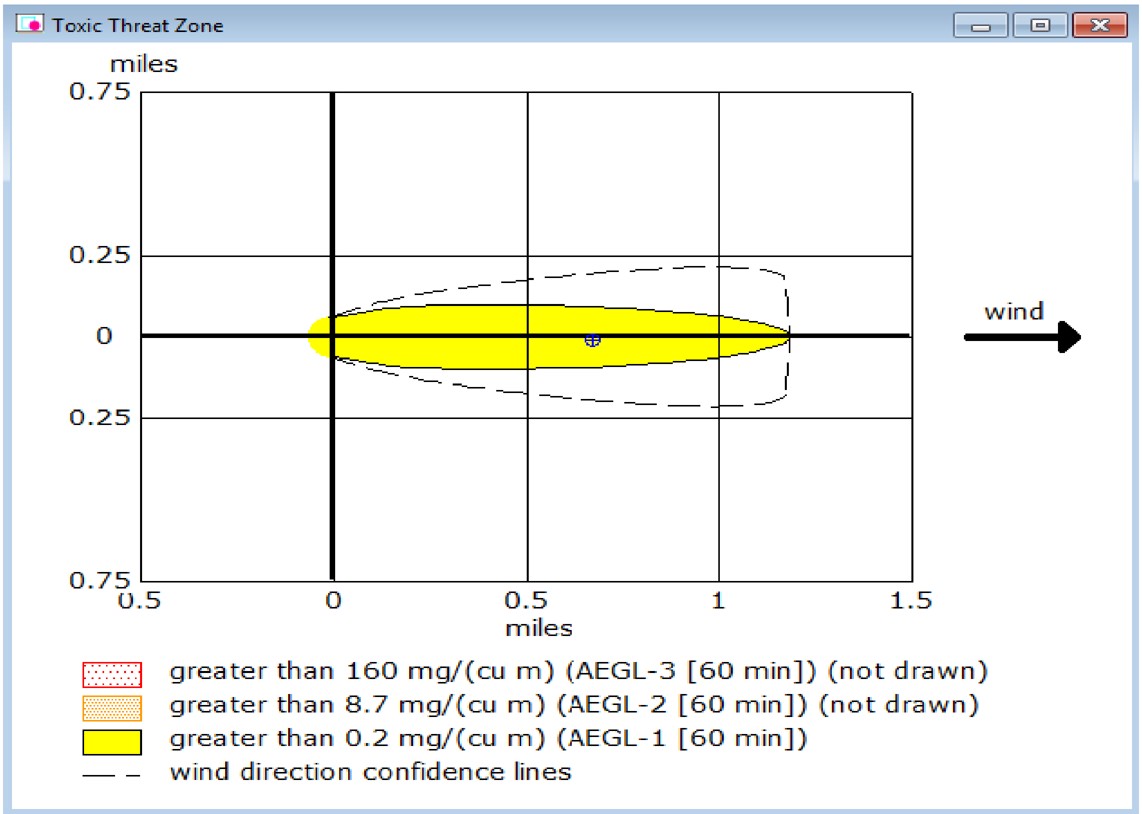


Figure 4.13: Toxic Threat Zone for July

Figure 4.14: Toxic Dispersion Area for July

July 2016 has the wind speed with 4 m/s and the amount of the release was estimated for about 455 pounds. The highest distance for the toxic dispersion is 1.2 miles. Figure 4.14 shows the toxic dispersion area indicated by the yellow zone. From the figure, the toxic dispersion affected part of our study area, public road used to connect the Kemaman Supply Base (KSB) with the Teluk Kalong Industrial Area 2 other plant area which are Perwaja Steel and Schlumberger WTA.

4.2.8 August

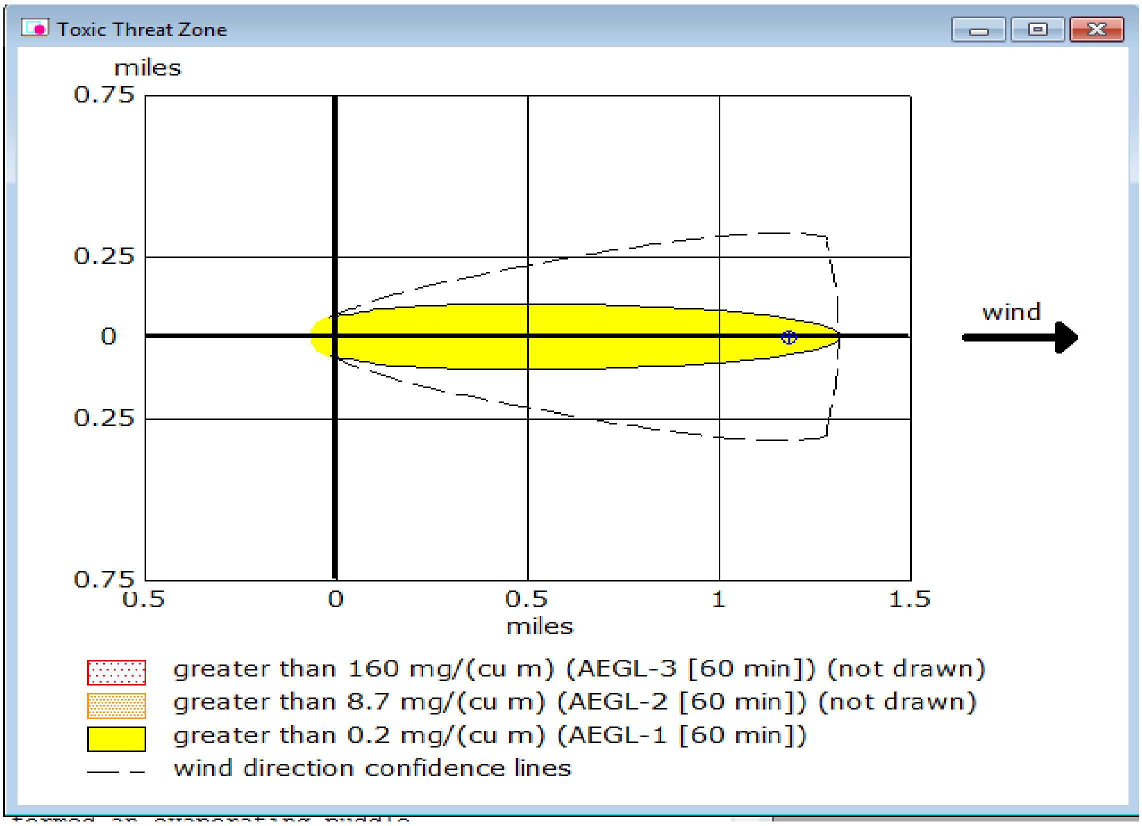


Figure 4.15: Toxic Threat Zone for August

Figure 4.16: Toxic Dispersion Area for August

August 2016 has the wind speed with 3 m/s and the amount of the release was estimated for about 426 pounds. The highest distance for the toxic dispersion is 1.3 miles. Figure 4.16 shows the toxic dispersion area indicated by the yellow zone. From the figure, the toxic dispersion affected all the area of our study area and also the public road used to connect the Kemaman Supply Base (KSB) with the Teluk Kalong Industrial Area.

4.2.9 September

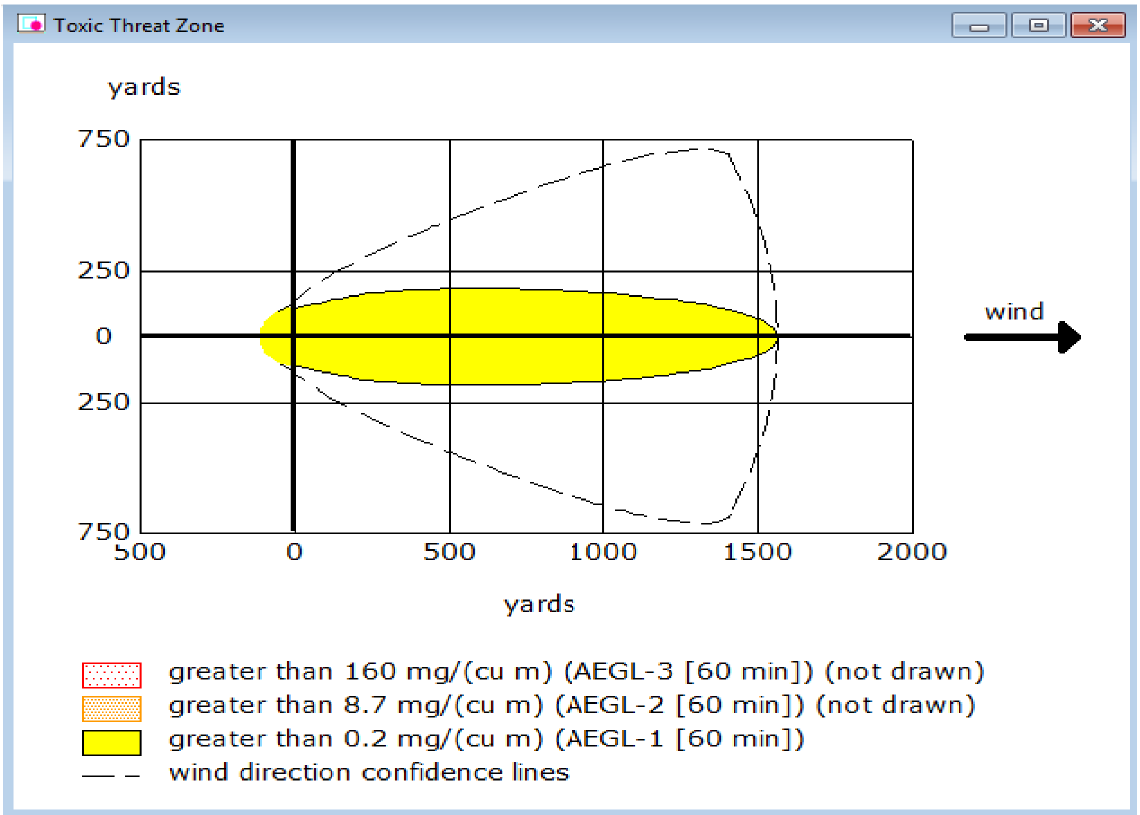


Figure 4.17: Toxic Threat Zone for September

Figure 4.18: Toxic Dispersion Area for September

4.2.10 October

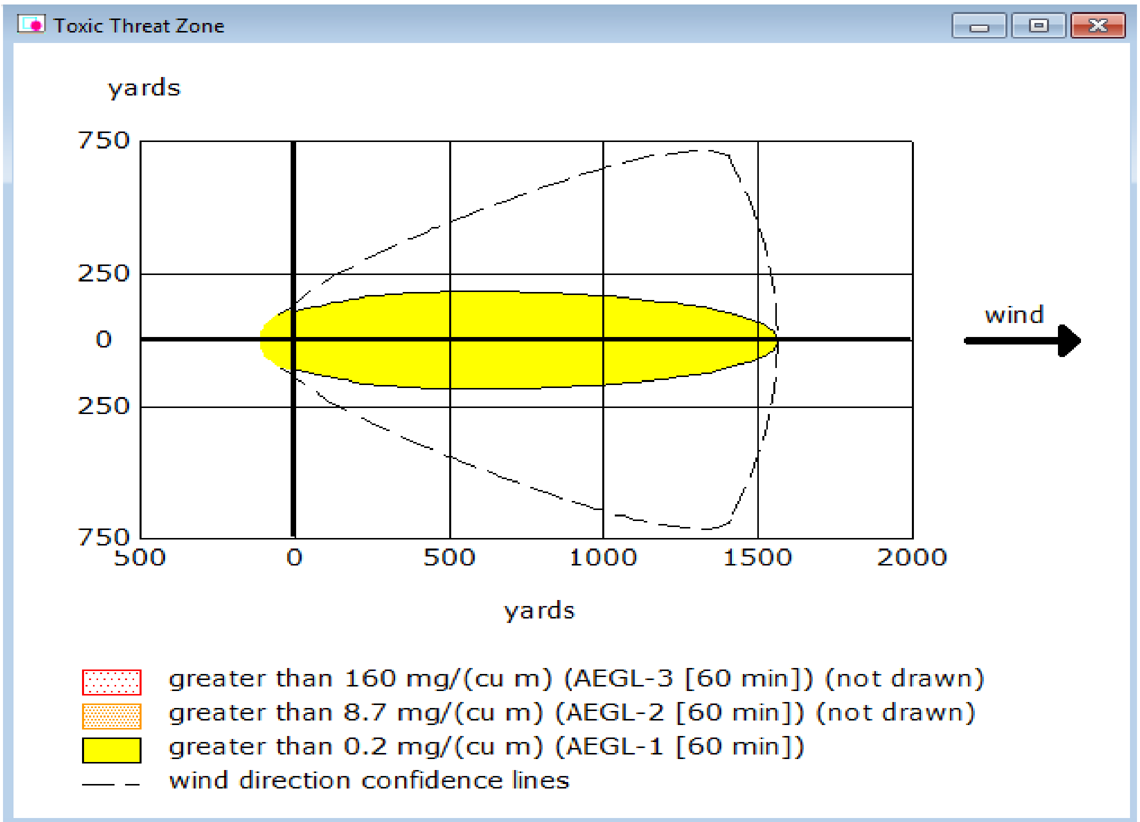


Figure 4.19: Toxic Threat Zone for October

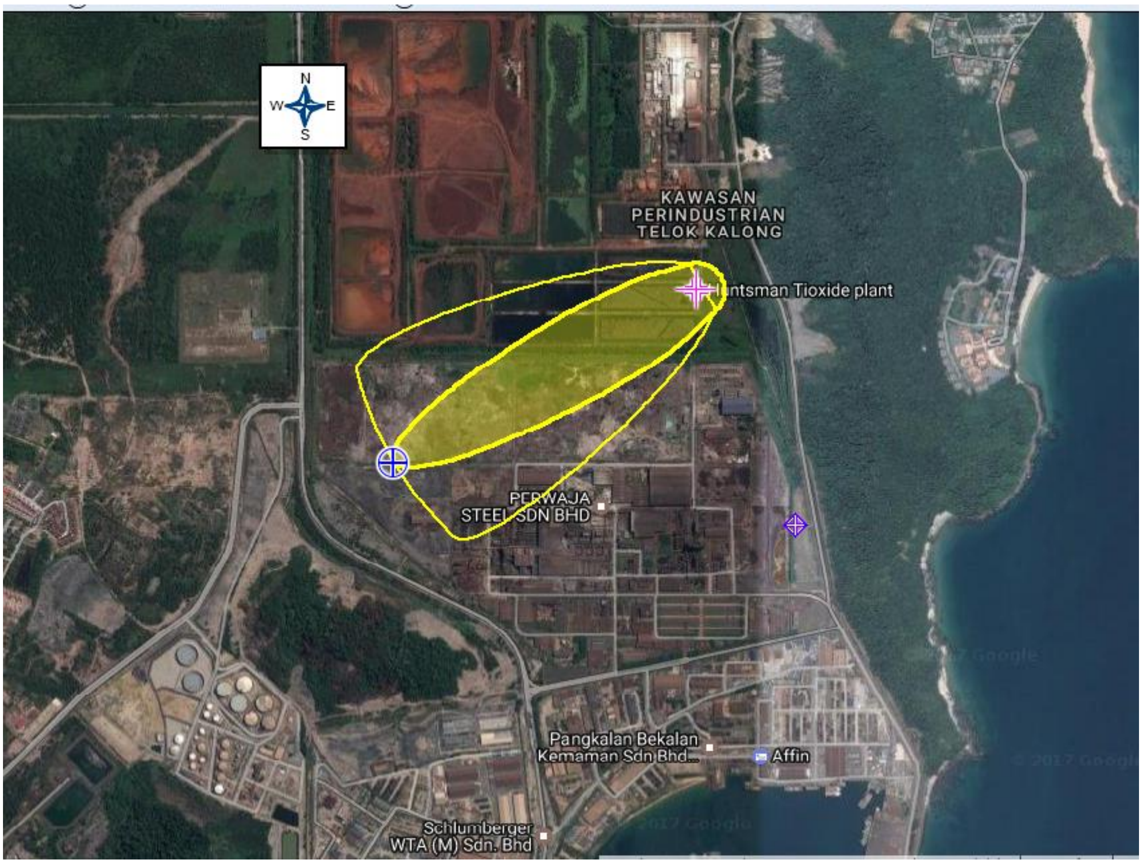


Figure 4.20: Toxic Dispersion Area for October

September 2016 has the wind speed with 2.4 m/s and the amount of the release was estimated for about 380 pounds. The highest distance for the toxic dispersion is 1572 yards. Figure 4.10 shows the toxic dispersion area indicated by the yellow zone. From the figure, the toxic dispersion affected all the area of our study area and other area rea safe from the dispersion.

4.2.11 November

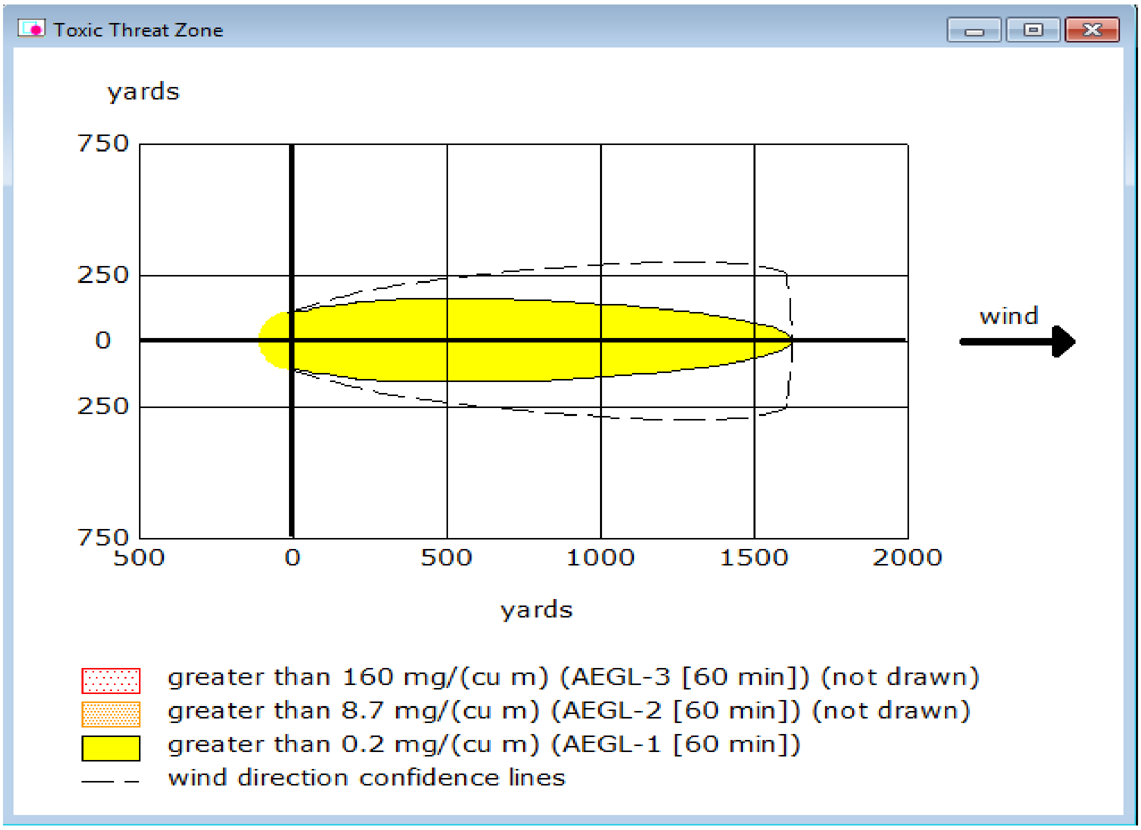


Figure 4.21: Toxic Threat Zone for November

Figure 4.22: Toxic Dispersion Area for November

November 2016 has the wind speed with 4 m/s and the amount of the release was estimated for about 356 pounds. The highest distance for the toxic dispersion is 1630 yards. Figure 4.22 shows the toxic dispersion area indicated by the yellow zone. From the figure, the toxic dispersion affected all the area of our study area and only small area of Perwaja Steel plant.

4.2.12 December

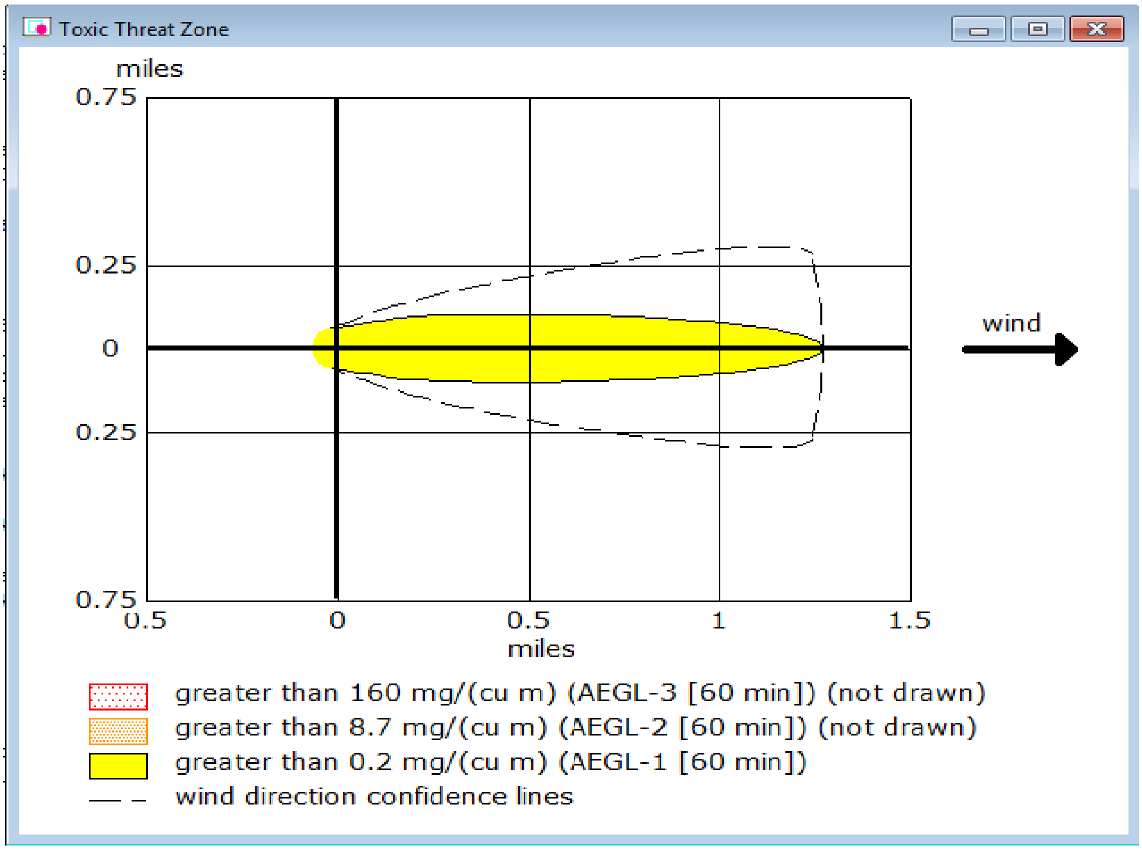


Figure 4.23: Toxic Threat Zone for December

Figure 4.24: Toxic Dispersion Area for December

December 2016 has the wind speed with 3.1 m/s and the amount of the release was estimated for about 413 pounds. The highest distance for the toxic dispersion is 1.3 miles. Figure 4.24 shows the toxic dispersion area indicated by the yellow zone. From the figure, the toxic dispersion affected all the area of our study area, small area of Perwaja Steel plant and also the public road used to connect the Kemaman Supply Base (KSB) with the Teluk Kalong Industrial Area. The other road is the road which is heading to the city of Kemaman.

4.3 Worst Case Scenario

Worst case result is indicated by the highest concentration of toxic gas being dispersed. But as for this cases, all the simulations has the same maximum concentration which is 0.2mg/m^3. Hence, the worst case was considered for the highest dispersion area that affect the workers, residents and public facility such as road (Daniel and Joseph, 2002). Based on the result of worst case, the affected area by the sulfuric acid dispersion has been identified and evacuation routes has been developed.

Figure 4.25 and Table 4.1 below show the trend of the indoor and outdoor concentration from minutes of 0 till 60. As time increase, the concentration of the sulfuric acid will also increase until it achieves the concentration limit. This finding shows the mutual result with the other study in journal of accident modelling and analysis in process industries where the concentration of the gas release shows the same trend as time increase (Faisal et al.,2014). This result prove that time is playing a vital role in the evacuation process during the day of the incident. Hence, the evacuation routes that safest and takes the shortest time to the safer place will be the most favorable.

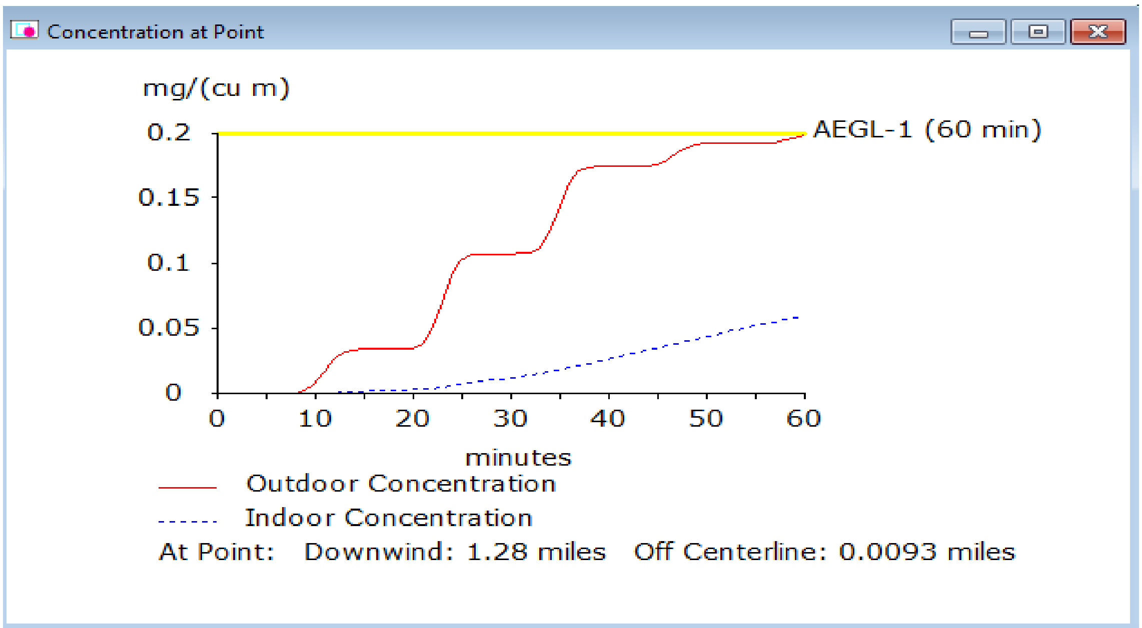


Figure 4.25: Concentration at Point

Table 4.1: The trend of sulfuric acid concentration for indoor and outdoor

Time (min)	Concentration of the sulfuric acid release (mg/m^3)	
	Indoor	Outdoor
0	0	0
10	0	0.01
20	0.005	0.03
30	0.015	0.12
40	0.03	0.17
50	0.05	0.19
60	0.06	0.2

Figure 4.26: Threat Zone on Teluk Kalong Industrial Area Map

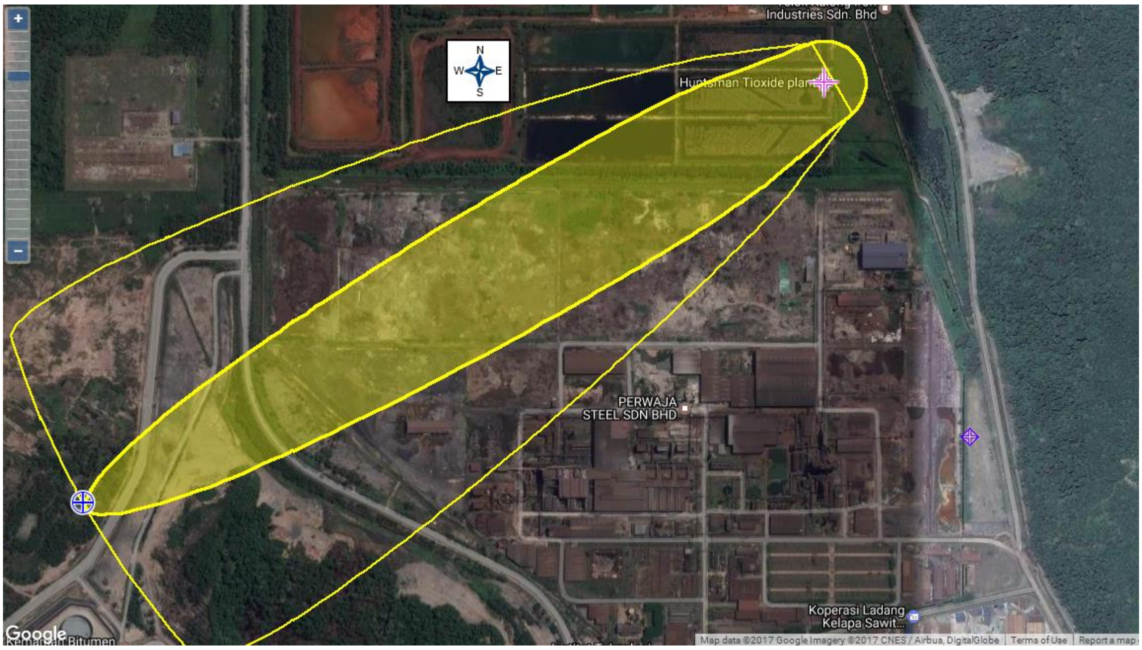


Figure 4.27: Threat Zone on Teluk Kalong Industrial Area Map (Zoom In)

Figure 4.26 and 4.27 show the toxic threat zone generated by ALOHA Software in the map of Google Earth. Yellow zone in the figure indicates the area that was affected by the release of sulfuric acid. All the analyzed data in the text summary was exported to the Google Earth by included the exact coordinate of the selected petrochemical plant. With the wind speed of 3.1 meter per second from 060 degrees at 5.2 meter height above the ground and has D atmospheric stability class which is stable. The radius of wind confidence line which is the longest distance travelled due to the release from the source point is 1.3 miles which is equal to 2.09 kilometer.

The toxic gas disperses to the atmosphere 2.09 kilometer with the wind prevailing at 060 degrees. The yellow zone affects several area almost all area in the study area and also several public roads. The roads affected is the road heading to the rest of the industrial area, which are Schlumberger and Kemaman Supply Base. Another road that is being affected is the road heading to the residents area which are Kampung Bukit Kuang and Kampung Sungai Terjun. It is also the road which shortest distance from the study area to Chukai City.

4.4 Proposed Emergency Evacuation Plan for Adjacent Areas

Figure 4.28: Proposed Safe Evacuation Route

Figure 4.28 represent the safe evacuation route for the adjacent affected area. The arrows show the safe direction which free from the sulfuric acid dispersion. Based on the wind prevalence during the day, the safe evacuation route to exit the radius of wind confidence line is by following the arrow. The blue arrow indicates the safe road that should be taken which heading to the Route 3/AH18. The orange arrows indicates the evacuation route for the workers. This road will be heading to Chukai city which will avoid the yellow zone. The purple arrow will be evacuation route which will be taking the same route as orange route while the white arrow is the evacuation route that will be heading to Kampung Bukit Kuang.

Figure 4.29: Unsafe route

Figure 4.29 show the unsafe route for affected area. There are several roads that affected from the sulfuric acid dispersion and need to be closed from the public usage. The red arrows show the unsafe route or road. The area that is located within the yellow line should be avoided during the day of the incident to avoid the inhalation of that toxic gas which will cause a health effect to those who are accidentally inhaled the released gas.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From the study, it is found out that sulfuric acid dispersion from the storage tank in a chemical plant can create an event with hazards potential. The simulation using the hole opening for about 4 inches shows the area of the dispersion can be spread up to 1.3 miles or equal to 2.09km. The event will be more serious if there will be a huge opening at the sulfuric acid storage tank and the area of the dispersion will be wider than the simulated result.

December has been chosen as the worst case of the dispersion. This is due to longest distance of the toxic dispersion. The downwind concentration for the sulfuric acid release is increasing as time increase. The highest concentration is recorded at the time of 60 minutes which is 0.2mg/m^3. Meanwhile, the threat zone is determined by the yellow zone which has the radius of 1.3 miles. Based on the data findings, it can be concluded that the radius of sulfuric acid dispersion affect the adjacent facilities use by public and other petrochemical plants in the Teluk Kalong Industrial Area. Based from this result, the evacuation route was proposed where the affected area will be avoided.

5.2 Recommendation

As for recommendation, in order to prevent the Major Accident Event (MAE) occurrence in petrochemical plant industry, the role of facility management is essential to ensure the facility is safe from MAE towards workers, public and environment. The management need to ensure adequate inspection and maintenance of the system and process plant. Management also can install High Level Overfill Prevention Switch at the tank to indicate when the liquid in the tank reaches a dangerously high condition. Besides, management need to ensure the tanks are installed with the Temperature Sensor, Radar Level Gauge and Tank Side Monitor to prevent leakage of toxic material from the tank. In addition, to improve off-site and on-site emergency evacuation planning in Teluk Kalong Industrial Area, management need to fully cooperate with other authority including Fire and Rescue Department.

REFERENCES

1. Arunraj, N. S., & Maiti, J. (2009). A methodology for overall consequence modeling in chemical industry. Journal of hazardous materials, 169(1), 556-574.
2. Assael, M. J., & Kakosimos, K. E. (2010). Fires, explosions, and toxic gas dispersions: Effects calculation and risk analysis. CRC Press.
3. Aziz, H. A., Shariff, A. M., & Rusli, R. (2014). Managing process safety information based on process safety management requirements. Process Safety Progress, 33(1), 41-48.
4. Baybutt, P. (2014). Requirements for improved process hazard analysis (PHA) methods. Journal of Loss Prevention in the Process Industries, 32, 182–191. http://doi.org/10.1016/j.jlp.2014.08.004
5. Bigley, G. A., & Roberts, K. H. (2001). The incident command system: High-reliability organizing for complex and volatile task environments. Academy of Management Journal, 44(6), 1281-1299.
6. Bowen, G. A. (2009). Document analysis as a qualitative research method. Qualitative research journal, 9(2), 27-40.
7. Bragatto, P. A., Pittiglio, P., & Ansaldi, S. (2009). The management of mechanical integrity inspections at small-sized “Seveso” facilities. Reliability Engineering & System Safety, 94(2), 412–417. http://doi.org/10.1016/j.ress.2008.04.005
8. Chao, E. L., & Henshaw, J. L. (2001). How to Plan for Workplace Emergencies and Evacuations. Occupational Safety & Health Administration OSHA, 3088.

9. Cole, D., & St Helena, C. A. (2001). Chaos, Complexity, and Crisis Management: A New Description of the Incident Command System. National Fire Academy.
10. Corbin, J., & Strauss, A. (2014). Basics of qualitative research: Techniques and procedures for developing grounded theory. Sage publications.
11. Crowl, D. A., & Louvar, J. F. (2001). Chemical process safety: fundamentals with applications. Pearson Education.
12. Department of Health and Human Services, 2009. Evaluation Briefs No. 18 January 2009 Data Collection Methods for Evaluation: Document Review
13. Do, N. (2015). Integration of engineering change objects in product data management databases to support engineering change analysis. Computers in Industry, 73, 69–81. http://doi.org/10.1016/j.compind.2015.08.002
14. EPA & NOAA, 2007. Manual, ALOHA User'S. "The CAMEO Software System." EPA/NOAA, February (2007).
15. Folkestad, B. (2008). Analysing Interview Data (No. 13). Eurosphere working paper series. Online Working Paper.
16. Jones R, Lehr W, Simecek-Beatty D, Reynolds RM (2013) ALOHA® (Areal Locations of Hazardous Atmospheres) 5.4.4 technical documentation. In: NOAA technical memorandum NOS OR&R 43, November 2013
17. Jones, R., W. Lehr, D. Simecek-Beatty, 2013. ALOHA (AREAL LOCATION of HAZARDOUS ATMOSPHERES) Tech Document.
18. Khan and Abbasi (1999). Major accidents in process industries and an analysis of causes and consequences. Journal of Loss Prevention in the Process Industries, 12(5), 361–378. http://doi.org/10.1016/S0950-4230(98)00062-X

19. Koller, G., Fischer, U., & Hungerbühler, K. (2000). Assessing Safety, Health, and Environmental Impact Early during Process Development. Industrial & Engineering Chemistry Research, 39(4), 960–972. http://doi.org/10.1021/ie990669i

20. Koller, G., Fischer, U., & Hungerbühler, K. (2000). Assessing safety, health, and environmental impact early during process development. Industrial & Engineering Chemistry Research, 39(4), 960-972.

21. Kothari, C. R. (2004). Research Methodology: Methods and Techniques. New Age International. Retrieved from https://books.google.com/books?hl=en&lr=&id=hZ9wSHysQDYC&pgis=1

22. Künzer, L. (2016, January). Myths of Evacuation. Retrieved May 10, 2016, from http://feuertrutz.com/myths-of-evacuation/150/39717/

23. Louvar, J. (2010). Guidance for safety performance indicators. Process Safety Progress, 29(4), 387–388. http://doi.org/10.1002/prs.10418

24. Miles, J., & Gilbert, P. (2005). A Handbook of Research Methods for Clinical and Health Psychology. Oxford University Press. Retrieved from https://books.google.com/books?hl=en&lr=&id=kmZ3Yt5pY0YC&pgis=1

25. NOAA. (2016). Levels of Concern | response.restoration.noaa.gov. Retrieved May 11, 2016, from http://response.restoration.noaa.gov/locs

26. Pasquill, F. (1961). The estimation of the dispersion of windborne material.Meteorol. Mag, 90(1063), 33-49.

27. Paulette Rothbauer. (2008) . "Triangulation" Thousand Oaks, CAThe SAGE Encyclopedia of Qualitative Research Methods p. 893 - 894

28. Pohanish, R. P., & Greene, S. A. (2009). Wiley guide to chemical incompatibilities. John Wiley & Sons.

29. Shaluf, I. M., & Ahmadun, F. (2003). Major hazard control: the Malaysian experience. Disaster Prevention and Management, 12(5), 420–427. http://doi.org/10.1108/09653560310507244
30. Tseng, J. M., Kuo, C. Y., Liu, M. Y., & Shu, C. M. (2008). Emergency response plan for boiler explosion with toxic chemical releases at Nan-Kung industrial park in central Taiwan. Process Safety and Environmental Protection, 86(6), 415-420.
31. Tubbs, J., & Meacham, B. (2007). Egress design solutions: A guide to evacuation and crowd management planning. John Wiley & Sons.
32. US Environmental Protection Agency and National Oceanic and Atmospheric Administration. (2015). ALOHA Example Scenarios. Retrieved May 11, 2016, from https://www.epa.gov/cameo/aloha-software
33. United States Department of Labor. (2002). Occupational Safety and Health Standards. Retrieved May 10, 2016, from https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10114
34. United States Department of Labor. (2013, February 8). Appendix C to §1910.119 -- Compliance Guidelines and Recommendations for Process Safety Management (Nonmandatory). Retrieved May 10, 2016, from https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS
35. WHIMS 1988 Drury, P. (1988). Workplace Hazardous Materials Information System (WHMIS) and you!. Canadian journal of medical technology, 50(2), 124-125.

36. Wenzel, R. N. (1949). Surface Roughness and Contact Angle. The Journal of Physical Chemistry, 53(9), 1466-1467.

37. Williams, P. (2015, July 23). Mechanical Integrity (MI). Retrieved May 10, 2016, from https://inspectioneering.com/tag/mechanical integrity