Assessing Risk and Modeling a Sudden Gas Release Due to Gas Pipeline Ruptures

Report to:

U.S. Department of the Interior
Minerals Management Service

by:

S.L. Ross Environmental Research Ltd.
Ottawa, Canada

SINTEF
Trondheim, Norway

&
Wellflow Dynamics
Oslo, Norway

July, 2009

SL ROSS

Executive Summary

The objectives of this project were to 1) develop a computer software solution to model the behavior of wet or dry gas from a single-phase sub-sea pipeline release from sea-bed to harmless in-air concentration; 2) to utilize the software system to model the behavior of gas released from hypothetical sub-sea pipeline ruptures; and 3) to estimate the probability of occurrence of pipeline ruptures in the MMS OCS regions using relevant historical pipeline spill statistics.

Minerals Management personnel in the Pacific Region provided example pipeline rupture scenarios for use in the model development, testing and impact assessment phases of the project. The pipelines selected were 12, 24 and 36-inch diameter systems with varying length, depths, operating pressures, environmental conditions and gas types. Detailed descriptions of these scenarios are provided in Table 3.1, Table 3.2 and Table 3.3.

The MMS Pipeline Gas Release Computer Model (WCDgas.exe) delivered with this report provides a methodology to predict the behavior of gas discharges from sub sea pipelines. The MMS POSVCM oil pipeline discharge model was modified to accommodate gas release, the behavior of the gas bubble plume and generation of output suitable for air dispersion modeling. A summary of the WCDgas modeling results for the example scenarios developed for this project can be found in Table 7.2. Peak gas discharge rates ranging from 10,000 to 1.6 million g/s were predicted depending on the release characteristics. Release durations between 5 minutes and 3 hours were identified.

The OCD/5 atmospheric dispersion model developed for MMS was used to model the behavior of the gas after exiting the water surface. Modifications were made to this software to improve its ease of use and data output reporting. A summary of the OCD/5 modeling results for the example scenarios developed for this project can be found in Table 7.3. The primary hazard surrounding natural gas dispersions in air is the explosive zone downwind of the release. The model predicts that this zone will be less than 1200 m in all of the cases studied and typically less than 500 m.

Software installation instructions and a quick guide to the basic use of the software are provided in Appendix E.

The potential damage to marine biota from a gas pipeline rupture will be negligible due to the non-toxic nature of the gas, the small release duration and relatively small volumes of water affected. The risk to human health and safety will be limited to the explosive zone surrounding the gas discharge location and will only be present for the short duration of the release (minutes to a few hours at most).

Based on historical Gulf of Mexico pipeline infrastructure and spill incident data the implied frequency of catastrophic gas pipeline releases is 0.43 incidents per year, or one every 2.3 years for the Gulf of Mexico Region and 0.0045 incidents per year, or one every 220 years for the Pacific Region.

Table of Contents

Assessing Risk and Modeling a Sudden Gas Release Due to Gas Pipeline Ruptures

1 Introduction

This report was prepared to meet the requirements of topic #3 of the White Paper Solicitation M07RS13346 issued by MMS Operational Safety and Engineering Research (OSER). White papers were originally requested to "Assess Risk and Model a Sudden Gas Release Due to a Gas Pipeline Rupture on the Pacific OCS". The scope of the original request subsequently was expanded to include additional offshore regions, a larger range of pipeline sizes and the delivery of a user-friendly computer model similar to the oil pipeline release model developed for MMS TAR (MMS TAR report #390). A study team comprised of individuals from SL Ross Environmental Research Ltd, Sintef and Well Flow Dynamics was assembled to meet the requirements of the request and were contracted to complete the work. SL Ross was the prime contractor and was responsible for the spill risk assessment, air-side gas modeling and sensitivity modeling components of the study. Well Flow Dynamics developed the gas discharge model for the sub sea pipeline ruptures. Sintef completed the modifications of the POSVCM model (previous oil pipeline discharge model developed for MMS) to accommodate gas release, the behavior of the gas bubble plume and generation of output suitable for the air dispersion modeling.

2 Project Objectives and Goals

2.1 Objectives

The objectives of this project were:

1. to develop a computer software solution to model the behavior of wet or dry gas from a single-phase sub-sea pipeline release from sea-bed to harmless in-air concentration;
2. to utilize the software system to model the behavior of gas released from sub-sea pipeline ruptures as it travels from the discharge point, through the water column, exits at the water surface and then disperses in the atmosphere. The effects of gas source and environmental input parameters on the ultimate fate and effects of the gas were addressed through a sensitivity analysis of these factors, and;
3. to estimate the probability of occurrence of pipeline ruptures in the Pacific, Alaskan and Gulf of Mexico OCS regions using relevant historical pipeline spill statistics.

2.2 Goals

More specifically, the goals of the project were to:

1. Work with MMS representatives to identify a number of typical sub-sea gas pipeline release scenarios of interest.
2. Estimate the probability of pipeline ruptures in the Pacific, Alaskan and Gulf of Mexico OCS regions using relevant historical pipeline spill statistics.

3. Develop a computer model to predict the release rate versus time of gas from a damaged (small hole to guillotine rupture) sub-sea pipeline. This gas pipeline release model was built by modifying the Pipeline Oil Spill Volume Computer Model (POSVCM) previously developed by SINTEF for MMS. This minimized development time and cost and resulted in a software implementation similar to that already in use by MMS.
4. Develop and implement algorithms to predict the 3-dimensional (3D) behavior of the gas as it rises from the sea-bed to the surface and to predict the source strength and area of the gas at the surface over the life of the release.
5. Integrate the results from the sub-sea gas release models to the Offshore and Coastal Dispersion (OCD) model previously developed for MMS to predict the zone of influence of the in-air gas cloud generated by the pipeline rupture.
6. Document the methods used in the gas release modeling and the steps necessary to link the in-water modeling results to the air-side dispersion model.
7. Apply the integrated models to specific US Outer Continental Shelf (OCS) gas pipeline release scenarios to demonstrate the systems capability, to determine the sensitivity of gas fate to release conditions and environmental variables, and to identify potential environmental and health and safety impact zones.
8. Deliver a computer software package that can be used by MMS and others to model user-defined sub-sea gas pipeline ruptures.
9. Prepare a final report detailing the work completed.

3 Example Pipeline Rupture Scenarios

Minerals Management personnel in the Pacific, Gulf of Mexico and Alaskan Regions were asked to provide example pipeline rupture scenarios to be used in the model development, testing and impact assessment phases of the project. The Pacific Region provided three pipeline setups each with a deep and shallow water spill scenario. The pipelines were 12, 24 and 36-inch diameter systems with varying length, depths, operating pressures, environmental conditions and gas types. Detailed descriptions of the Pacific Region scenarios are provided in Table 3.1, Table 3.2 and Table 3.3. A single spill scenario has also been developed for the Gulf of Mexico Region to enable the implementation of the software in the Region. The characteristics of this scenario are provided in Table 3.4. This scenario is identical to the 36-inch Pacific scenarios with the exception that Gulf of Mexico specific over-land and over-water meteorological data have been specified. More details concerning the use of the data provided in these tables is provided in the modeling sections of the report.

Table 3.1 Pacific Region 12-Inch Diameter Pipeline Scenario Description

Gas Pipeline Release: Scenario Details				
Scenario Description				
MMS Region	Pacific			
Pipeline Geometry	**US**		**Metric**	
outer diameter	12	in	0.3048	m
wall thickness	0.5	in	0.0127	m
inner diameter	11	in	0.2794	m
length	6	mi	9.6	km
Flow Conditions				
max. allowable operating press(MAOP)	1440	psi	9928	kPa
flow rate	12	MMcfd	3.93	m3/s
minimum shutdown time (min)	2	min	2	min
gas type	locally produced gas			
Rupture Characteristics	**US**		**Metric**	
guillotine break- pipe id	11	in	0.2794	m
small hole diameter	1	in	0.0254	m
Deep Water Location (offshore)	**longitude**		**latitude**	
location (decimal degrees)	120.1205		34.3907	
	English		**Metric**	
water depth at rupture	800	ft	243.84	m
bottom water temperature	44	°F	6.7	°C
surface water temperature		°F		°C
distance to shore	6	mi	9.6	km
Shallow Water Location (near shore)	**longitude**		**latitude**	
location (decimal degrees)	120.0658		34.4375	
	US		**Metric**	
water depth at rupture	300	ft	91.44	m
bottom water temperature	53	°F	11.7	°C
surface water temperature		°F		°C
distance to shore	3	mi	4.8	km
Meteorological Information Sources				
Land Side				
SCRAM Mixing Height Station	23230	Oakland/WSO AP		
SCRAM Surface Data Station	23174	Los Angeles Int'l Arpt		
note:pcrammet.exe used to merge files for use in OCD5				
Water Side				
National Data Buoy #	46023	or	46235	
note:buoymet.exe used to modify file and add over water mixing height for OCD5				
note: surface water temperatures as per buoy data				

Table 3.2 Pacific Region 24-Inch Diameter Pipeline Scenario Description

Gas Pipeline Release : Scenario Details				
Scenario Description				
Platform / Pipeline name	New Facility			
MMS Region	Pacific			
Pipeline Geometry	**US**		**Metric**	
outer diameter	24	in	0.6096	m
wall thickness	0.875	in	0.022225	m
inner diameter	22.25	in	0.56515	m
length	35	mi	56	km
Flow Conditions				
max. allowable operating press(MAOP)	2000	psi	13789	kPa
flow rate	1000	MMcfd	327.74	m3/s
minimum shutdown time (min)	2	min	2	min
gas type	90% methane from LNG facility			
Rupture Characteristics	**US**		**Metric**	
guillotine break- pipe id	22.25	in	0.56515	m
small hole diameter	na	in	na	m
Deep Water Location (offshore)	**longitude**		**latitude**	
location (decimal degrees)	119.25		33.8696	
	English		**Metric**	
water depth at rupture	3000	ft	914.4	m
bottom water temperature	42	°F	5.6	°C
surface water temperature		°F		°C
distance to shore	35	mi	56	km
Shallow Water Location (near shore)	**longitude**		**latitude**	
location (decimal degrees)	119.2632		34.163	
	US		**Metric**	
water depth at rupture	160	ft	48.768	m
bottom water temperature	57	°F	13.9	°C
surface water temperature		°F		°C
distance to shore	3	mi	4.8	km
Meteorological Information Sources				
Land Side				
SCRAM Mixing Height Station	23230	Oakland/WSO AP		
SCRAM Surface Data Station	23174	Los Angeles Int'l Arpt		
note:pcrammet.exe used to merge files for use in OCD5 (edit file for year format)				
Water Side				
National Data Buoy #	46023			
note:buoymet.exe used to modify file and add over water mixing height for OCD5				
note: surface water temperatures as per buoy data				

Table 3.3 Pacific Region 36-Inch Diameter Pipeline Scenario Description

Gas Pipeline Release : Scenario Details				
Scenario Description				
Platform / Pipeline name	New Facility			
MMS Region	Pacific			
Pipeline Geometry	**English**		**Metric**	
outer diameter	36	in	0.9144	m
wall thickness	1	in	0.0254	m
inner diameter	34	in	0.8636	m
length	13	mi	20.8	km
Flow Conditions				
max. allowable operating press(MAOP)	1500	psi	10342	kPa
flow rate	1400	MMcfd	458.84	m3/s
min shutdown time (min)	2	min	2	min
gas type	90% methane from LNG facility			
Rupture Characteristics	**English**		**Metric**	
guillotine break- pipe id	34	in	0.8636	m
small hole diameter	na	in	na	m
Deep Water Location (offshore)	**longitude**		**latitude**	
location (decimal degrees)	117.4595		32.5227	
	English		**Metric**	
water depth at rupture	3000	ft	914.4	m
bottom water temperature	42	°F	5.6	°C
surface water temperature		°F		°C
distance to shore	13	mi	20.8	km
Shallow Water Location (near shore)	**longitude**		**latitude**	
location (decimal degrees)	117.2973		35.5227	
	English		**Metric**	
water depth at rupture	160	ft	48.768	m
bottom water temperature	57	°F	13.9	°C
surface water temperature		°F		°C
distance to shore	3	mi	4.8	km
Meteorological Information Sources				
Land Side				
SCRAM Mixing Height Station	23230	Oakland/WSO AP		
SCRAM Surface Data Station	23188	San Diego/Lindbergh Fld		
note:pcrammet.exe used to merge files for use in OCD5 (edit file for year format)				
Water Side				
National Data Buoy #	46023			
note:buoymet.exe used to modify file and add over water mixing height for OCD5				
note: surface water temperatures as per buoy data				

Table 3.4 Gulf of Mexico Region 36-Inch Diameter Pipeline Scenario Description

Gas Pipeline Release : Scenario Details				
Scenario Description				
Platform / Pipeline name	New Facility			
MMS Region	Gulf of Mexico			
Pipeline Geometry	**English**		**Metric**	
outer diameter	36	in	0.9144	m
wall thickness	1	in	0.0254	m
inner diameter	34	in	0.8636	m
length	13	mi	20.8	km
Flow Conditions				
max. allowable operating press(MAOP)	1500	psi	10342	kPa
flow rate	1400	MMcfd	458.84	m3/s
min shutdown time (min)	2	min	2	min
gas type	90% methane from LNG facility			
Rupture Characteristics	**English**		**Metric**	
guillotine break- pipe id	34	in	0.8636	m
small hole diameter	na	in	na	m
Deep Water Location (offshore)	**longitude**		**latitude**	
location (decimal degrees)	117.4595		32.5227	
	English		**Metric**	
water depth at rupture	3000	ft	914.4	m
bottom water temperature	42	°F	5.6	°C
surface water temperature		°F		°C
distance to shore	13	mi	20.8	km
Shallow Water Location (near shore)	**longitude**		**latitude**	
location (decimal degrees)	117.2973		35.5227	
	English		**Metric**	
water depth at rupture	160	ft	48.768	m
bottom water temperature	57	°F	13.9	°C
surface water temperature		°F		°C
distance to shore	3	mi	4.8	km
Meteorological Information Sources				
(data from Douglas 2008)				
Land Side (OCD Group 4a & 4b)				
Upper Air Station ID	53813	Slidell		
Weather from various sources		New Orleans		
note:pcrammet.exe used to merge files for use in OCD5 (edit file for year format)				
Water Side (OCD Group 4a & 4b)				
National Data Buoy #	42007			
note:data pre-formatted to OCD structure by Douglas, 2008				
note: surface water temperatures as per buoy data				

4 Probability of Gas Pipeline Ruptures

In this section, the occurrence rate of gas pipeline ruptures is examined. Accident statistics from the Gulf of Mexico and Pacific regions are summarized, then compared with the exposure factor of "mile-years" of pipeline service to produce an accident rate.

4.1 Pipeline Incidents

MMS maintains a record of pipeline incidents, and publishes this information on the web (MMS 2009). Information is based on that contained in the MMS Technical Information Management System, and records are available for the years 1996 to 2006. For that eleven-year period, Table 4.1 shows the annual breakdown of pipeline incidents for the Gulf of Mexico (GOM) and Pacific Regions.

Table 4.1 All pipeline incidents in GOM and Pacific Regions, 1996 to 2006

Region	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
GOM	7	13	2	7	7	11	8	9	8	6	0
PAC	0	0	0	1	0	0	1	0	0	0	0
Total	7	13	2	8	7	11	9	9	8	6	0

A total of 80 pipeline incidents were reported for the years 1996 to 2006. Of these, only five involved a catastrophic rupture of a gas pipeline, summarized below in Table 4.2, with each incident described briefly below.

Table 4.2 Gas pipeline incidents involving a catastrophic rupture

Region	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
GOM	0	0	0	0	0	1	3	2	0	0	0
PAC	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	1	3	2	0	0	0

4.1.1 Incident Summaries

April 29, 2001
Texaco Exploration and Production — Pipeline segment no. 10393
South Marsh Island, Block 236 — Water Depth: 14 feet

An incoming 2-inch gas lift line was ruptured. The break caused damage to the upper work deck, handrails, flowline, and riser. The line appeared to have been pulled from the structure prior to the rupture possibly by a shrimp vessel since the line was buried. Personnel working on an adjacent well heard the bleeding gas, reported the incident to Texaco personnel who immediately shut-off the supply of gas to the line. No injuries or pollution were reported.

January 3, 2002
Chevron USA Inc. Pipeline segment no. 13154
West Cameron, Block 48 Water Depth: 22 feet
During an ESD shut-in, the 10-inch incoming shutdown valve closed, but the safety system on the platform failed to operate. Shortly after, the platform operators noticed gas bubbles in the water approximately 300 feet from the platform. The pipeline, which was 37 years old, was allowed to bleed for 90 minutes, and was later found to have ruptured in three places. It appears that the safety system failure was due to freezing problems in the ¼-inch tubing, which runs approximately 40 feet to the transmitter.

January 15, 2002
Transcontinental Gas Pipeline Company Pipeline segment no. 1526
Vermillion, Block 67 Water Depth: 40 feet
The operator at an adjacent platform reported a pipeline rupture with a fire on the water, located ½ to ¾ miles west of their location. Within 2 hours Transco confirmed it was their pipeline, a 16-inch gas pipeline. The pipeline was shut it in and the fire ceased. No injuries or pollution were reported.

July 6, 2002
ChevronTexaco Corporation Pipeline segment no. 3540
South Marsh Island, Block 217 Water Depth: 15 feet
The pipeline was reported as having ruptured, with the ensuing fire having flames 100 feet high. The location of the rupture was 6000 feet north of SM 217 A. The flames lasted for 2 hours. The pipeline PSL shut-in the platform at the time of the rupture.

January 7, 2003
Walter Oil & Gas Corporation Pipeline segment no. 11052
South Timbalier, Block 260 Water Depth: 303 feet
A vessel moored 2.2 miles from the platform snagged the associated gas pipeline while retrieving its anchor. The vessel began pulling up the anchor and halted the operation an hour later when the Captain realized he had snagged a heavy object. Ten minutes later, the Captain noticed fire and smoke under the platform and notified the USCG. Subsequently, the platform operator felt several jolts to the platform that intensified in strength and eventually rocked the platform. The operator shut-in the platform's two producing wells. About 10 minutes later, the platform was jolted again: the gas pipeline broke loose and an explosion and fire erupted from the severed pipeline beneath the platform. The three individuals on the platform at the time evacuated the facility via helicopter. The vessel had been moored outside of the designated lightering area per the instructions of the Mooring Master. The Mooring Master and the Captain were unaware of any pipelines in the mooring area as apparently neither one had a copy of the pipeline overlay to the NOAA nautical chart.

December 2, 2003
South Pipeline Company, LP — Pipeline segment no. 5105
Eugene Island, Block 39 — Water Depth: 10 feet

A dredge barge, dredging the Atchafalaya Channel for the Corp of Engineers, impacted and severed the 20-inch gas pipeline. The barge was dredging the channel floor to a depth of 22 feet BML in the vicinity of the pipeline; however, the burial depth of the pipeline was not known. A representative of the pipeline company was not on board at the time of incident. The project engineer did not account for the length of the dredge (420 feet) in determining where to halt dredging operations relative to the location of the pipeline. The pipeline caught on fire as a result of the impact from the dredge. Approximately 1,500 feet of pipe was pulled apart or ripped.

4.2 Exposure Factor

A rational exposure factor must be used in order to express an accident statistic as a rate. For pipeline accidents, the most commonly used factor is the length of pipeline, times the years of service, resulting in "mile-years" of exposure.

The "Pipeline Masters" database maintained by MMS for the Gulf of Mexico was used to estimate the length of gas pipeline in operation during each year from 1996 to 2006. (MMS 2009). The focus of this analysis was on gas pipelines, so pipelines with product code designations of Gas, G/C, BLKG and BLGH were used in the analysis. Pipelines with Flare, Injection and Supply product codes were excluded from the analysis because these smaller pipelines are not of primary concern in this study. The length of Lift lines was determined separately as there has been one spill incident reported in the GOM for a Lift line. Pipeline segments with no reported length, no indication of the date of start of operation (construction date, approval date, pressure test date), and those with a status of abandoned but with no date of abandonment were excluded from the assessment. The total length of gas pipeline, according to the above assumptions, is summarized in Table 4.3.

Table 4.3 Total length of gas pipeline in the Gulf of Mexico Region, 1996 to 2006

Year	Pipeline length, miles
1996	12,851
1997	13,579
1998	14,156
1999	14,530
2000	14,819
2001	15,491
2002	16,338
2003	16,888
2004	17,404
2005	17,741
2006	17,849

There is approximately 188 miles of gas pipeline in the Pacific Region, approximately 1% of the total in the GOM region.

4.3 Probability Estimates

Summing the lengths for each year in Table 4.3, results in a total of 171,645 mile-years of pipeline operation. For the 11-year record under consideration, there were five incidents in the Gulf of Mexico involving a catastrophic rupture of a gas pipeline. The estimated incident rate is therefore (5 / 171,645 mile-years) equal to 2.9×10^{-5} incidents per mile-year.

As noted above, one of the five incidents involved a gas lift line. These comprise a much smaller subset of the above numbers, for a total of 5,407 mile-years. With one incident reported, the rate for gas lift lines is 1.8×10^{-4} incidents per mile-year.

If gas lift lines were excluded from the analysis, the total pipeline length under consideration becomes 166,238 mile-years, and with four incidents, the incident rate becomes 2.4×10^{-5} incidents per mile-year.

The total length of gas pipeline in the Gulf of Mexico, not including gas lift lines, as of 2008, is 17,777 miles. Based on a rate of 2.4×10^{-5} incidents per mile-year, the implied frequency of catastrophic incidents becomes 0.43 incidents per year, or one every 2.3 years.

There were no incidents reported for the Pacific Region. The incident rate estimate derived from the GOM dataset has been applied to the Pacific Region. The total length of gas pipeline in the Pacific Region is 188 miles. Based on the GOM rate of 2.4×10^{-5} incidents per mile-year, the implied frequency of catastrophic incidents for the Pacific Region becomes 0.0045 incidents per year, or one every 220 years.

5 Sub Sea Pipeline Gas Release Model

5.1 General Model Characteristics

The MMS Pipeline Gas Release Computer Model (WCDgas.exe) delivered with this report provides a methodology to predict the behavior of gas discharges from seafloor pipelines. The model can be used for worst-case guillotine break scenarios as well as smaller diameter punctures. The primary focus in this study has been on worst-case release scenarios as this was the main interest of MMS in this project. Inputs to WCDgas are parameters describing the configuration and characteristics of a pipeline system, the fluid it contains, and the leak or break from which the discharge occurs. Key outputs are the evolution of the release rate over time, the total mass of gas released, and an estimate of its surfacing rate and area of the boiling zone. The system is composed of a Release Module (that determines the gas release rate at the seafloor from the pipeline rupture) and a Near Field Module (that models the movement of the gas from the seafloor to the water surface), linked together with necessary databases through a Graphical User Interface (GUI).

Limitations of application are:

- Single "tree" pipeline networks with all branches (pipelines) converging toward a single outlet point at its root;
- No closed re-circulating loops;
- One and only one leakage point;
- Maximum of 100 pipeline segments per branch (i.e. between junctions) and 5 junction points;
- Maximum of 5 pipeline segments attached to a single junction;
- Only pipeline objects may connect directly to junctions or connectors;
- Pipeline object connected to non-pipeline objects at both ends;
- Maximum of 50 branches (series of Pipeline objects between junctions);
- Connection object connects exactly two pipeline objects;
- Junction object connects at least 3, and not more than 10 pipeline objects;
- An Inlet must be at the start of an incoming branch;
- Outlet object must connect to only one incoming pipeline object;
- Leakage point must be attached to a Pipeline object
- Diameter of leak cannot exceed pipe diameter. (This is checked and corrected automatically in the Release Module.)

Necessary inputs for simulation of a given scenario are:

- Gas composition:
  - Fraction of each component in the gas (mol %)
  - Mol weight for each component (can use defaults provided)
  - Liquid densities (g/cm^3)
- Flow inlet properties:
  - Depth (positive down; negative above mean sea level)
  - Total gas flow rate
  - Fluid temperature

  - Closing (or shut-in) time
- Pipeline or riser segment
  - Length
  - Inside diameter
  - Roughness coefficient (can default to 5.0 x 10^{-5})
  - Heat transfer coefficient (can default to 1 J/s)
  - Ambient temperature
- Pipe connector or junction
  - Depth
- Outlet (to remainder of pipeline system or storage
  - Depth
  - Fluid pressure
  - Closing (or shut-in) time
- Leak properties
  - Distance from upstream endpoint
  - Nominal diameter (not larger than pipeline diameter)
  - Water depth.

5.2 Model Installation Instructions

Run the file WCDgas_2-0_Setup.exe to install the program. Follow the instructions provided in the installation package. Detailed instructions for installing and running all of the software components delivered in this project are provided in Appendix E.

5.3 Basic Model Use Instructions

Double-click the WCDgas.exe file or the WCDgas icon on the desktop and the main program window appears with an empty work desk, Figure 5.1. The first row of menu items are referred to as the "Main Menu" items in the remainder of this report. All functions of the model can be accessed from the main menu. The second row of menu items are basic file handling options. The third row houses a number of icons that provide quick access to pipeline objects, pipeline integrity checking and scenario calculation initiation.

Click objects on the toolbar (either using the third row icons or the drop-down submenu items in the Object menu) and click again on the work-desk to construct a diagram of the pipeline system of interest. Alternatively open a pre-defined scenario from the 'File' menu option. When the diagram is printed or saved, the contents of the work-desk will be saved. All of the pipeline network information and leak characteristic for a scenario are saved in a file with an extension designation of "wcd". The saved data is retrieved from this file when the scenario is re-opened using WCDgas.

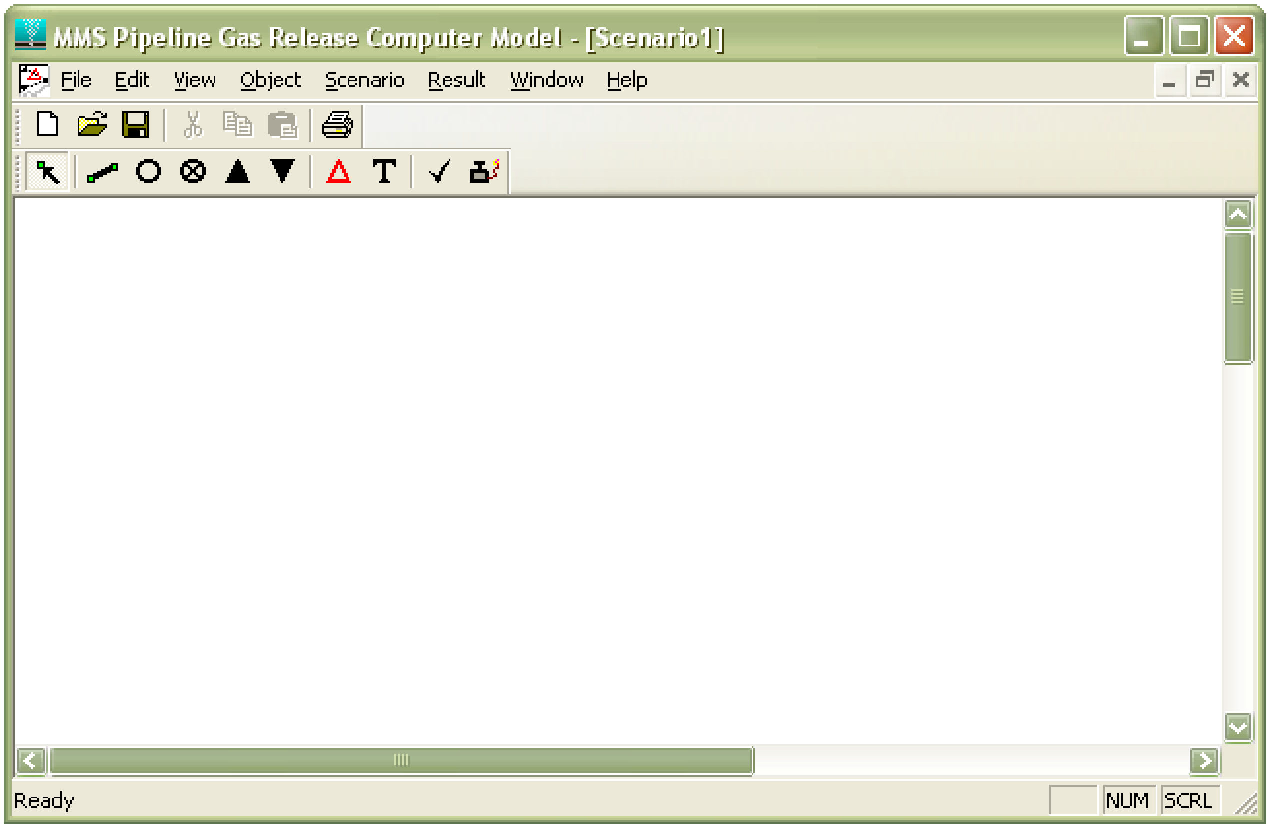


Figure 5.1 Main window for WCDgas.

5.3.1 Create a New Scenario

A scenario consists of a constellation of connected objects, each assigned a set of parameters. Under the Object menu or on the object toolbar there are six options:

- Pipeline
- Connection
- Junction
- Inlet
- Outlet
- Leakage

The parameters defining each object are given in Table 5.1.

Choose the component you want to place on your work desk, and click it into the work area. An example pipeline network is shown in Figure 5.2.

When a pipeline segment or leak point is inserted into the work area, it will appear with small green boxes defining the connection points. Pipeline segments can be resized by dragging one of these green boxes. Objects can be moved on the work-desk by click-and-drag.

Table 5.1 Parameters defining objects in a discharge scenario

Object	Parameters				
Pipeline Segment	Length	Diameter	Roughness	Heat Transfer Coefficient	Ambient Temperature
Connector	Depth				
Junction	Depth				
Inlet (Flow Source)	Depth	Flow Rate	Fluid Temperature	Closing (or Shut-in) Time	
Outlet (Flow Sink)	Depth	Pressure			
Leak Point	Distance from upstream endpoint	Nominal Diameter	Depth at leak location	Back Pressure	

To delete an object, click on the object and press the Delete key (or use the Delete command under the Edit menu).

All objects must be connected together before a scenario will run. Pipelines and Leak Points can connect to Connectors, Junctions, Inlets, and Outlets at any of their blue connection markers. The green box in the center of the Leak Point, or at the end of the Pipeline segment, will turn red when the connection has been properly made.

To verify that a connection has been properly made, click and drag the Connector, Junction, Inlet, or Outlet (not the Pipeline Segment or Leak Point), and see that the attached object follows after. (Clicking on the pipeline element will detach it from its connectors and junctions.)

Notes:

1. When opening an existing scenario, some pipelines may appear to be disconnected from their junctions and connectors. This is a visual effect resulting from the use of long text strings in names of elements, and does not affect the integrity of the scenario. These text strings mask the placement of objects. Simply click on the junctions and connectors, and the pipelines will return to their correct positions.
2. The layout on the desktop is generally not to scale. Only the parameters such as length and depth) allocated to each element in the diagram are used in the actual calculations. Moving an object manually on the desktop will not alter the basis for the computations in the WCDgas.

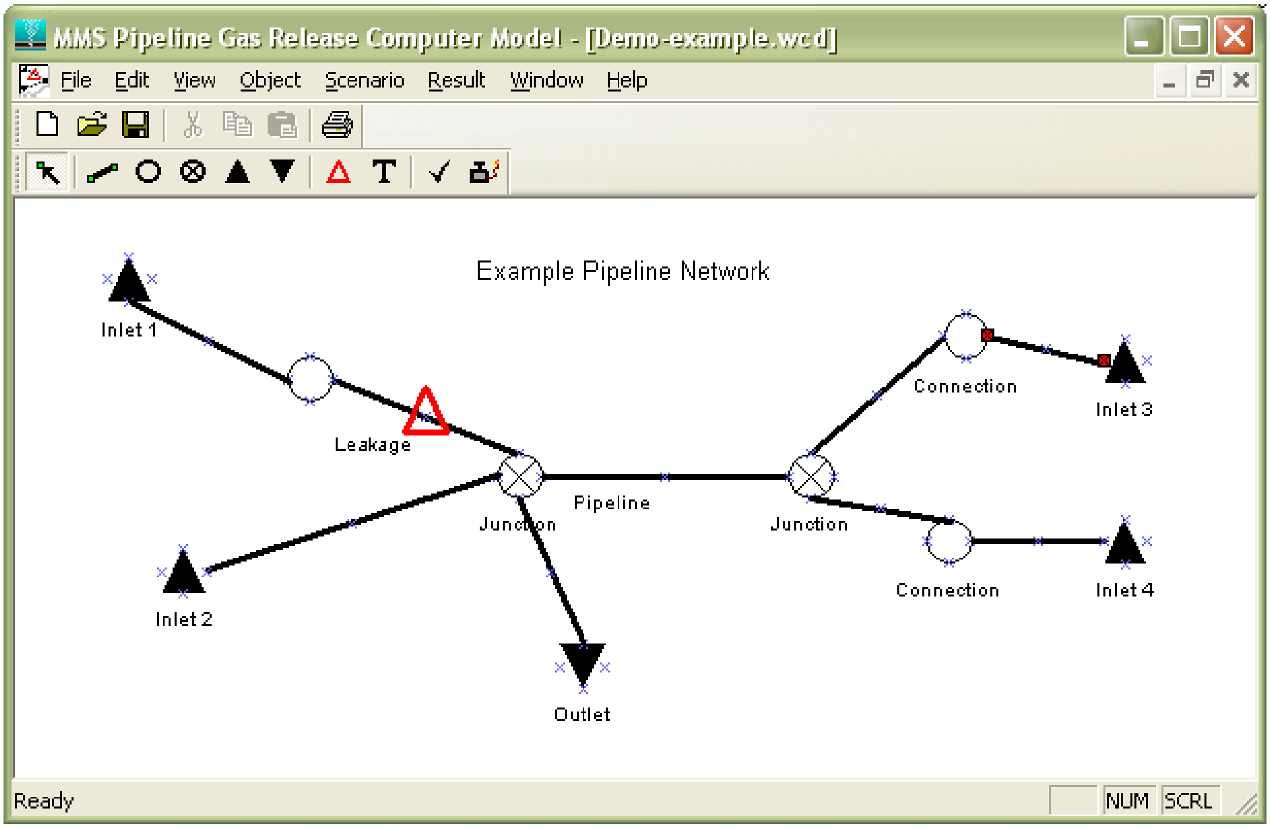


Figure5.2 Example Pipeline Network

5.3.2 Object Properties

After placing a selected object one has to supply required parameters. Right-click the object and choose Properties, or double-click and the Properties box appears. Fill in specifications for each object. Figure 5.3 shows the Object Properties dialog boxes. The following sections provide additional details regarding the data entered in these dialogs.

5.3.2.1 Flow Inlet Specifications

For every flow inlet in the network the depth, total gas flow rate, fluid temperature and the closing time have to be specified. The specified flow rate is fixed until the inlet choke closes. The closing time is the duration from the time the leak occurred to the time production is shut down.

5.3.2.2 Flow Outlet Specification

In contrast to the inlet specifications where several inlets are possible, only one pipeline outlet can be specified. At the pipeline (or network) outlet, the receiving pressure is required. The outlet pressure is the fixed pressure at the outlet of the pipeline, typically upstream of a choke at the receiving facility. This receiving pressure is usually known.

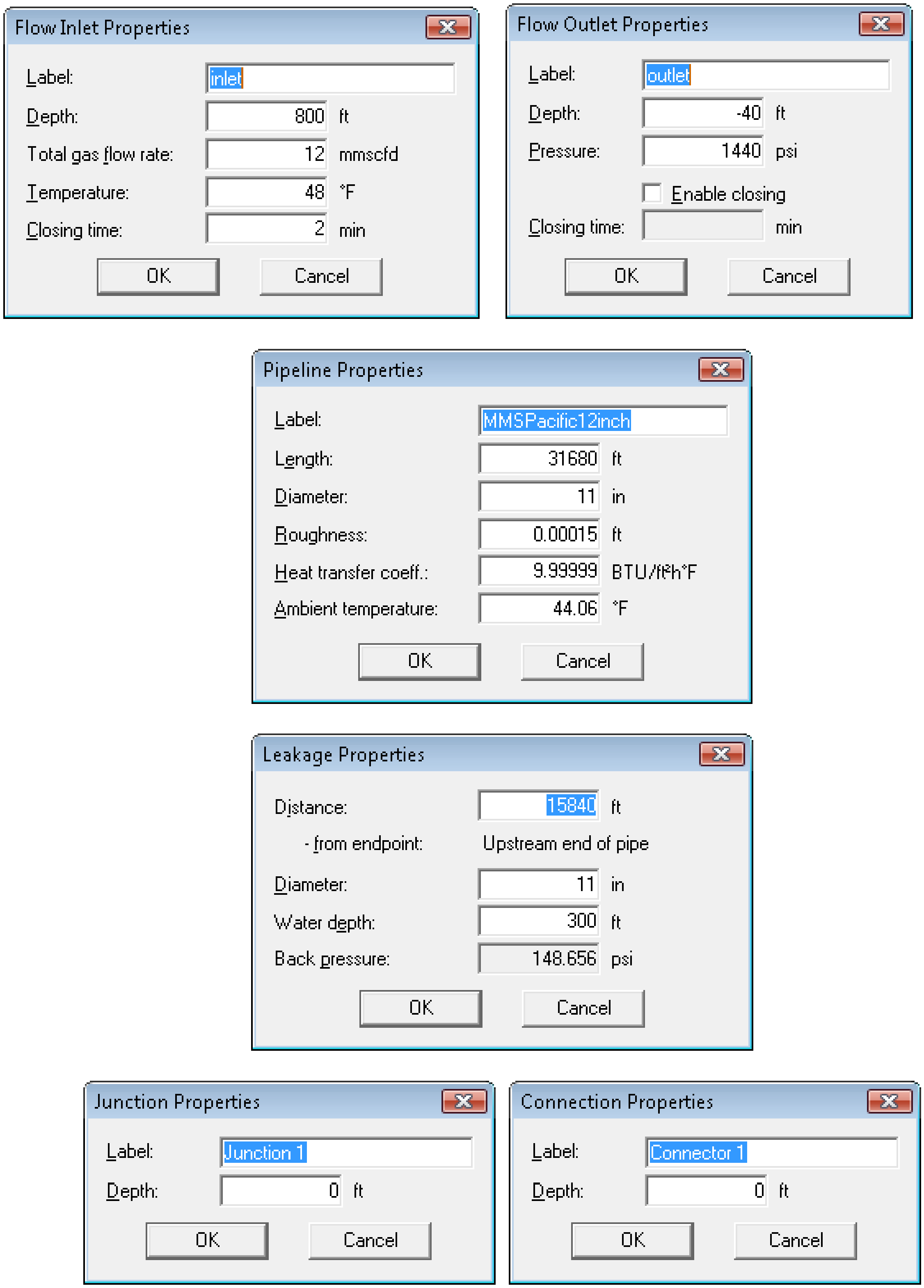


Figure 5.3 Object properties input dialogs. Labeling objects is not required, but is recommended as an aid in locating problems with the scenario setup.

Note: The outlet pressure can be the same as operating pressure, but that depends on the definition of "operating pressure". Usually, the "operating pressure" is used in connection with the "maximum operating pressure" and is the design limit of the pipeline or equipment, i.e. the pressure should not exceed the maximum anywhere in the system. Operating pressure can be this pressure, it can be the pipeline input pressure, or it can be an average pressure in the pipeline. Based on the user specified flow rate and the outlet pressure, the model calculates the pressure drop and hence, the pipeline inlet pressure as well as the entire pressure profile in the pipeline network.

The software handles networks with several inlets, but only one outlet and one leak or rupture as seen example in Figure 5.4.

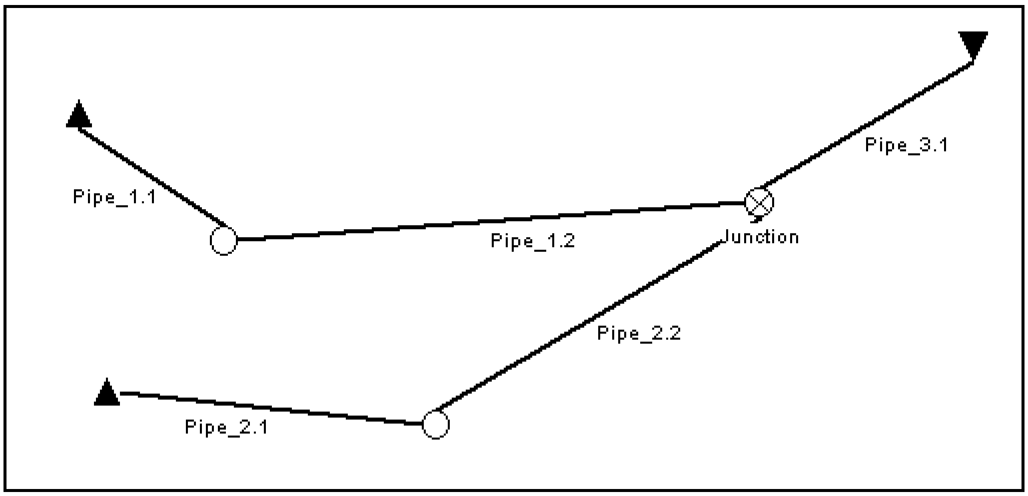


Figure 5.4 Example of a network with two inlets and one outlet

5.3.2.3 Pipeline Properties

Pipelines should be modeled with several pipe segments to account for the seabed topography and variation in inclination. Every pipeline segment is labelled with a description, given a length and an internal diameter. A pipeline has to be connected to an inlet, connection, junction or outlet.

The pipe roughness is used when calculating the frictional pressure drop in the pipeline. The internal pipe roughness for the gas pipelines will usually be low, typically 10E-5 ft, and smaller changes are not believed to have a significant effect on the pressure drop.

The overall heat transfer coefficient “U” is used to calculate the heat transfer from the fluid and radially through the pipe wall layers to the surroundings at ambient temperature.

A typical U value for an unburied, un-insulated pipeline can be 10 btu/(hr ft2 degF). A typical U value for an insulated (and buried) pipeline can be 0.5 - 2 btu/(hr ft2 degF).

5.3.2.4 Pipeline Connection

A pipeline is usually modeled with several pipeline segments with different angles. Between two segments, a connection is included with a depth specification.

5.3.2.5 Pipeline Junction

A pipeline junction defines a point with three or more pipelines are connected and is used when modeling networks. The required input data is depth.

5.3.2.6 Leakage Properties

The leak is modeled by a critical choke with a diameter equal to the leak size. The leak is snapped to a pipeline and the distance from the upstream end of the pipe is specified. The water depth is used to calculate the ambient back-pressure at the leakage.

For large ruptures, the simulations can become unstable because of rapid pressure transients. A workaround is to run the simulation with a smaller leak diameter.

5.3.3 Verify Pipeline Layout

After creating your scenario, select Scenario menu\Verify Layout (or the Network Check button on the toolbar). This checks a number of potential problems in the network layout, such as:

- Missing or invalid object parameters,
- Outlet point connected to more than one in-coming branch,
- Pipeline segment shorter than depth difference between endpoints,
- Maximum number of objects exceeded (100 pipeline segments, 5 junction, 10 segments per junction), and
- More than one leakage point found.

In general, these messages are self explanatory, and lead the user quickly to the problem area. If the “valid network” message appears one can continue with the analysis. Otherwise the message-box identifies the problem.

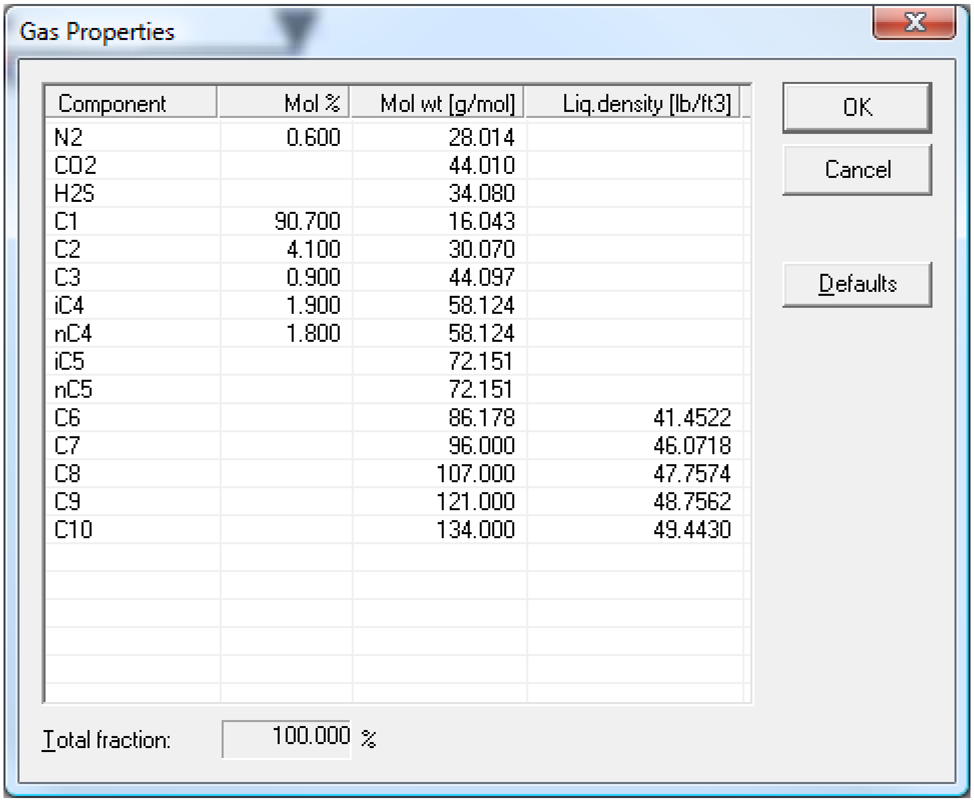
Shortcut: Select Calculate Discharge from the Scenario menu (or use the Worst Case discharge button on the toolbar). This automatically runs the Verify Layout test prior to estimating the discharge for the given scenario.

5.3.4 Gas Composition

The property of the gas in the pipeline is specified on a compositional basis using WCDgas’s “Scenario->Gas Composition” menu item. The available components include nitrogen, carbon dioxide, hydrogen sulfide and hydrocarbon components from C1 to C10. Figure 5.5 provides an example gas composition. The user enters the Mol% value for each component present in the gas. The total mole fractions must sum to 100%. The gas composition is entered and stored for each individual scenario.

5.3.5 Discharge Setup

Optional discharge model parameters can be entered in the Scenario->Discharge Setup menu item. These input items can be left blank for normal simulations and are provided for advanced model users.



Component	Mol %	Mol wt [g/mol]	Liq.density [lb/ft3]
N2	0.600	28.014	
CO2		44.010	
H2S		34.080	
C1	90.700	16.043	
C2	4.100	30.070	
C3	0.900	44.097	
iC4	1.900	58.124	
nC4	1.800	58.124	
iC5		72.151	
nC5		72.151	
C6		86.178	41.4522
C7		96.000	46.0718
C8		107.000	47.7574
C9		121.000	48.7562
C10		134.000	49.4430

Figure 5.5: Example Gas Composition

5.3.6 Nearfield Setup

The Scenario-> Nearfield Setup menu is used to provide the necessary input information for the modeling of the gas rise from the release point at the pipeline to the water surface. The water temperature and ”Output to OCD/5” air emission model are the two boxes of primary concern in this dialog. The water temperature is entered for the location of the leakage point. The box selecting output to OCD/5 should be selected if atmospheric dispersion modeling of the gas at the water surface is of interest following the simulation. The discharge start date and time of day are not critical data entry items in the present model configuration and can be left to the default values. The mass rate smoothing distance can be modified if the mass gas flow rate at the surface is not uniform otherwise the default value of zero should be used.

The algorithms used to predict the behavior of the gas as it rises to the surface are described in detail in Appendix B.

The Release module must be run before the Near Field module, since the latter uses results from the former to compute the timing, rates, and boiling zone of gas at the sea surface. To set up the Near Field module, select the menu item Scenario, Near Field Setup (Figure 5.6).

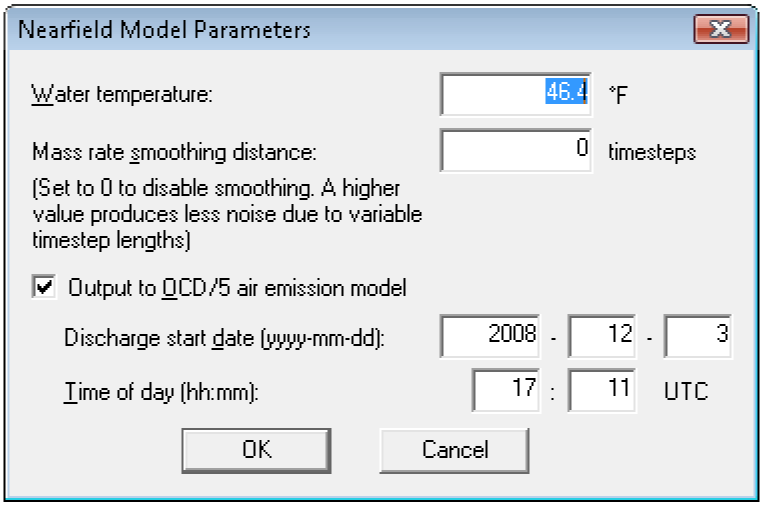


Figure 5.6 Near Field setup dialog box.

Description of entries in Near Field Setup Dialog shown in Figure 5.6:

- Water temperature: This is the temperature of the sea water at the location of the leakage point.
- Mass rate smoothing distance: The output can be averaged over several samples (or successive time steps) to dampen some of the artifacts that can occur when the input data to the Nearfield Module becomes very noisy ("ripples" in the curves, for instance). Note that this "input" is equivalent to the "output" or result produced by the preceding Release Module. Using a value of 3, for example, means that the averaging at each point in time will consider 3 points before and 3 points after the current sample, a total of 7 point to average each point in the output time series.
- Output to OCD/5 air emission model: This is optional, but if used it will produce an extra text output file (.DAT) that can be used by the OCD/5 atmospheric dispersion model. A starting date and time (using UTC time zone) is specified to correspond to the first time that gas was observed to emerge at the surface. This is used to produce the corresponding timestamps in the .DAT file.

5.4 Discharge Calculation

The gas release predictions are initiated using the Scenario->Calculate options after the pipeline network has been established and the gas composition entered. The discharge of gas from the pipeline rupture and the movement of the gas from the rupture to the surface both can be modeled independently using the "Calculate Discharge" and Calculate Nearfield" options in sequence. Since both models complete their calculations quickly it is more efficient in most cases to simply use the "Calculate All" option that automatically runs the two processes in sequence. The algorithms used to predict the behavior of the gas as it exits the pipeline puncture are described in detail in Appendix A. The algorithms used to predict the behavior of the gas as it rises to the surface are described in detail in Appendix B.

5.5 View Simulation Results

Once the scenario has been completed the results can be viewed using the main menu "Result" dialogs. A Discharge Summary similar to Figure 5.7 automatically appears at completion of the discharge calculation (if this option is selected in the main menu Options dialog), and is also accessible via the Result menu. This summarizes the gas flow characteristics at the rupture location.

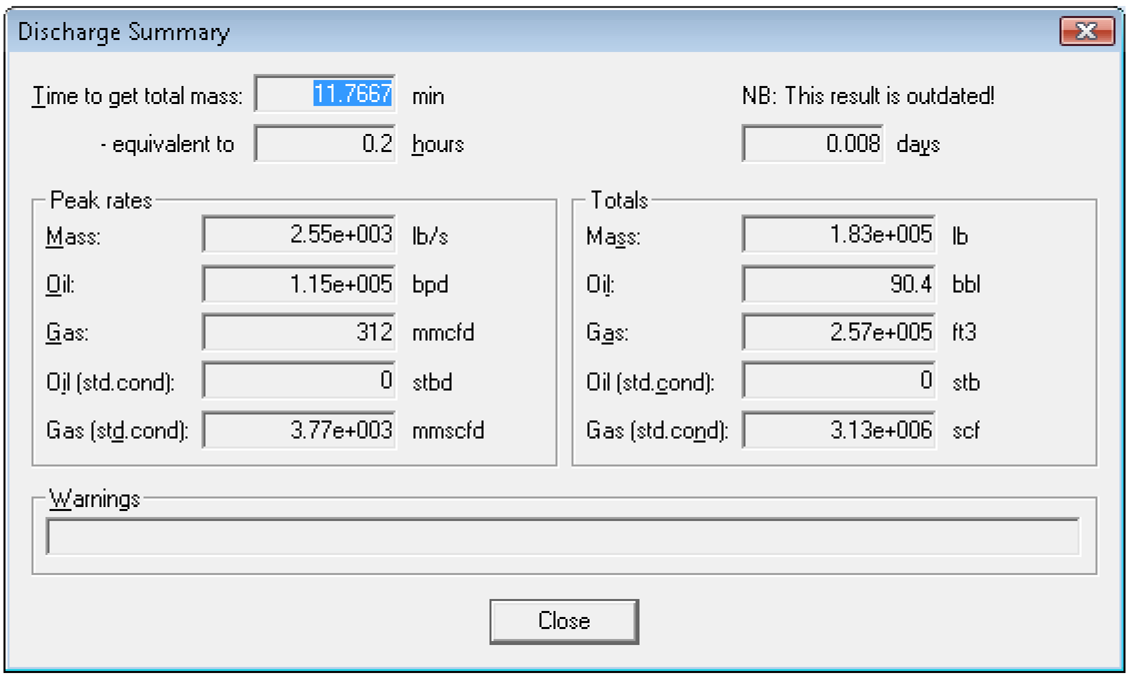


Figure 5.7 Sample Discharge Summary Report

Time series plots of the gas discharge characteristics at the rupture location and at the water surface can be generated using the "Results->Release Plots" and "Results->Nearfield Plots" options. In each of these options several variables can be selected for plotting using the selection dialog at the top of the plot. Figure 5.8 is an example plot of gas release at the leak or rupture location.

The variables that can be plotted at the discharge point include:

- Accumulated Mass
- Total Mass Flow Rate
- Gas Mass Flow Rate
- Oil Mass Flow Rate
- Gas Flow Rate at Standard and Outlet Conditions
- Oil Flow Rate at Standard and Outlet Conditions
- Pressure and Temperature at the Rupture
- Pressure at the Pipeline Inlet and Outlet
- Total Mass Flow Rate at the Pipeline Outlet

Time series results that can be plotted from the Nearfield module are:

- Accumulated mass surfaced (kg)
- Vertical velocity of gas at the surface (m/s)
- Radius of gas bubble plume at the surface (m)
- Gas rise time rupture to surface(s)
- Gas mass flow rate at surface (kg/s)

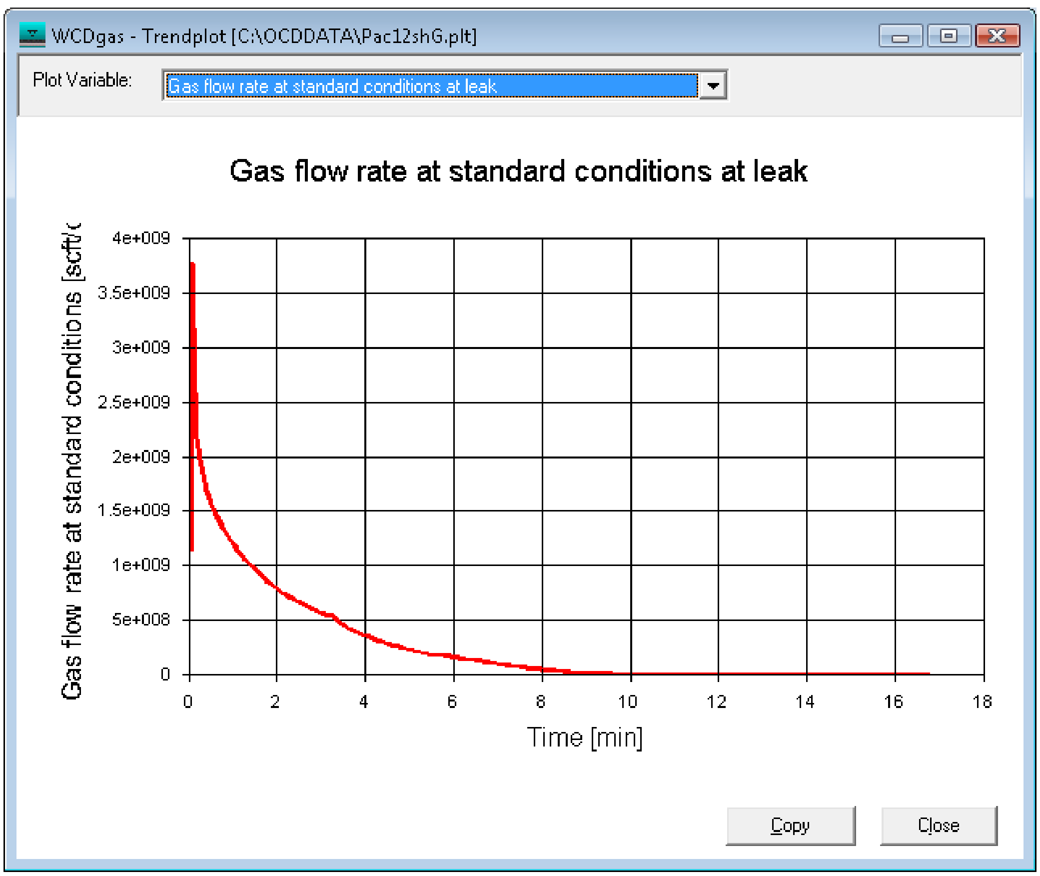


Figure 5.8 Example Plot of Gas Release at the Rupture Location

6 Atmospheric Dispersion Modeling

6.1 Background

The Offshore and Coastal Dispersion Model (OCD) developed for MMS in the late 80's and early 90's has been adapted for use in this project. This model is currently the MMS sanctioned atmospheric dispersion model (Herkhof, 2008. pers. comm.). Modifications to the model have been implemented to improve its data input and output components. Version 5 of the model (OCD/5) was downloaded from the US EPA web site for use in this project (http://www.epa.gov/scram001/dispersion_prefrec.htm). The source code was modified and recompiled as described in Appendix C and as such the version of OCD delivered with this report should be used only for the pipeline discharge application unless tested for other uses. A users manual for the OCD/5 software also was delivered with the final project deliverables.

6.2 OCD Implementation

The OCD is a complex model that requires the setup of a geographic database, extensive over-land and over-water meteorological data, pollutant emissions data, source and receptor input data. The following describes how this model has been implemented for the modeling of sub sea natural gas pipeline accidental releases in the Pacific and Gulf regions of the United States. As users become familiar with the software they may wish to explore the features of OCD/5 in more detail than that provided here. Basic help documentation is included with the software and digital versions of the users manuals and guides were provided with the final project deliverables to assist users in expanding their understanding and use of the software. The primary goal of the information provided in this report is to guide the user in the basic use of the model using a number of pre-set release scenarios.

6.3 Software Installation Instructions

The OCD/5 software is installed using the Setup.exe file present in the subfolder 1OCD5setupDirectory. Detailed instructions for installing, removing and running all of the software components delivered in this project are provided in Appendix E.

6.4 Getting Started

Once the software has been installed start OCD/5 using the on-screen icon or by running the program OCDMENU.exe from its folder in Windows Explorer. Using the main menu File -> Open option select either the GOMEX.DAO or PACIFIC.DAO files. These are pre-defined geographic study areas within the Gulf of Mexico and Pacific regions for use in the natural gas pipeline release modeling. Other regions or sub regions can be established in the future as required. A number of data input variables and program settings have been stored in these pre-defined "study areas". By clicking on the main menu "Input" option a number of sub-selections are made available. The “Sequential “ sub-option is used when the user wants to enter a complete new set of inputs. Rather than review the Sequential option we will look at each sub-menu item individually. The following “screen captures” introduce the user to the input data necessary for the pipeline release modeling for the nine available input categories.

6.4.1 OCD/5 Input Screens

6.4.1.1 Run Information (Figure 6.1)

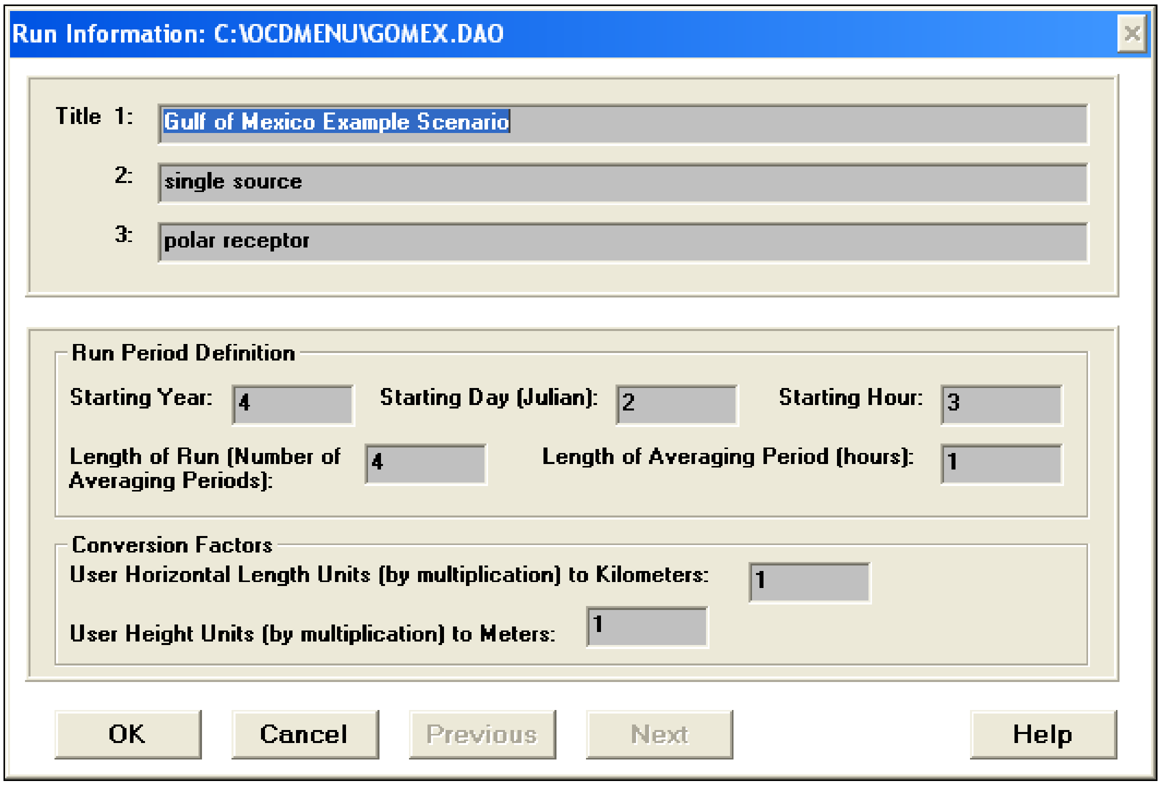


Figure 6.1 OCD/5 Run Information Input Dialog

The three title lines in Figure 6.1 are input to differentiate the model results from other simulations. Any text information can be entered here to describe the simulation.

The Run Period Definition is used to identify the starting hour, day and year of the gas discharge.

- The starting year data for must match the over-land and over-water meteorological data files entered elsewhere. This input is not Y2K compliant but the two digit specifications such as 99 for 1999 or 04 for 2004 are valid entries.
- The starting hour cannot be such that the simulation period extends into the next days data. For example, if the length of run is 4 then the Starting hour must be 20 or less.
- The length of run must match (or at least not exceed) the number of hourly emission data entries in the emissions.dat file entered elsewhere.
- The length of averaging period should be kept at 1 hour for this application.

For the sample study areas establish for this project the conversion factors should be l.

6.4.1.2 Model Domain (Figure 6.2)

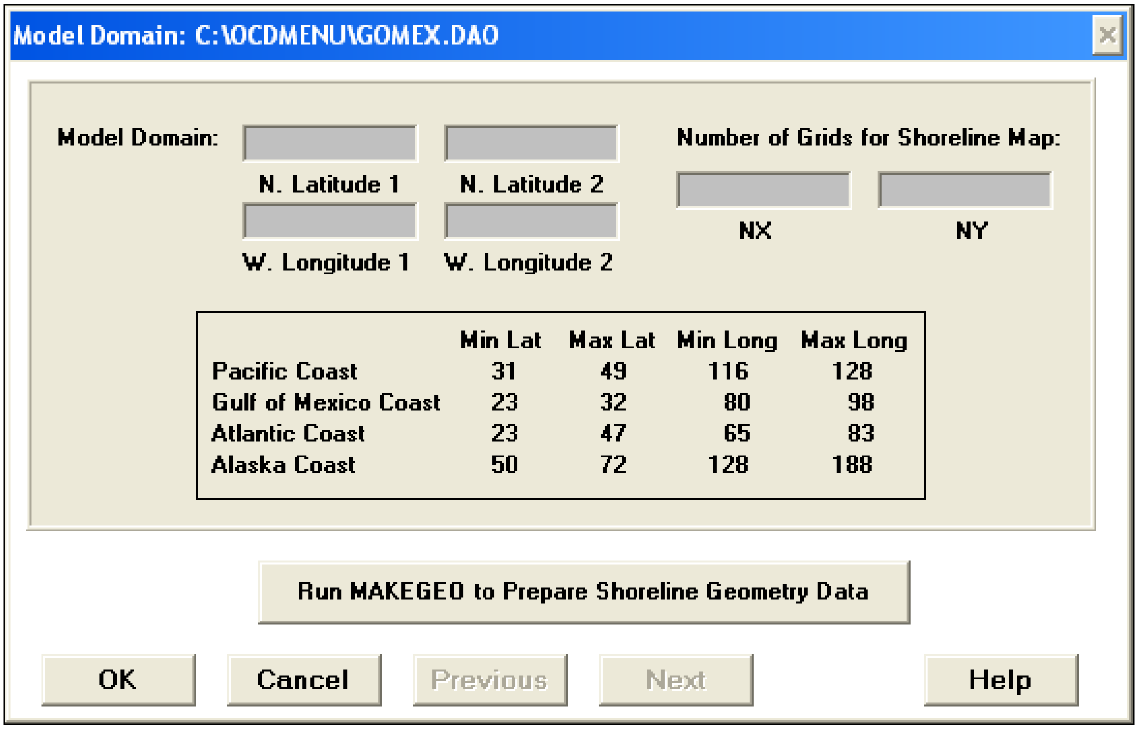


Figure 6.2 OCD/5 Model Domain Information Input Dialog

The Figure 6.2 dialog is used to enter the land and water boundaries over the extent of the study area of interest. The longitude and latitude extents of interest and the number of grid lines in the X and Y directions are entered and the MAKEGEO button is pressed to develop the internal geographic land/water boundary dataset. The dataset uses an internal X Y coordinate system that is used to display the land/water boundary and for the entry of spill source and pollutant receptor locations that will be described later. Longitudes and latitudes of these receptors and sources have to be manually converted to the internal XY coordinates prior to entry. This step has already been completed and stored in the GOMEX.DAO and PACFIC.DAO files and should not be repeated unless a new study area is being established for other uses. If the MAKEGEO option is re-run with different extents any emission source or receptor locations will no longer be valid. The latitudes and longitudes in degrees and grid numbers used in the pre-defined areas are shown in Table 6.1 along with the corresponding Domain X & Y values in kilometres.

Table 6.1 Model Domains for Sample Study Areas

Study Area	Latitude 1 (Domain Y)	Latitude 2 (Domain Y)	Longitude 1 (Domain X)	Longitude 2 (Domain X)	# X Grids	# Y Grids
GOMEX	29° (0.0)	31° (218.3)	88° (196.8)	90° (0.0)	120	120
PACIFIC	33° (0.0)	35.5° (287.7)	118° (313.5)	121.5° (0.0)	120	120

Once the domain extents have been established the X Y coordinate ranges can be viewed using the “Display Map of Shoreline” option described elsewhere.

6.4.1.3 Sources (Figures 6.3 and 6.4)

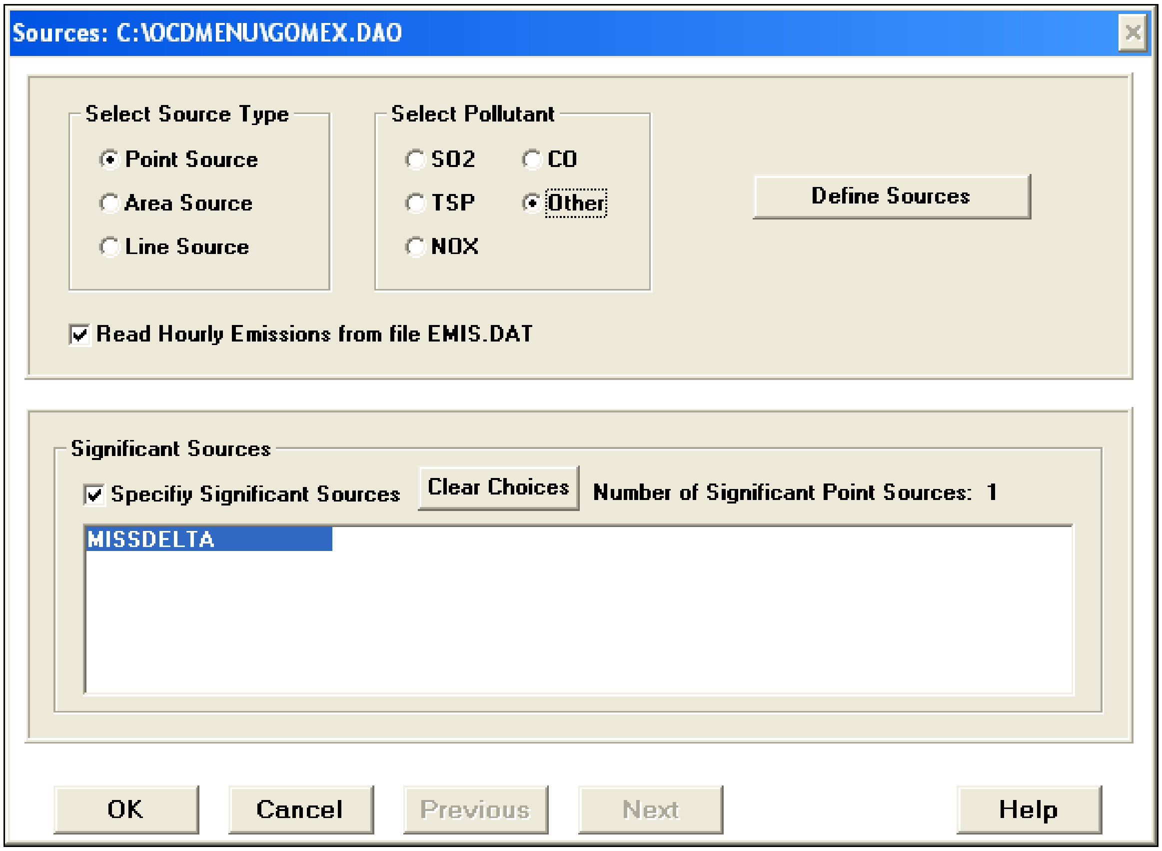


Figure 6.3 OCD/5 Gas Source Information Input Dialog

Because the Point Source type generates higher near source concentration estimates it should generally be selected for this modeling application to generate conservative concentration estimates.

The pollutant type selected should be "Other".

The "Read Hourly Emissions from EMIS.DAT" box in the dialog shown in Figure 6.3 should always be checked. The WCDgas pipeline release model is used to generate the natural gas emissions data files prior to implementing the atmospheric dispersion model in this application.

The "Specify Significant Sources Box" must be checked and the source of interest in the implementation should be highlighted. Only one point source should be selected for each simulation due to the data output graphing modifications implemented in this version of OCD/5.

Important Note: It appears that this data entry occasionally is corrupted and an error message indicating that the number of significant sources is incorrect will be issued during an OCD/5 run. If this occurs re-visit this dialog and de-select the Specify Significant Sources box and then re-select it. Then de-selecting the source from the named list so the number of sources reverts to zero, then re-select the source from the list to re-set the number of sources to 1. This should remedy the problem.

New sources are defined by clicking on the “Define Sources” button that brings up the dialog in Figure 6.4. For the gas pipeline discharge application only one source can be defined in the list in the Figure 6.4 dialog at a given time even if only one significant source is selected in the Figure 6.3 dialog. If more than one source is defined in the Figure 6.4 dialog, an error is encountered and OCD/5 does not run to a successful completion.

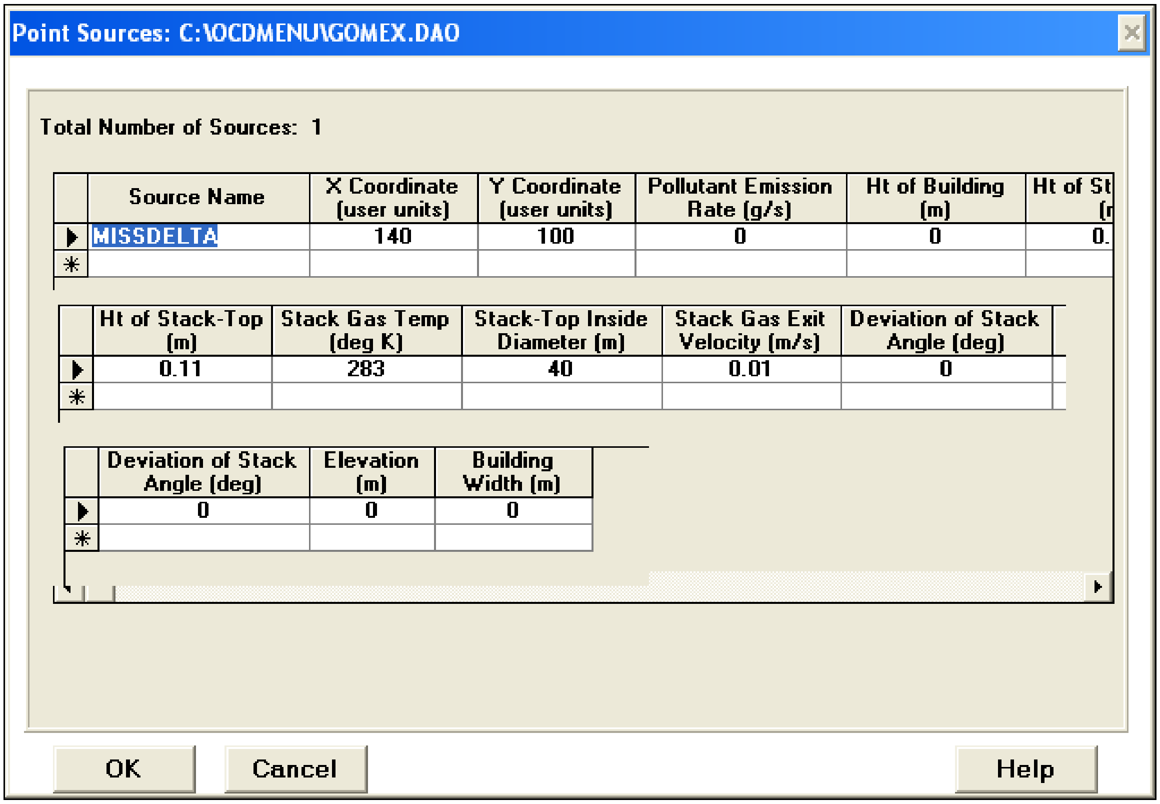


Figure 6.4 OCD/5 Gas Source Information Input Dialog

The X and Y coordinates, height of Stack-Top, Stack Gas Temperature and Stack Gas Exit Velocity need to be entered for each Source Name specified. The positional coordinates must be entered in Study Domain units. A manual conversion of Longitude and Latitude values must be made. The Longitude/Latitude and Domain X/Y equivalents in Table 6.1 can be used to convert Longitude and Latitude data for the two sample study areas provided. The stack height must be greater than 0.1 m so a value of 0.11 is entered to represent gas exiting at the water surface. The stack gas exit velocity of 0.01 m/s is entered to give the gas low momentum at the water surface that results in conservative gas concentration estimates. The Stack Gas Temperature should reflect the surface water temperature at the site of the gas source since the gas temperature should be close to water temperature at exit to the atmosphere. All other values are not used in this open-water analysis and zero values can be entered for them. There appears to be a ‘bug’ in the OCD/5 software. If more than one source is defined in the dialog of Figure 6.4 an error is encountered and the simulation will not run to completion.

6.4.1.4 Dispersion (Figure 6.5)

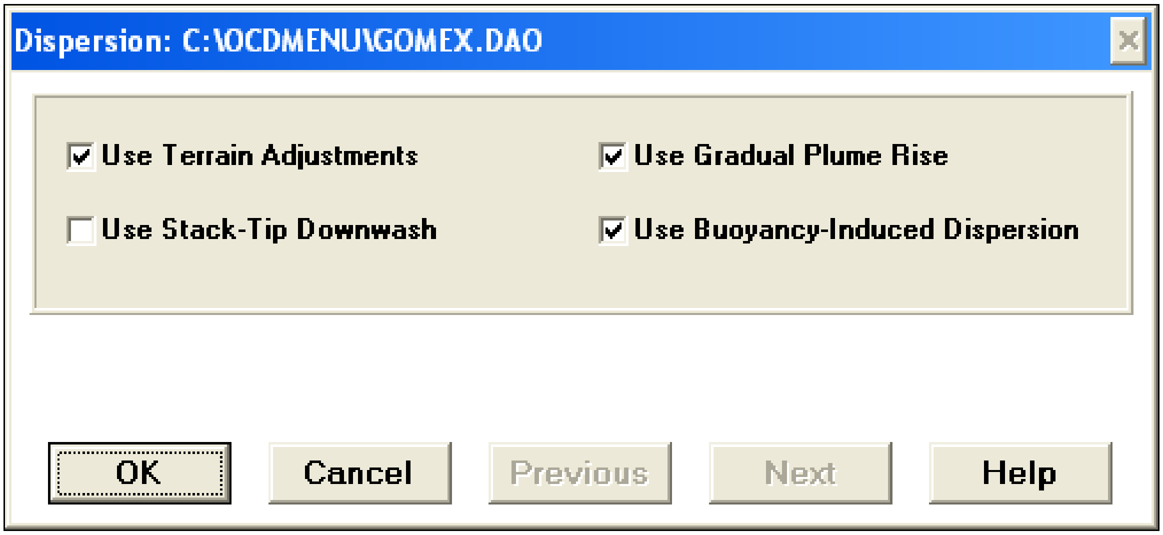


Figure 6.5 OCD/5 Dispersion Options Input Dialog

The Use Terrain Adjustments, Use Gradual Plume Rise and Use Buoyancy-Induced Dispersion options in the dialog of Figure 6.5 can be checked for this modeling. For the sample scenarios simulated in this project the natural gas disperses to below significant concentrations within at most a few kilometres from the source so in all cases the pollutant does not reach the water land boundary. As such, the Use Terrain Adjustment Option is really not necessary in the cases modeled.

6.4.1.5 Receptors (Figures 6.6 & 6.7)

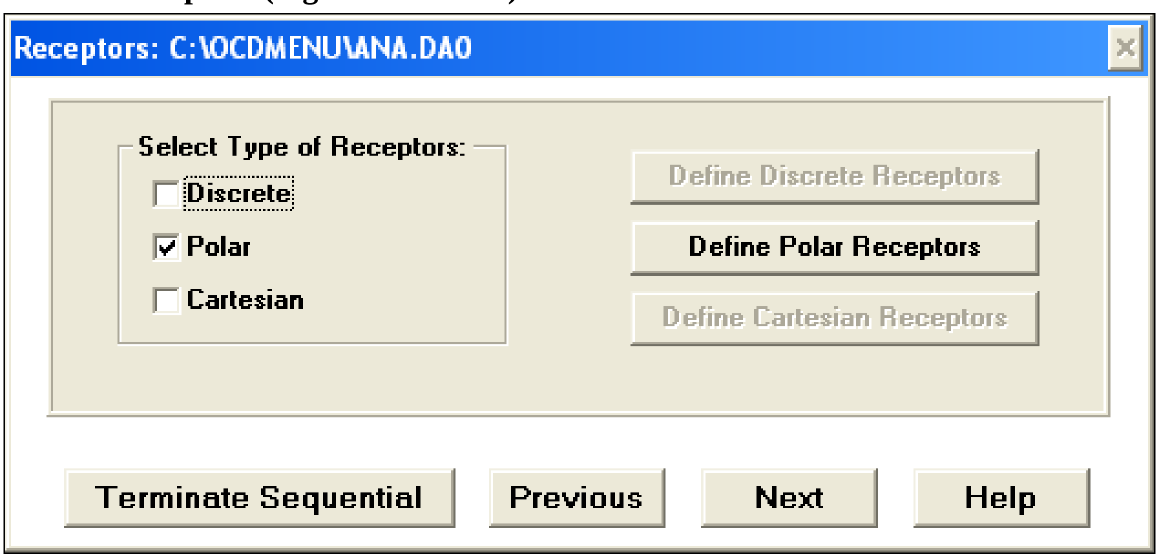


Figure 6.6 OCD/5 Receptor Options Input Dialog

The selection of Polar receptors in the dialog shown in Figure 6.6 is recommended for this application. The plotting function implemented at the end of each simulation may not function properly if other receptor schemes are implemented. The locations of the receptors are entered by manually entering the data and using the "Define Polar Receptors" button that brings up the dialog shown in Figure 6.7.

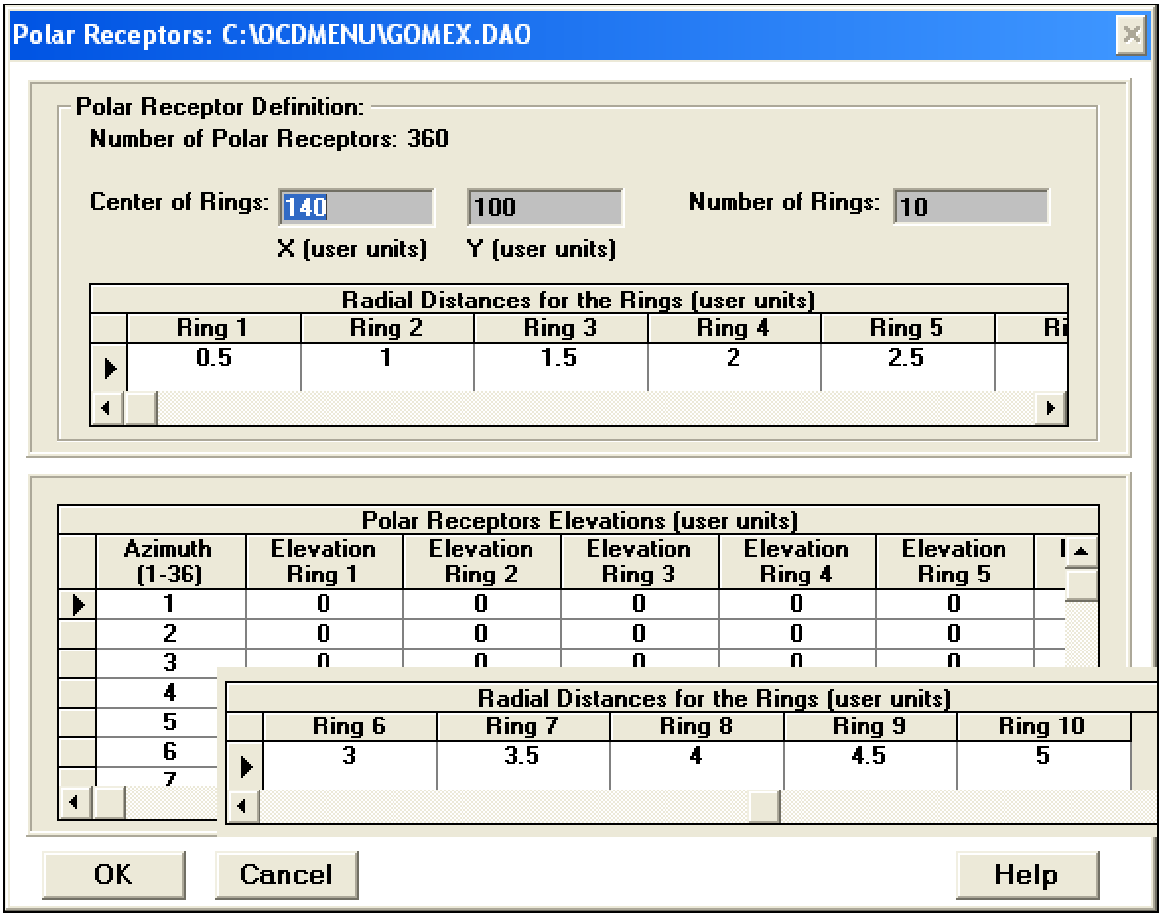


Figure 6.7 OCD/5 Receptor Options Input Dialog

The Center of Rings should be the same as the XY location of the emissions source that was set in the Sources dialog of Figure 6.4. Because the natural gas diffuses to below significant concentration quite rapidly receptor rings should be established in close proximity around the source. In the sample shown in Figure 6.7 ten rings have been entered at 0.5 km radial increments from the source out to 5 km from the source. If these receptors were to reach land then elevations should be entered for each of the receptors so land influence can be taken into account in the dispersion modeling. For the offshore cases being considered in this report land elevations were not required since the receptors are all over water and the gas concentration dropped to below significant levels well within the bounds of the receptors.

6.4.1.6 Meteorology (Figures 6.8 to 6.10)

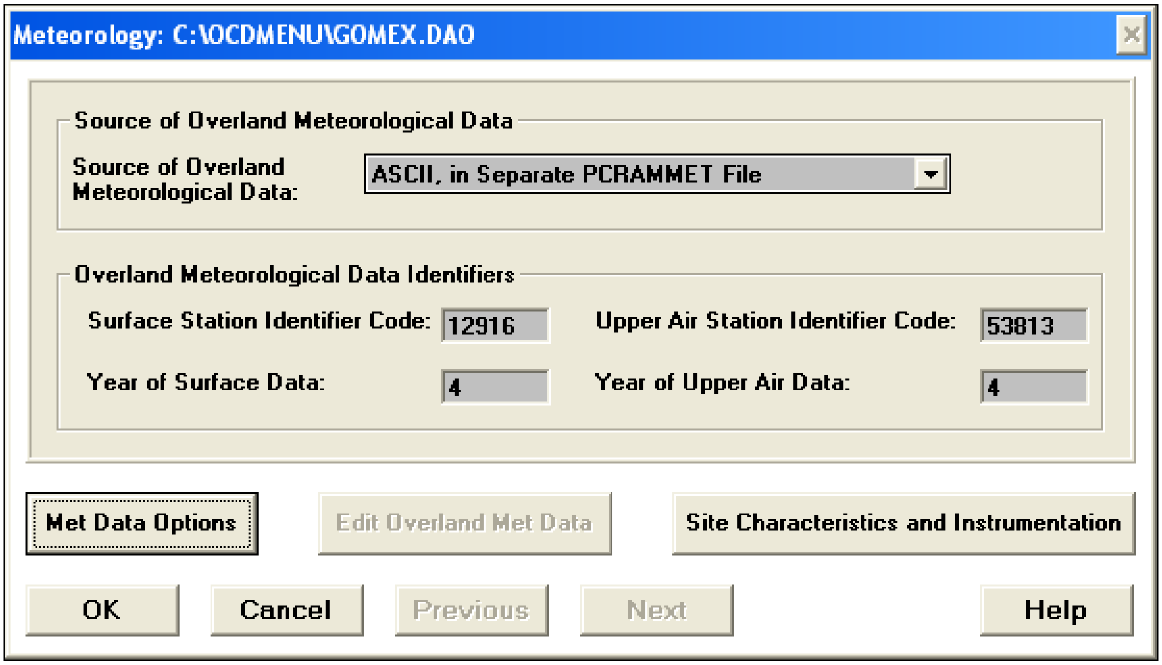


Figure 6.8 OCD/5 Meteorological Input Dialog #1

The "Source of Overland Meteorological (Met) Data" in the dialog of Figure 6.8 should be specified as "ASCII, in Separate PCRAMMET File". EPA and others commonly use this file format for Met data. A recent study (Douglas, 2008) completed for the MMS Gulf of Mexico Region (MMS GOM) developed OCD/5 compatible over-land (LMET) an over-water (WMET) meteorological data files for five full years (2000 to 2004) and these data sets are directly compatible with the version of OCD/5 delivered in this contract. A minor modification was made to the OCD/5 program to allow the model to accept the full Y2k compliant year data present in the headers of the LMET data sets developed under the MMS GOM contract. If a non-modified version of OCD/5 is used with these data files the year designation in the file headers have to be manually edited to 2 digit, non Y2k compliant dates before the model will run successfully.

The Surface and Upper Air Station Identifier codes entered in this dialog (Figure 6.8) must match those present in the PCRAMMET (LMET) data file header or the program will not run to completion. The years entered for the Surface and Upper Air Data must also match those present in the LMET header. These years must be entered in 2 digit codes in the dialog entry, not in Y2k compliant form. The data entered in the example of Figure 6.8 is for the year 2004.

For MMS regions where pre-developed LMET and WMET data are not available the user will have to develop the files using available MET data from several sources and tools designed to generate the files in the appropriate format. Detailed discussions of the available data sets and the methods used to generate the LMET and WMET data files are provided in Appendix D.

The Met Data Options and Site Characteristics and Instrumentation Buttons in Figure 6.8 are discussed with reference to Figures 6.9 and 6.10, respectively.

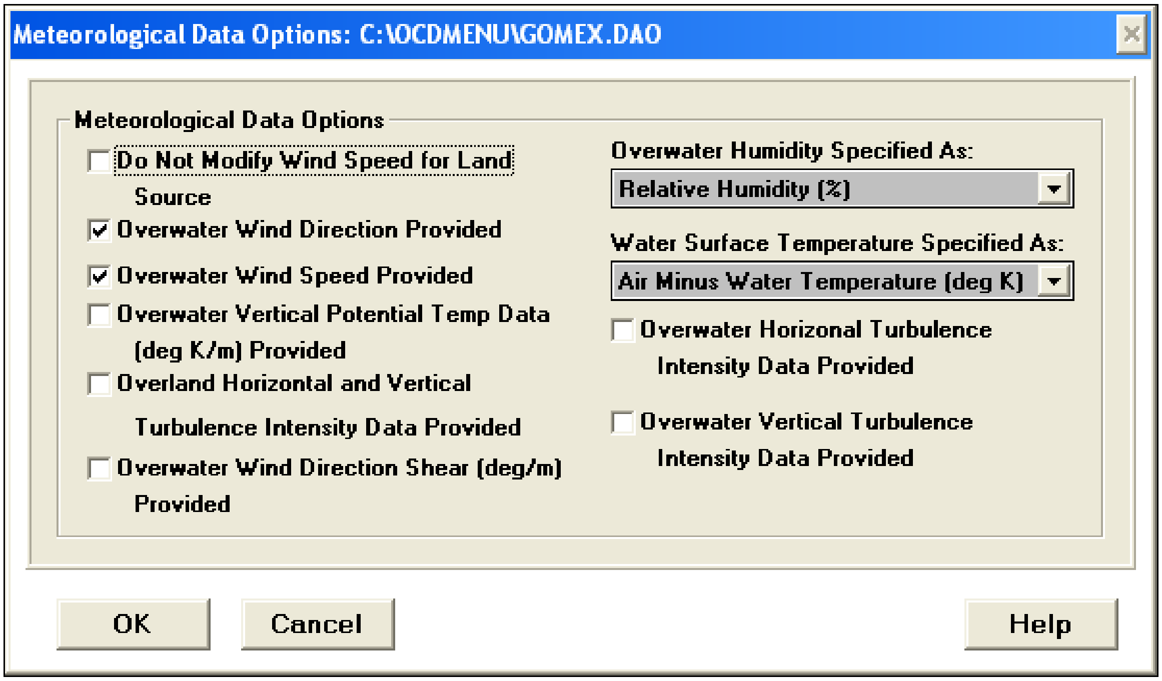


Figure 6.9 OCD/5 Meteorological Input Dialog #2

The options shown in Figure 6.9 must be selected when using the LMET and WMET data files available from the recent MMS GOM region study detailed above. When developing datasets using the methods described in Appendix B the “Over-water Humidity” option should generally be specified as Dew Point Temperature and the “Water Surface Temperature” option should be specified as Water Surface Temperature. These are the settings used in the example scenarios developed for the PACIFIC.DAO dataset delivered with this report.

The Site Characteristics and Instrumentation dialog of Figure 6.10 must be populated with sensor height information from the weather station or buoys from which the LMET and WMET data were obtained. The surface roughness value of 0.0001 should be used for all modeling over water surfaces. EPA recommends a “Minimum Miss Distance” of 10 m. The approximate latitude of the pollutant source is entered in the “Latitude of Source Region”.

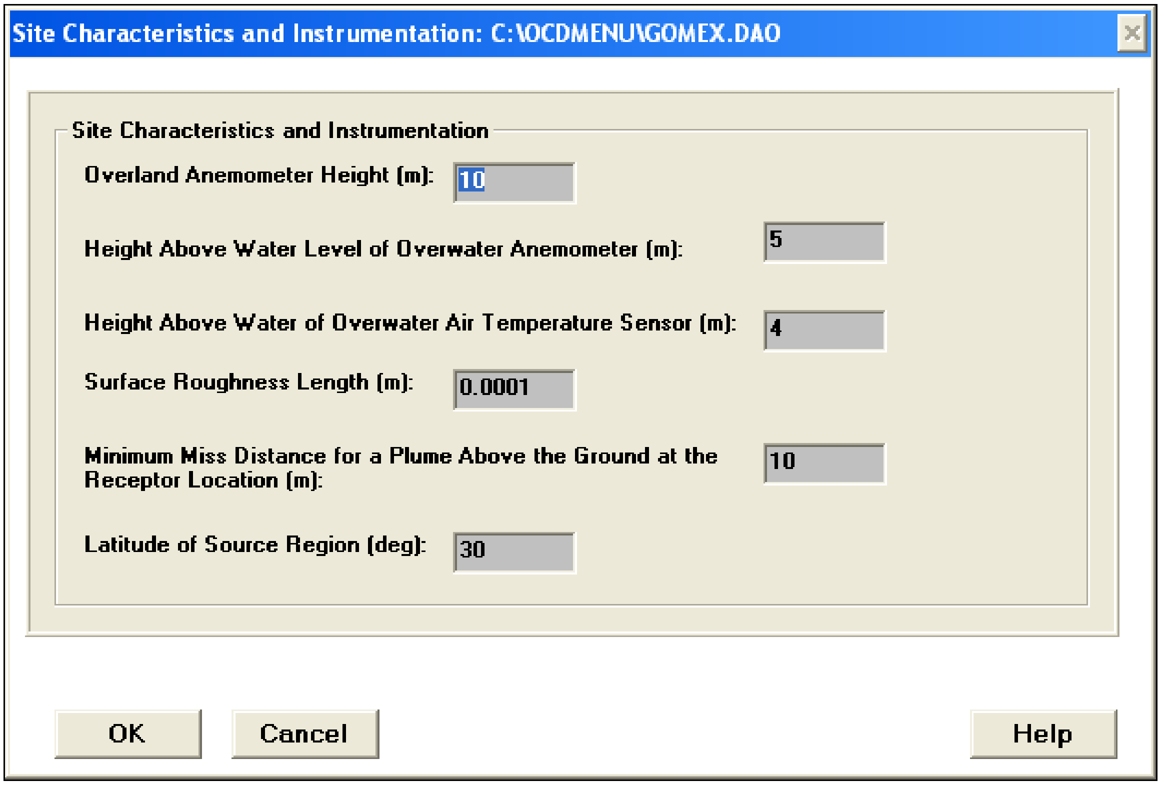


Figure 6.10 OCD/5 Meteorological Input Dialog #3

6.4.1.7 Chemical Transformations (Figure 6.11)

Natural gas will not decay via chemical transformation so the dialog shown in Figure 6.11 is left inactive.

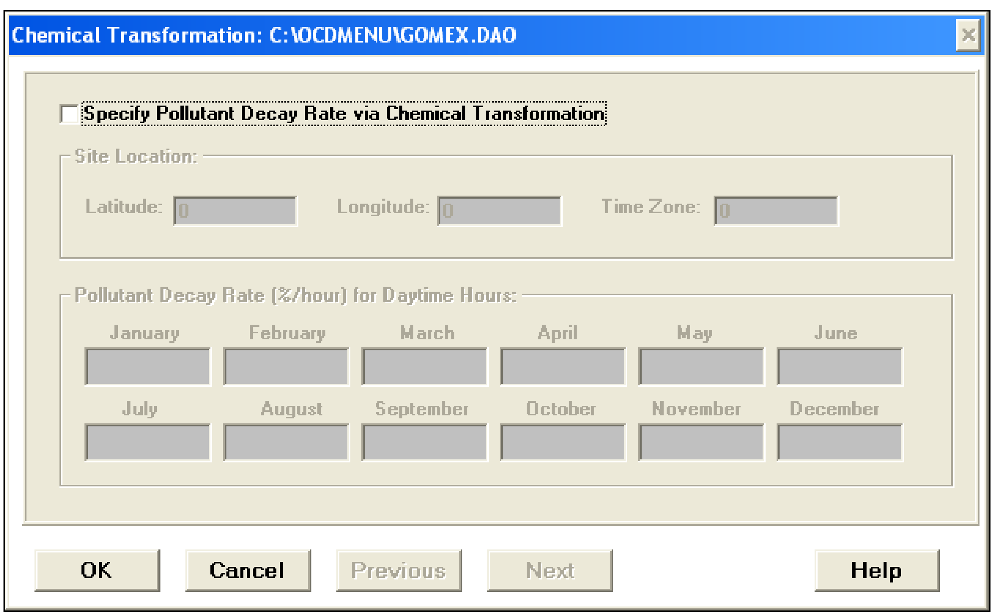


Figure 6.11 OCD/5 Chemical Transformation Input Dialog

6.4.1.8 Output Options (Figure 6.12)

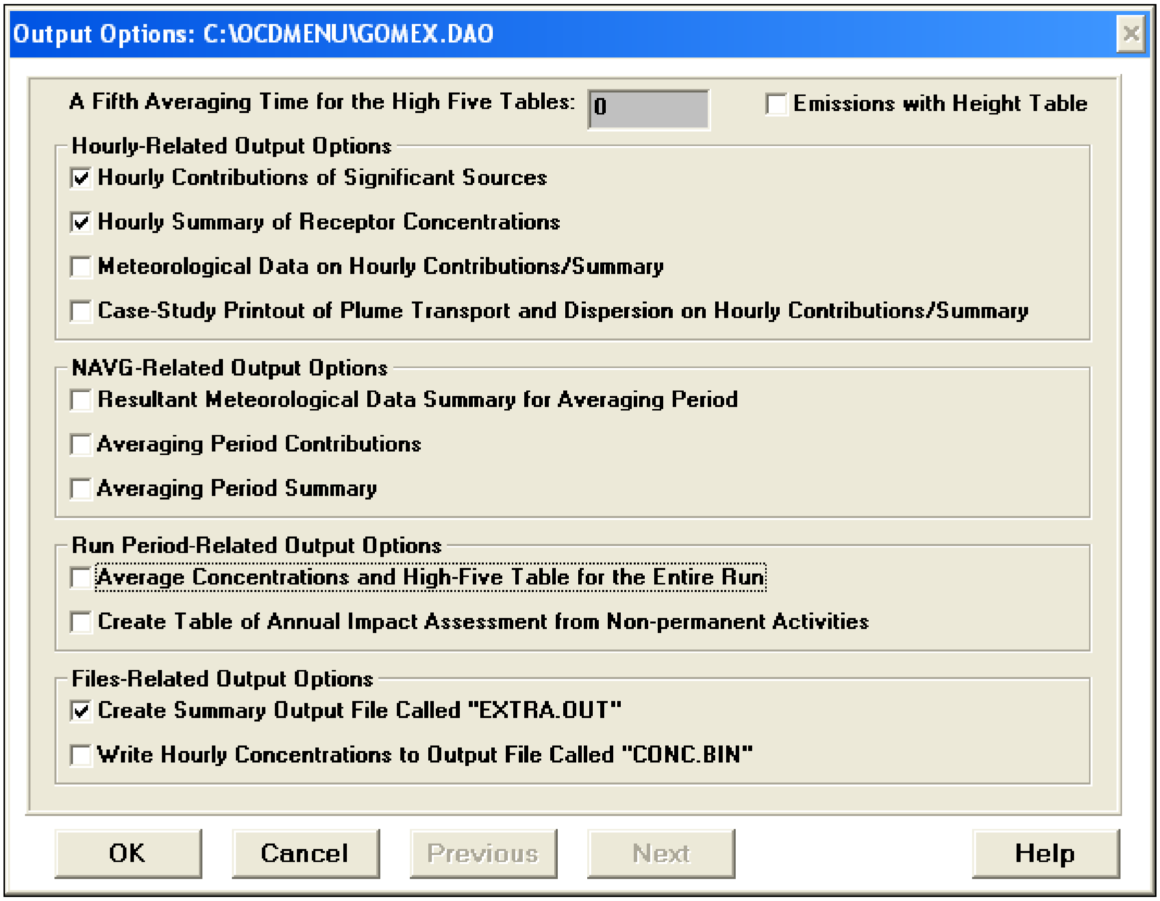


Figure 6.12 OCD/5 Output Options Dialog

The three items checked in Figure 6.12 should be selected for output. The hourly input emissions source data and final receptor concentration data will be recorded in the main Output Listing File for the scenario when the first two items are checked. It is essential to check the "Create Summary Output File Called "EXTRA.OUT" for a plot of the final dispersion prediction. The other data output options may be useful in some instances to better understand how the final results were arrived at. An automatic plotting of the dispersion predictions has been implemented in the version of OCD/5 delivered for this project to provide a more immediate and visual presentation of the results. As mentioned above, the plotting procedure uses the "EXTRA.OUT" summary data file as its source of information. A popular free-ware plotting package called GNUPLOT has been interfaced with OCD/5 to enable this plotting feature.

6.4.2 OCD/5 Run Gas Dispersion Simulation

There is only one sub-option in the Run dialog of OCD/5. The input requirements for this dialog are discussed using Figure 6.13 as a guide.

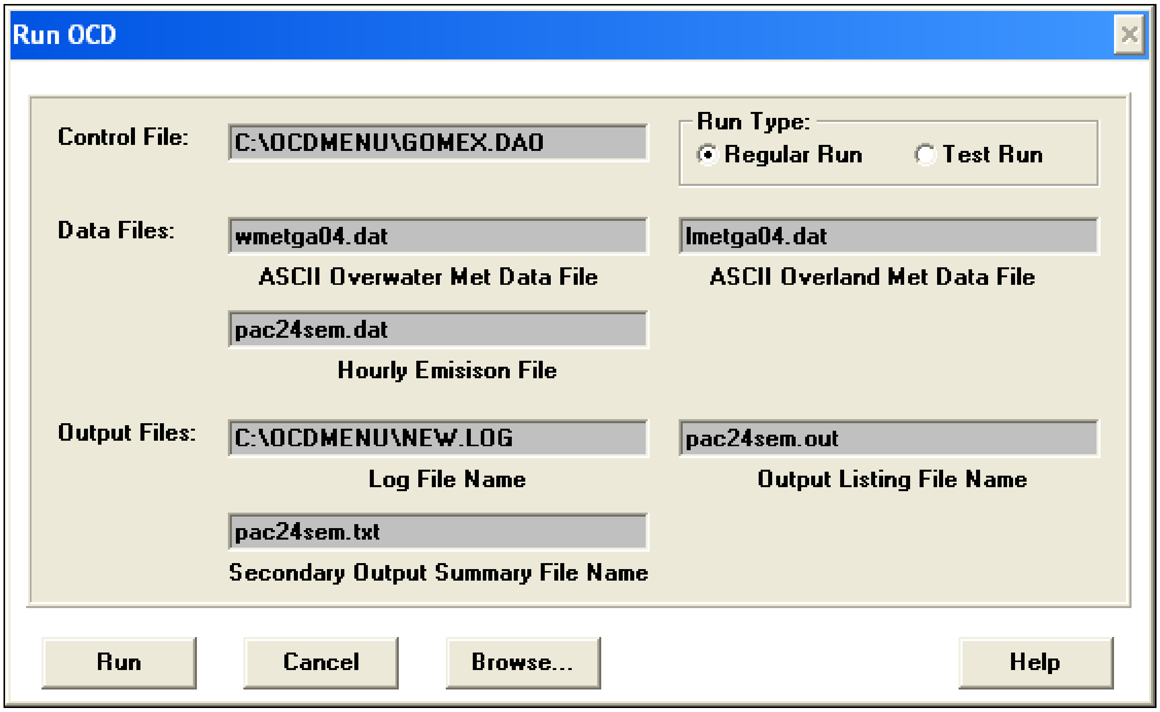


Figure 6.13 OCD/5 Scenario Run Dialog

The Control File is automatically established when the study area is opened immediately after starting the OCDMENU software.

All simulations should be run using the Regular Run setting.

The ASCII Over-water and Over-land data files must hold data that matches the information entered in the dialog shown in Figure 6.8 and have data for the dates specified in the Figure 6.1 dialog. The descriptive information entered in the dialogs of Figures 6.9 and 6.10 should also pertain to the data in these two files.

The pipeline gas release model ‘WCDgas’ generates the “Hourly Emission File”. This file will have one line of data for each hour or sub-hour of natural gas emissions. The number of lines in the file must match or exceed the “Length of Run” information entered in the dialog of Figure 6.1 or an “end of file” error will terminate the simulation.

The Log file provides a record of the simulations that have been completed. This file is appended to each time a run is completed. The filename does not have to be changed unless a clean record of simulations is wanted.

The Output Listing and Secondary Output File Names should match the Hourly Emissions name so a triplet of files is maintained for each simulation. The file extensions of dat, out and txt are not mandatory but a consistent naming convention will help organize the simulation results.

Once the fields are populated the RUN button initiates the air dispersion modeling. At the end of the simulation a plot of the results is automatically generated through a GNUPLOT script file. The plot includes the Lower Explosive Limit (LEL) concentration for natural gas and a 3-D representation of the predicted gas concentration based on the data provided in the Secondary Output file. The plot view can be manipulated by right clicking on the plot and dragging the view orientation to the view of interest. The GNUPLOT "Pause" dialog can be dragged to the side for an unobstructed view of the plot. The plot view is terminated by clicking the Pause button. This returns the user to OCDMENU. Archived simulations can be plotted independently from OCD/5 using the 'Replot' batch file. Sample views of a single simulation are shown in Figures 6.14 through 6.16.

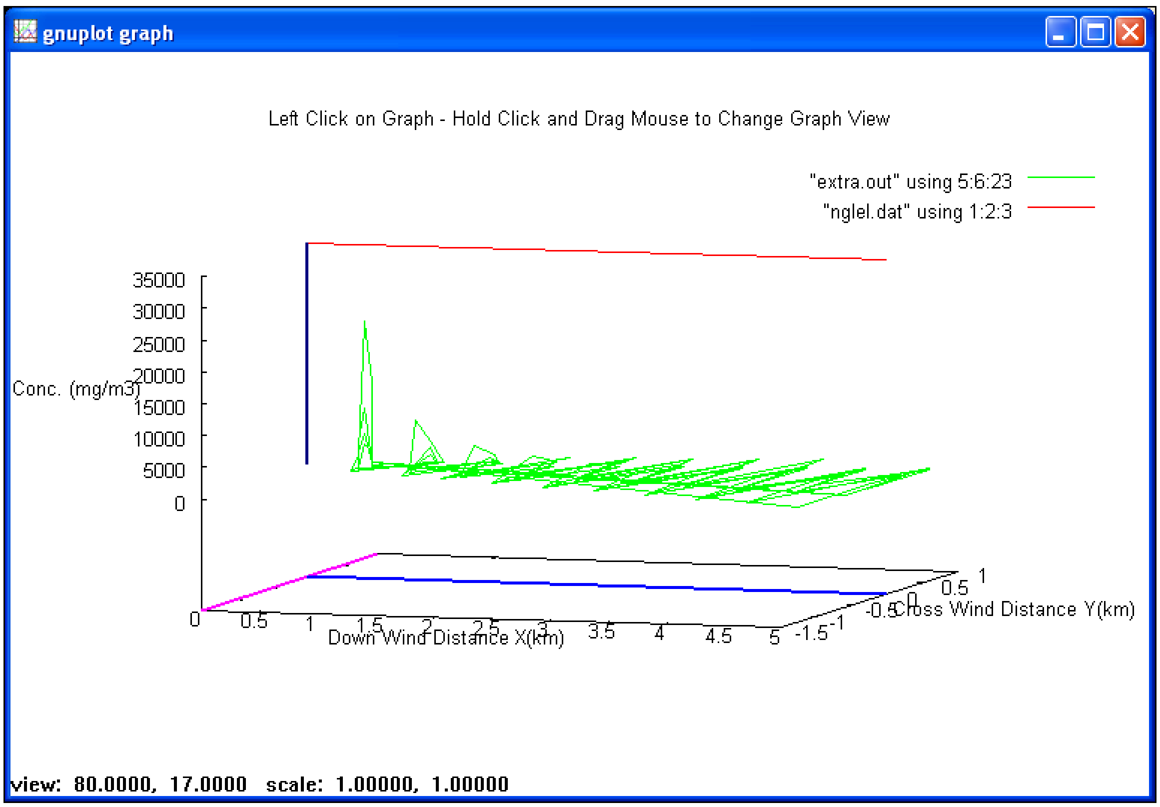


Figure 6.14 Example GNUPLOT Output of OCD/5 Modeling Results

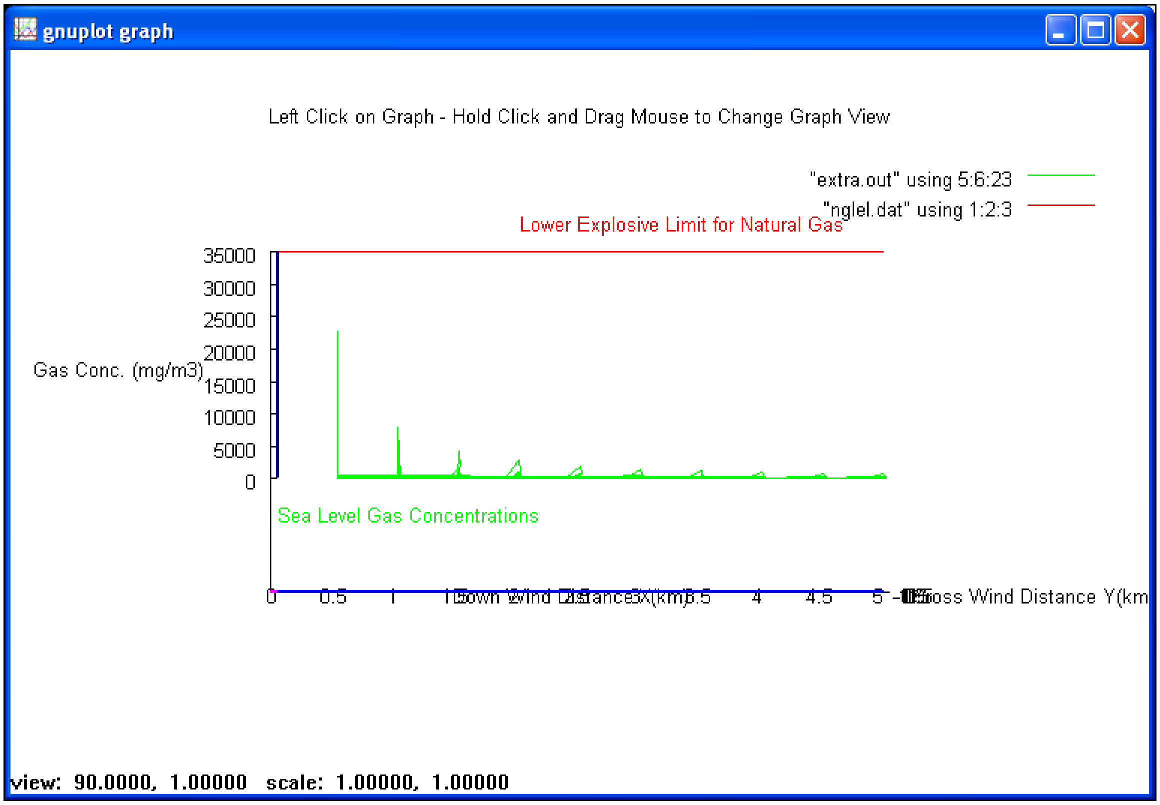


Figure 6.15 Example GNUPLOT Output of OCD/5 Modeling Results

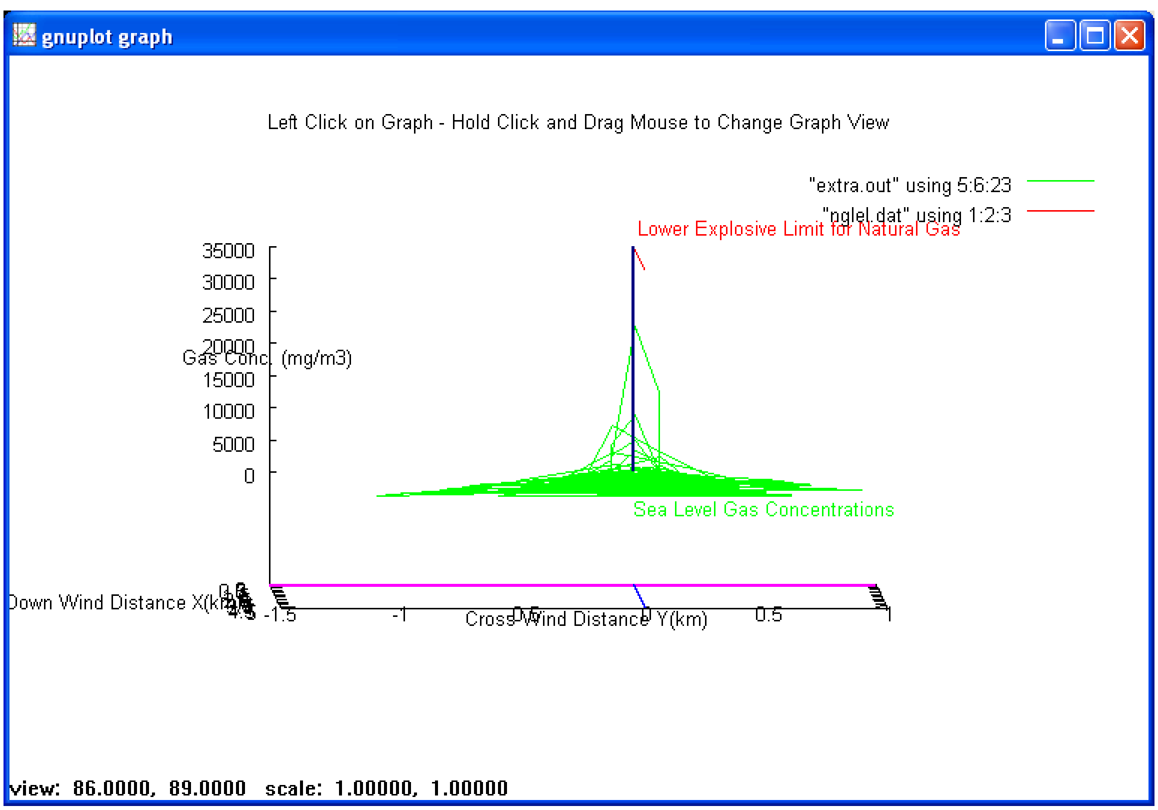


Figure 6.16 Example GNUPLOT Output of OCD/5 Modeling Results

7 Modeling Results: Example Gas Pipeline Rupture Scenarios

7.1 Modeling Procedure

The general procedure for modeling a gas pipeline release from the sea floor to final atmospheric dispersion using the provided software is as follows:

1. Build the pipeline network and enter the appropriate pipeline operating parameters and leak characteristics within WCDgas or select a previously defined network.
2. Use the "Calculate All" option in WCDgas to simulate the sub sea and near field gas behavior. Make sure the option to generate the emissions.dat file is selected prior to running the WCDgas simulation.
3. Open the OCDmenu software and select the study area of interest (PACIFIC.DAO or GOMEX.DAO).
4. Enter a "Length of Simulation" in the Run Information dialog that matches the number of hours of gas release shown in the emissions.dat file created by the WCDgas simulation of step 2. Or specify a 1 hour length to generate the worst case plot for a guillotine type rupture. Also specify the date and time of day for the dispersion modeling in this dialog.
5. Specify the Wmet, Lmet and hourly emissions input files and the various output files appropriate for the release location and timing in the "Run OCD" dialog (see section 6.4.2).
6. Run the OCD/5 simulation and the 3-dimensional plot of the surface gas concentration will automatically be generated along with numerous supporting data files.
7. Note: the WCDgas and OCD/5 programs are standalone applications and can be run independent of each other in any order so long as the appropriate data files are present for their proper operation. The emissions.dat file generated by WCDgas is used by OCD/5 as its gas source term and is the link between the two applications. Once the emissions file is generated by WCDgas the OCD/5 model can be run multiple times without re-running WCDgas to investigate different atmospheric conditions etc.

7.2 Description of Example Scenario Input Files

The example gas pipeline information provided in section 3 has been used to develop 8 example gas pipeline rupture scenarios for the Pacific Region. Six of the scenarios are guillotine pipeline breaks and two are one inch diameter punctures or failures. The WCDgas input file names assigned to these scenarios are provided in Table 7.1. The Wmet, Lmet Hourly Emissions, and Secondary Output Data filenames used in the example simulations or generated by OCD/5 are also included in Table 7.1. When operating in the Pacific Region choose the PACIFIC.DAO study area file when the OCD Main Menu first appears (Using the File->Open option or by selecting a recently opened file from the list at the bottom of the "File" submenu options). The overland meteorological data used in the example scenarios (Lmet91) were derived from 1991 data sets using the procedures outlined in Appendix D. The 1991 overland data was the most recent available for the Pacific Region. It is appropriate to note that OCD/5 predicts the dissipation of the gas cloud to below hazardous conditions while still over water in all simulations completed in this study. The overland Met data is therefore not critical in the air-side dispersion assessments completed for this project. Met data for other years can be developed using the procedures provided in Appendix D and substituted for the files used in the provided examples. The Wmet data file named B4602391.dat was delivered with the project to work in conjunction with the 1991 Lmet data file. The first six characters in this file name describes the buoy number from which the data was extracted and the last two characters the year that the data was recorded. The OCD/5 model uses an over-water humidity term that is specified in the meteorology dialog of Figure 6.9. The actual humidity, wet bulb temperature or dew point temperature must be available. Most of the buoys in the Pacific region do not record these data. Buoy 46023 does gather dew point temperature so it was selected to provide example data for this project. The data sets developed for the Gulf of Mexico provide a direct measure of Relative Humidity.

When operating in the Gulf of Mexico (GOM) region open the GOMEX.DAO study area file. The Lmetga04 and Wmetga04 meteorological data files shipped with the project deliverables were used in the OCD/5 simulations in the Gulf of Mexico. These data sets were acquired from the MMS Gulf of Mexico Regional office as described in Appendix D. Any of the gas emissions files developed for the Pacific Region can be used in the GOM Region in lieu of GOM specific pipeline release data.

Table 7.1 Example Gas Pipeline Rupture Simulation Input and Output Data Files

		OCD/5 Input Files			
Scenario Description (pipeline diameter, puncture depth and hole size)	WCDgas Input Filename (.wcd)	Hourly Emissions Filename (.dat)	Wmet Filename (.dat)	Lmet Filename (.dat)	Secondary Output Filename (.txt)
12 inch, shallow, guillotine	Pac12shG	Pac12shG	B4602391	Lmet91	Pac12shG
12 inch, deep, guillotine	Pac12dpG	Pac12dpG	B4602391	Lmet91	Pac12dpG
12 inch, shallow, 1” puncture	Pac12sh1	Pac12sh1	B4602391	Lmet91	Pac12sh1
12 inch, deep, 1” puncture	Pac12dp1	Pac12dp1	B4602391	Lmet91	Pac12dp1
24 inch, shallow, guillotine	Pac24shG	Pac24shG	B4602391	Lmet91	Pac24shG
24 inch, deep, guillotine	Pac24dpG	Pac24dpG	B4602391	Lmet91	Pac24dpG
36 inch, shallow, guillotine	Pac36shG	Pac36shG	B4602391	Lmet91	Pac36shG
36 inch, deep, guillotine	Pac36dpG	Pac36dpG	B4602391	Lmet91	Pac36dpG
36 inch, shallow, guillotine	Gom36shG	Gom36shG	Wmetga04	Lmetga04	Gom36shG
36 inch, deep, guillotine	Gom36dpG	Gom36dpG	Wmetga04	Lmetga04	Gom36dpG

7.3 WCDgas Simulation Results

The detailed results for the in-water gas behavior predictions for each of the simulations can be viewed by opening each scenario individually in WCDgas. Table 7.2 provides a summary of the key “in-water” simulation results for the example scenarios.

The total release times shown reflect the time taken for all of the gas to exit the pipeline at the puncture location. The gas flow slows significantly during the latter stages of the release so for the purposes of surface air modeling it is instructive to know the time period over which the bulk of the gas exits the water surface. Column three shows the time required for 90% of the gas to exit at the water surface. The OCD air dispersion model accepts 1-hour minimum gas source durations, since it was not originally designed for use in short duration pollutant releases. A worst-case gas source term is calculated from the WCDgas results for each scenario for use as input to OCD/5. If the time for 90% of the gas to exit the water surface is less than 1 hour the total gas mass discharged over the entire release is divided by the time taken for 90% of the gas to exit at the surface to determine this rate. If the gas exit at the surface takes longer than 1 hour the quantity exiting the surface over each full hour is divided by an hour to determine the hourly gas source rates. The maximum hourly rates calculated for each scenario using this logic is provided in column 4 of Table 7.2. The *.dat files generated by WCDgas contain the detailed surface gas source information that is subsequently used by OCD/5. The air dispersion model results will be conservative for those scenarios where most of the gas exits the surface in considerably less than an hour since in these cases longitudinal dispersion of the gas will be occurring and this process is not considered by OCD/5. The bubble plume radius, gas rise time and bubble rise velocity data provided in Table 7.2 reflect the results from the beginning of the release (larger radius, short rise times and high velocities) to the point where about 90% of the gas has been discharged and the flow is significantly reduced (smaller radius, larger rise times and slower velocities).

Table 7.2 WCDgas Results Summaries

Scenario	Total Release Time at Leak (min)	Time for 90% of Gas to Exit at Surface (min)	Maximum Hourly Gas Flow Rate At Surface (g/s)	Bubble Plume Radius at Surface (m)	Bubble Rise Time Range (s)	Bubble Rise Velocity Range (m/s)
Pac12shG	12	5.2	264,677	20 to 40	10 to 40	2 to 12
Pac12dpG	22	13.0	93,874	30 to 80	50 to 300	1 to 8
Pac12sh1	348	212	9,533	17 to 22	30 to 60	1.7 to 3.3
Pac12dp1	228	160	9,264	40 to 45	180 to 220	1.25 to 2.1
Pac24shG	254	114	521,039	20	2 to 10	5 to 20
Pac24dpG	98	64	339,409	150 to 250	300 to 800	1.5 to 8
Pac36shG	38	18	1,592,500	20 to 45	2 to 6	10 to 40
Pac36dpG	72	64	277,017	150 to 250	300 to 800	1 to 6

7.4 OCD/5 Simulation Results

The OCD/5 input files shown in Table 7.2 were used in the OCD/5 Run dialog to generate the air dispersion estimates for the example gas release scenarios. The runs were completed for three different time periods to show the effects of differing winds on the air dispersion results. The simulations were completed in calm winds of approximately 1 m/s (Julian day 6, starting at hour 7), 5 m/s (Julian Day 31, starting at hour 22) and 10 m/s (Julian Day 50, starting at hour 11). All scenarios were run using the B4602391 Wmet dataset. All runs were completed using a point source designation for the gas to provide conservative estimates of downwind gas concentrations. The distances downwind from the source where gas concentration dropped below the lower explosive limit (LEL) of 35 g/m^3 are reported in Table 7.3 for the three wind speed conditions. These data were interpolated from the graphs generated at the end of the OCD/5 runs. The graphs can be re-generated by opening a command window in the OCD/5 directory and using the "replot filename.txt" command, where the filename is the name of the secondary output filename from the OCD/5 simulation (see last column of Table 7.1)

Only one of the scenarios resulted in explosive gas concentrations beyond 1 kilometer from the discharge location. For most of the scenarios explosive gas concentrations only will exist inside 500 meters of the release location. It is important to re-state that two modeling input conditions used in this modeling will result in conservative gas concentration estimates. The OCD/5 model does not account for downwind dispersion as it is usually used for longer-term gas releases. As a result the downwind concentrations for the short events will be over-estimated. The specification of a point source of gas in these situations, where the gas will rise from the water surface over areas with radii of between 20 and 250 m (see Table 7.2), results in an over-estimation of the gas concentrations. The Pac36shG scenario has been re-run using a gas release diameter of 60 meters and the distance to LEL concentration dropped to 800 m from the 1100 m distance determined when a point source was used. If a 90 m diameter gas source (the predicted surface bubble plume diameter during the peak gas flow period) is used in this scenario the predicted gas concentrations drop below the LEL in less than 250 m from the source.

Table 7.3 OCD/5 Example Scenario Results Summary

Scenario	Approximate Distance Downwind where Gas Concentration Drops Below the Lower Explosive Limit for Natural Gas (m)		
	1 m/s Wind Speed	5 m/s Wind Speed	10 m/s Wind Speed
Pac12shG	300	300	300
Pac12dpG	< 250	< 250	< 250
Pac12sh1	< 250	< 250	< 250
Pac12dp1	< 250	< 250	< 250
Pac24shG	425	475	450
Pac24dpG	350	400	375
Pac36shG	900	1100	750
Pac36dpG	300	375	350

8 Model Sensitivity Testing

The purpose of the sensitivity analysis is to identify the input parameters that are essential to the successful modeling of a sub sea gas pipeline release from a guillotine break and those that are not as critical to a reasonable prediction of the fate of gas in such an event.

8.1 Pipeline Gas Release Modeling: WCDgas

There are several data input requirements necessary when defining the gas pipeline release scenario in WCDgas. Table 8.1 lists the inputs and ranks their general significance with respect to the final accuracy or relevance of the final modeling results. The items deemed essential are the primary parameters that describe the basic pipeline and the puncture: its length, diameter, operating flow rate and pressures, the time to stop the pipe flow in the event of an accident and the diameter of the puncture. If reasonably confident values for these parameters are not known then the model outcome will not reflect the situation at hand. The best available information for these parameters must be used in the modeling session. The input variables tagged with the question marks in the "Significant" category have been investigated in a sensitivity analysis to determine how important their contribution is to the final gas release process and thus give the model user some guidance as to how precise these input data need to be for reasonable modeling outcomes.

The representative pipeline release scenarios developed with MMS have been used as the basis for this sensitivity analysis. The basic pipeline and rupture conditions identified in these scenarios (see section 3) have been used as the starting point for the assessment and the remaining input variables have been varied one at a time over a range of reasonable values to determine their significance on the modeling results. The maximum hourly emission rate of gas at the sea surface has been used to characterize the model output variability with these input changes. One of the primary goals of the modeling is to identify maximum possible hazard zones at the sea surface from the pipeline discharges so reasonable worst-case results (maximum hourly surface emission rates as defined in section 7.3 are of primary interest. Guillotine breaks have been used in all modeling as this generates the maximum possible flows from the pipeline. Preliminary modeling has indicated that punctures in the center of the pipeline segment (distance of puncture from upstream end) result in the maximum emission rates at the surface because the gas is exiting from both ends of the pipeline over the full duration of the discharge. Center pipeline releases have thus been used during the sensitivity modeling for other variables.

Table 8.1 WCDgas Data Input Requirements

Input Variables	Known Importance of Variable Prior to Sensitivity Testing		
	Essential	Significant	Minor/No Influence
Pipeline Segment			
Label			X
Length	X		
Diameter	X		
Roughness		?	
Heat Transfer Coeff.		?	
Ambient Temperature		?	
Inlet			
Label			X
Depth		?	
Gas Flow Rate	X		
Temperature		?	
Closing Time	X		
Outlet			
Label			X
Depth		?	
(operating) Pressure	X		
Closing Time		?	
Puncture / Leakage			
Distance from upstream end		?	
Diameter	X		
Water Depth		?	

8.1.1 Pipeline Roughness

Pipeline roughness values are typically $10x10^{-5}$ ft (30 microns) or smaller (Morten Emilsen pers comm. 2009). Base pipeline release scenarios for the 36 inch and 12 inch pipelines have been modeled using $1x10^{-5}$ ft, $10x10^{-5}$ ft and $100x10^{-5}$ ft roughness values. The results of this sensitivity assessment are plotted in Figure 8.1. The maximum hourly emission rate estimates at the surface changed by less than 3% from the typical roughness value. Based on this assessment it is recommended that a pipeline roughness value of $10x10^{-5}$ ft (30 microns) be used in simulations when a specific roughness for the pipeline is not available.

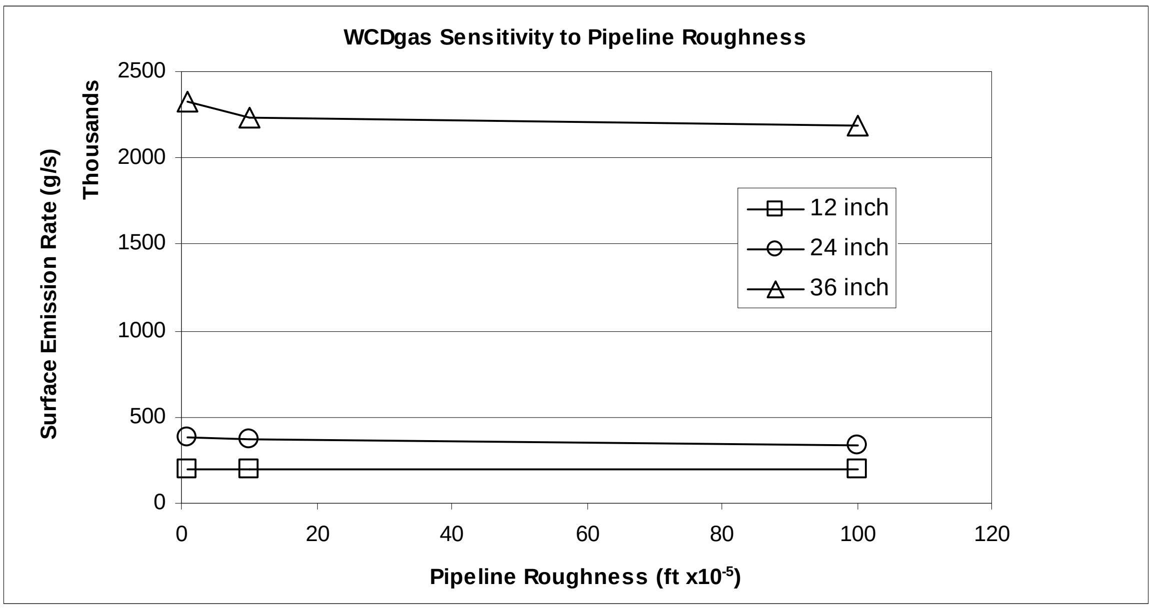


Figure 8.1 WCDgas Sensitivity to the Pipeline Roughness

8.1.2 Heat Transfer Coefficient (k) and Inlet Gas Temperature

Unburied and un-insulated pipelines have heat transfer coefficients on the order of 10 BTU/hr ft^2 °F (57 W/m^2 °C) and insulated or buried pipelines have heat transfer coefficients of between 0.5 to 2 BTU/hr ft^2 °F. The same base scenarios used for the pipeline roughness sensitivity modeling have been used to determine the sensitivity of the model results to the heat transfer coefficient (using the $10x10^{-5}$ ft roughness value) with the exception that the inlet gas temperature has also been varied to establish the importance of this input variable on the model results. Gas inlet temperatures of -4 and 48 F were used. Heat transfer coefficients of 0.5, 2, 10 and 30 BTU/hr ft^2 °F have been used in the assessment. The results shown in Figure 8.2 indicate that the inlet gas temperature has little influence on the initial high flow episode in the guillotine type break scenarios being considered. The heat transfer coefficient has considerable impact on the emission rate results from the model for the 36 inch pipeline scenario considered, especially for the low heat transfer situation in the insulated or buried cases. Because of this, the heat transfer coefficient value entered should minimally reflect whether the pipeline is insulated/buried or simply on the seabed. A heat transfer coefficient of 0.5 BTU/hr ft^2 °F should be used for buried or insulation pipelines and a value of 20 BTU/hr ft^2 °F should be used for non-insulated pipelines on the seabed when actual heat transfer coefficients are not available. These inputs will result in reasonable maximum surface gas emission rates. If the buried/insulated status of the pipeline is not known run the simulation twice with the two default values to determine if there is any significant difference in the final model outcome.

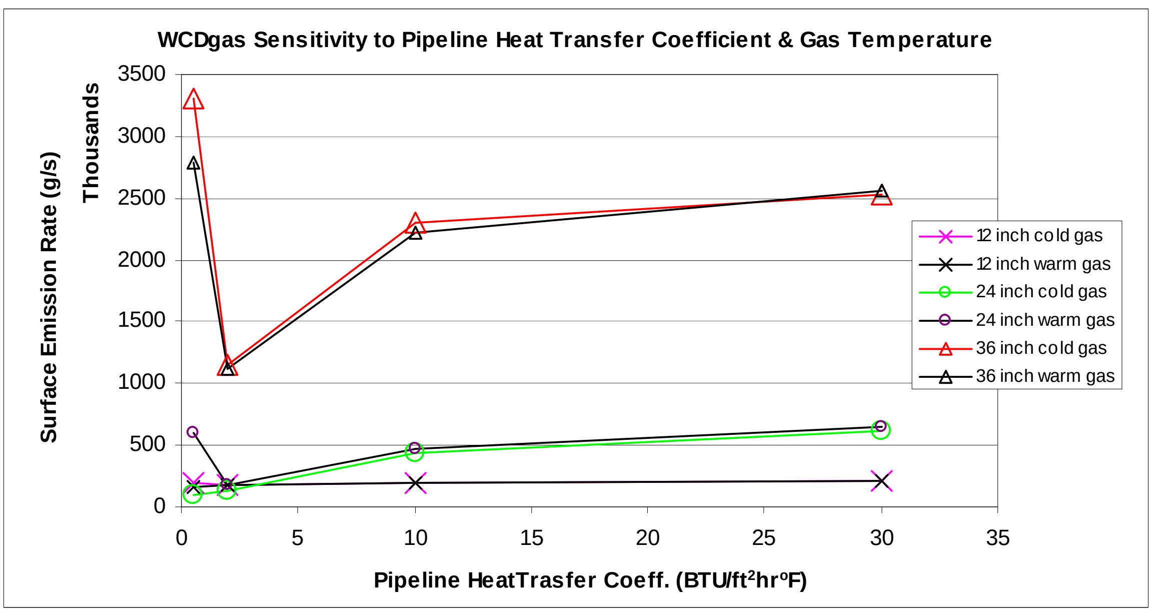


Figure 8.2 WCDgas Sensitivity to the Pipeline Heat Transfer Coefficient and Inlet Gas Temperature

8.1.3 Depth of Gas Inlet Into Pipeline

The 24-inch and 36 inch pipeline base scenarios have been used to test the sensitivity of the model results to the gas inlet depth. Inlet depths of 60, 300 and 900 m (approximately 200, 1000, and 3000 ft) have been used in the assessment. The depth of the pipeline break has also been varied to include near surface breaks (1 m depth) and deep breaks (the same depth as the gas inlet depth). Figure 8.3 shows the results of this assessment. If the break is at the surface the inlet gas depth has little influence on the surface emission rate. If the break is at depth then the inlet gas depth can have a significant influence on the maximum surface emission rate, especially for the larger pipeline scenario.

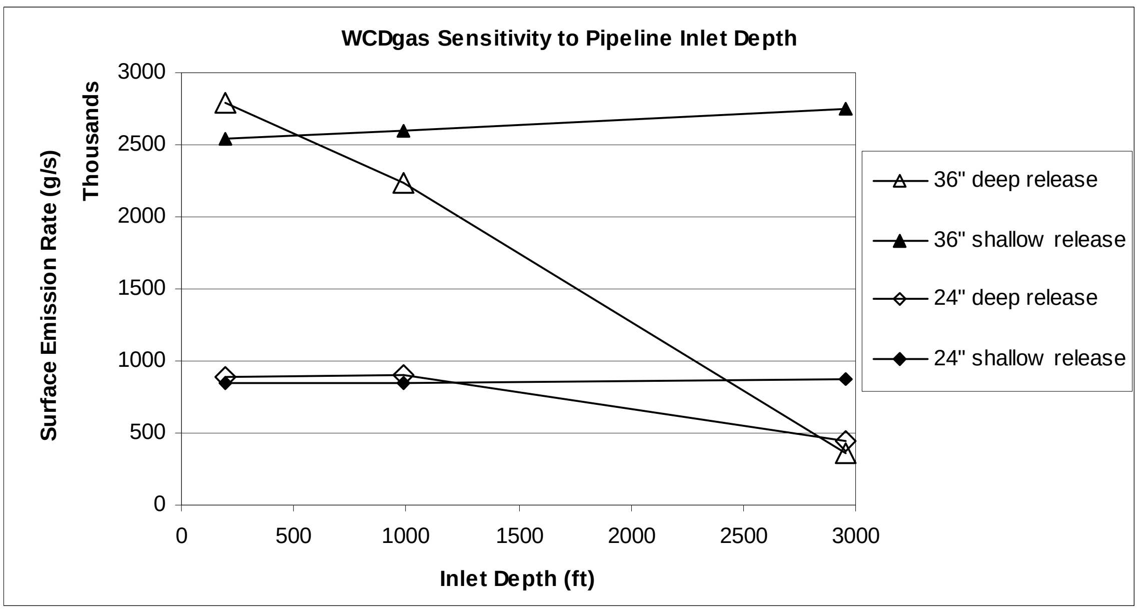


Figure 8.3 WCDgas Sensitivity to the Pipeline Gas Inlet Depth

8.1.4 Pipeline Outlet Depth and Outlet Closure

In this assessment it was assumed that the pipeline outlet would always be on land at or above the water surface. Three outlet “depths” were evaluated: 0, 164 and 1640 ft above sea level (0, 50, 500 m). The scenarios were run with no outlet closure and with the outlet closed after 2 minutes. The results of the model runs are shown in Figure 8.4. The results indicate that the outlet depth had little influence on the maximum surface gas emission rate and that by closing the outlet there was a reduced maximum emission only for the case of the pipeline outlet at water level. It is recommended that a zero pipeline outlet depth and no outlet closure be used in simulations where specific data are not available.

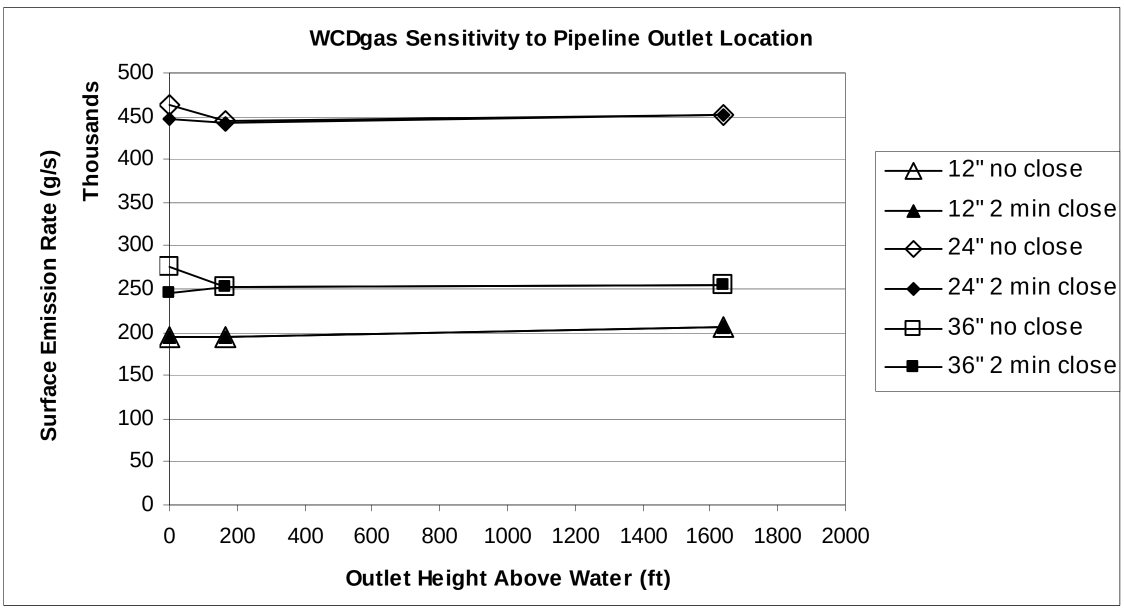


Figure 8.4 WCDgas Sensitivity to the Pipeline Gas Outlet Depth and Outlet Closure

8.1.5 Water Depth at Pipeline Rupture

The effect of the depth of the water over the puncture location has been investigated using the base scenarios with puncture locations at the center of the pipelines and three puncture depths. The modeling results are shown in Figure 8.5. As would be expected the results show that the water depth over the rupture is important in determining the maximum surface gas emission, especially for the larger diameter pipelines and in the deeper water scenarios. The influence of the over-water pressure was not significant in the shallower 12-inch pipeline scenario. Based on these results it is apparent that a reasonably accurate water depth is a necessary input to the model to achieve reasonable results.

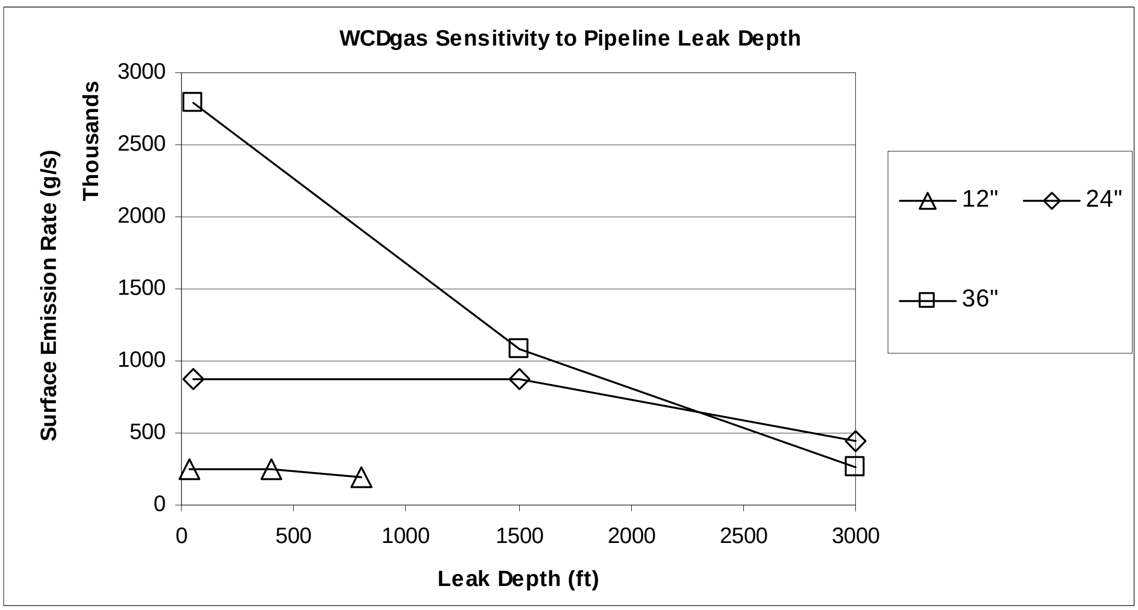


Figure 8.5 WCDgas Sensitivity to the Pipeline Rupture Depth

8.1.6 Pipeline Ambient Temperature

In this assessment it was assumed that the pipeline ambient temperature was the water temperature at the depth of the pipeline segment. Temperatures of 35, 60 and 85 °F have been used in the basic scenarios to assess the impact of this input parameter. It is not reasonable to assume that the high water temperatures would exist in the deep water situations but the model was run to assess the impact of the full range of temperatures for all three of the base scenarios. The results shown in Figure 8.6 indicate that the ambient water temperature does not have a significant affect on the release rate of the majority of the gas in guillotine break situations. If the ambient water temperature is not known a best guess approach should suffice. Generally use a cold-water temperature for deep-water situations (40 °F) and warmer temperatures (50 to 60°F) in shallow temperate zone waters.

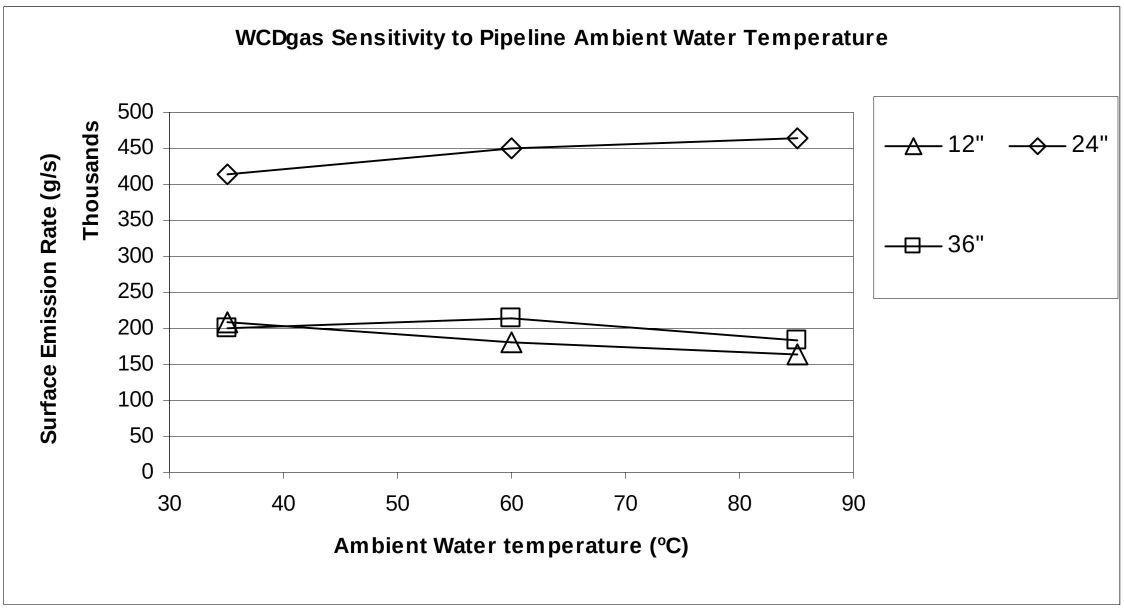


Figure 8.6 WCDgas Sensitivity to the Pipeline Ambient Water Temperature

8.1.7 Summary of WCDgas Sensitivity Testing

The results of the WCDgas sensitivity modeling have been summarized in Table 8.2 to provide users a quick guide as to what input data are critical for a precise simulation and what default input values can be used if scenario specific data is not available. The best available data must be used for those items marked essential in Table 8.2.

Table 8.2 WCDgas Data Input Requirements Post Sensitivity Testing

Input Variables	Known Importance of Variable After Sensitivity Testing		
	Essential	Significance or Default Value if Applicable	Minor/No Influence
Pipeline Segment			
Label			X
Length	X		
Diameter	X		
Roughness		10x10-5 ft (30 microns)	
Heat Transfer Coeff.		0.5 BTU/hr ft^2 °F (buried or insulated) 20 BTU/hr ft^2 °F (non-insulated)	
Ambient Temperature		Not significant- use 40°F for deep water 55°F for shallow temperate waters	
Inlet			
Label			X
Depth		Can be significant- use best available information	
Gas Flow Rate	X		
Temperature		Not significant	
Closing Time	X		
Outlet			
Label			X
Depth		Not significant – use 0	
(operating) Pressure	X		
Closing Time		Not significant – do not close	
Puncture / Leakage			
Distance from upstream end		Punctures in pipeline center are worst case. Punctures close to either end result in similar rates.	
Diameter	X		
Water Depth		Important especially for deep water Use best available information	

8.2 Atmospheric Dispersion Modeling: OCD/5

The primary input variables that could affect the air dispersion modeling results for a given gas source rate are the type of source (point or area), and the atmospheric receiving conditions (air temperature, wind speed, atmospheric stability etc.). Point sources will generate the highest near source concentrations as identified in section 7.4. The gas exit radius is available from the WCDgas output so a specific source area is available if less conservative gas concentration estimates are of interest. The atmospheric conditions are provided to OCD/5 via the Wmet and Lmet data files. For the scenarios modeled in this study the over-water data is more critical since the gases disperse to below LEL prior to reaching land in all cases modeled. The B4602391.dat Wmet file used in the Pacific study area simulations was sorted by wind speed and air temperature to identify minimum and maximum air temperatures for three different wind speed conditions (1, 5 and 10 m/s). The Julian days and hours in the day when these conditions occurred were identified (see Table 8.3). The OCD/5 dispersion model was executed for each of these environmental input conditions using the gas source rate for the Pac36shg spill scenario (see Table 7.1) to assess the significance of the receiving environmental conditions on the dispersion process. The distance downwind where the gas concentration drops below the LEL is recorded in Table 8.3. The mid-range wind speed condition resulted in the longest hazard zone likely due to the more stable atmospheric conditions created by the moderate winds. Both the light and heavy wind conditions created smaller hazard zones presumably due to unstable atmospheric conditions that can arise in either low or high wind conditions. There was only about a 1.5 times variation in hazard zone over the range of conditions tested. For conservative modeling results it is recommended that simulations be completed in periods of moderate winds and temperatures.

Table 8.3 Inputs to OCD/5 for Sensitivity Assessment

Environmental Condition	B4602391 Input Data				
	Julian Day	Hour	Sea Wind Speed (m/s)	Sea Air Temp. (^oK)	Distance to Gas Concentration Below LEL (m)
Low wind / low temp.	75	19	1	287.3	800
Low wind / high temp.	227	7	1	292.9	750
Medium wind / low temp.	131	13	5	286.5	1100
Medium wind / high temp.	255	17	5	290.8	1000
High wind / low temp.	130	14	10	286.0	800
High wind / high temp.	267	6	10	291.0	850

9 Environmental, Health and Safety Risks from Sub Sea Gas Discharges

9.1 Environmental Risks

The overwhelming component in natural gas is methane. Methane is a colorless and odorless gas at standard conditions and is listed as non-toxic in hazardous material handbooks (Environment Canada 1984) except as an asphyxiant. Little is known about the effects of natural gas on biota in marine waters. No references could be found in the literature on the levels of dissolved methane or natural gas that might cause lethal or sub-lethal effects on marine biota. The discharges in question will be violent, short-lived episodes that see large quantities of large bubbles of gas rising quickly from the sea bed to the surface. During the rise the gas bubbles will entrain water and generate 1 to 40 m/s velocities in the plume (see Table 7.2). The short rise times and large gas bubbles will limit the amount of gas that will dissolve in the water (Leifer 2006). The primary mechanisms for impact on marine biota will likely be through entrainment and displacement of organisms, turbulence and possibly asphyxiation. The overall impact from a single incident would be small, however, due to the short duration of the event and the small zone of influence of the spill (the maximum plume diameter at the surface will be on the order of two hundred meters). The total quantity of water entrained by each incident will be in the range of 10^7 to 10^9 m^3. This translates to less than a cubic kilometer of water in total that would be affected by the release. The impact to the biota within this volume would also likely be minimal due to the non-toxic nature of the gas and the small quantity dissolving during the short event. The potential risks from displacement and turbulence are not clear. However, the volume of water in question is small and the gas discharges should result in negligible impact.

9.2 Health and Safety

Natural gas or methane are non-toxic but are asphyxiants with respect to human health. The amount of natural gas or methane needed to cause asphyxiation is a considerably higher concentration than the lower explosive limit (LEL) for methane (3% by weight or approximately 35 g/m^3) and so the LEL is of primary concern from a health and safety standpoint. The conservative air concentration dispersion simulations completed in this study indicate that the sub sea gas pipeline releases will generate hazard zones less than 1100 m downwind of the gas source for the worst case scenario considered (see Table 7.3). In most instances the explosive zone will extend less than 500 m from the source. The guillotine pipeline ruptures modeled will also result in short episodes (see Table 7.2) with the entire loss of gas occurring usually in less than one hour (with a maximum 4 hour discharge) and the high discharge rate periods with maximum hazard zones lasting for even shorter times. The hazard zone will cease to exist prior to the loss of the last gas from the pipeline due to the slowing of the gas flow rate at the end of the release and the rapid dispersion of the gas in the air.

Another concern surrounding sub sea gas discharges often expressed by mariners is whether or not the gas plume could result in buoyancy loss to the point where a ship would sink if it were in the plume. Studies have been completed to investigate this concern (Milgram 1984 and Hammett 1985). These studies have shown that the vessels will not sink. It has been shown that the loss in buoyancy caused by the rising gas can be overcome by the upward momentum of the plume, the significant radial flow of water away from the plume rise location will push vessels away from the bubble zone and the bubble rise location is very dynamic due to the plume's turbulent nature. All of these factors eliminate the chance of a vessel sinking due to the presence of the bubble plume.

10 References

Douglas, S.G., A.B. Hudischewskyj.2008. Five-Year Meteorological Datasets for CALMET / CALPUFF and OCD5 Modeling of the Gulf of Mexico Region. Prepared by ICF International, MMS Contract 0306PO52847. July 2008.

Emilsen, Morten, H. 2009. Pers. comm.. Morten Emilsen, WellFlow Dynamics, Oslo, Norway.

Environment Canada, 1984. Manual for Spills of Hazardous Materials. Technical Services Branch, Environmental Protection Service, Environment Canada. Cat. No. En40-320/1984E.

Hammett, D.S. 1985. Drill Vessels Float in Aerated Water. Offshore Europe, 10-13 September, Aberdeen, UK. Society of Petroleum Engineers of AIME.

Herkhof, D. 2008. Pers. comm., Dirk Herkhof, MMS Meteorologist

Milgram, J., Paul R. Erb. 1984. How Floaters Respond to Sub Sea Blowouts. Petroleum Engineer International. June 1984. pp 64 to 72.

Leifer, Ira, et. al. 2006. Natural Marine Seepage Blowout: Contribution to Atmospheric Methane, Global Biogeochemical Cycles, 20 doi:10.1029/2005GB002668, 2006.

MMS. 2009. Pipeline Incidents, http://www.mms.gov/incidents/pipeline.htm. Minerals Management Service.

MMS. 2009. Pipeline Masters, http://www.gomr.mms.gov/homepg/pubinfo/freeasci/pipeline /freepipe.html. Minerals Management Service.

Appendix A: Pipeline Rupture Release Algorithm Details

1 The Peng Robinson Equation of State

1.1 General

A compositional model is used to predict the hydrocarbon phase behavior and thermodynamical properties. The calculations are based on the concept of an equilibrium constant, K value, defined as the ratio of the mole fraction of the component in the gas phase, y_i to the mole fraction of the same component in the liquid phase, x_i.

$$K_i = \frac{y_i}{x_i}$$

Unlike a single component fluid, a multi component mixture exhibits a phase envelope rather than a single equilibrium curve. This implies that pressures and temperatures inside the phase envelope, both liquid and gas phases exists in equilibrium.

The software requires a compositional input describing the hydrocarbon fluid and uses the Peng-Robinson Equation of State (EOS) to calculate the required fluid properties as functions of pressure and temperature. The equation of state is a thermodynamic equation describing the state of matter under a given set of physical conditions. The compressibility factors and phase distributions are determined from the EOS and the fluid properties are calculated. These will act as input to the two- phase flow model.

The Peng-Robinson equation is expressible in terms of the critical properties and the acentric factor. The equation is applicable to calculations of fluid properties in natural gas processes and is expected to provide good accuracy for the scenarios intended for the release model. The following chapters give a brief overview of the equation. For more details see Peng 1976.

1.2 Equations

The following equations describe the Peng-Robinson Equation of State:

$$p = \frac{R\,T}{V_m - b} - \frac{a\,\alpha}{V_m^2 + 2bV_m - b^2}$$

$$a = \frac{0.45724 R^2 T_C^2}{P_c}$$

$$b = \frac{0.07780 R T_C}{P_c}$$

$$\alpha = \left(1 + \left(0.37464 + 1.54226\omega - 0.26992\omega^2\right)\left(1 - T_r^{0.5}\right)\right)^2$$

$$T_r = \frac{T}{T_C}$$

where,

Vm - *molar volume, V / n*
ω - *acentric factor*
R - *universal gas constant, 8.314472 J/(K mol)*
Tc - *critical temperature*
Pc - *critical pressure*

An alternative form in terms of the compressibility factor Z replacing the molar volume from the real gas law is:

$$Z^3 - (1 + B - 2B)\cdot Z^2 + \left(A - B^2 - 2B - 2B^2\right)\cdot Z - A\cdot B + B^2 + B^3 = 0$$

where,

$$A = \frac{a\cdot p}{R^2\cdot T^2}$$

$$B = \frac{b\cdot p}{R\cdot T}$$

This equation is used both for the gas phase and for the liquid phase.

$$Z_L^3 - (1 + B_L - 2B_L)\cdot Z_L^2 + \left(A_L - B_L^2 - 2B_L - 2B_L^2\right)\cdot Z_L - A_L\cdot B_L + B_L^2 + B_L^3 = 0$$

$$Z_G^3 - (1 + B_G - 2B_G)\cdot Z_G^2 + \left(A_G - B_G^2 - 2B_G - 2B_G^2\right)\cdot Z_G - A_G\cdot B_G + B_G^2 + B_G^3 = 0$$

1.3 Critical values and acentric factors

Table A.1 shows the critical values and factors used by the equation of state.

Table A.1: Critical values, acentric factors and compressibility factor

		Critical temp	Critical pressure	Accen fac	Compr fac	Critical vol	Mol weight
Symbol	**Name**	**K**	**bar**	**-**	**-**	**cm/mol**	**g/mol**
H	hydrogen	33.2	12.8	-0.220	0.276	129.0	2.016
CO2	carbon diox.	304.2	72.8	0.225	0.274	94.0	44.010
N2	nitrogen	126-2	33.5	0.035	0.290	89.5	28.073
C1	methane	190.6	45.2	0.013	0.288	99.0	16.043
H2S	hydr. sulfide	373.2	88.2	0.100	0.284	98.5	34.080
C2	ethane	305-4	48.2	0.098	0.285	148.0	30.070
C3	propane	369.8	41.9	0.152	0.281	203.0	44.097
n-C4	n-buthane	425.2	37.5	0.193	0.274	255.0	58.124
i-C4	i-buthane	408.1	36.0	0.176	0.283	263.0	58.124
n-C5	n-penthane	469.6	33.3	0.251	0.262	304.0	72.151
C6	hexane	507.4	29-3	0.296	0.260	370.0	86.178
C7	heptane	540.2	27.0	0.351	0.263	432.0	100.205
C8	octane	568.8	24.5	0.394	0.259	492.0	114.232
C9	nonane	594.6	22.8	0.444	0.260	548.0	128.259
C10	decane	619.2	20.8	0.490	0.247	603.0	142.286

1.4 Solution algorithm

The compressibility factors for liquid and gas phase, the equations are solved iteratively. The following is a step by step algorithm to calculate the equilibrium constants.

1. The input data for the calculation are the pressure, temperature and fluid composition.
2. K_i values for each component are guessed using the Wilson correlation (see below)
3. On basis of the assumed K_i values, perform the flash calculations (see below)
4. Compositions of liquid and gas phases obtained from flash calculations can be used to determine the fugacity y coefficients from each component
5. Use the fugacity coefficient ratios to calculate the equilibrium constants K_i for each component
6. Compare the guessed constants calculated in step 2 with the calculated values in step 5.
7. If the convergence tolerance is satisfied for all components, the values of equilibrium constants are used to calculate the phase compositions required in determining phase physical properties. If not, the calculated values are used as the new guesses and steps 3 to 6 are repeated until convergence is achieved.

The Wilson correlation is used to estimate the K values initially as in step 2 above.

$$K_i = \frac{P_{ci}}{p} \exp\left[5.37\,(1+\omega_i)\left(1-\frac{T_{ci}}{T}\right)\right]$$

The flash calculations in step 3 above are performed using the following equation:

$$\sum_{i=1}^{n}(y_i - x_i) = \sum_{i=1}^{n}\frac{z_i(K_i - 1)}{(K_i - 1)\frac{G}{F} + 1} = f\left(\frac{G}{F}\right) = 0$$

Where,

F - number of moles of composition
L - number of moles of liquid
G - number of moles of gas
z_i - mole fraction of component i in composition
x_i - mole fraction of component i in liquid phase
y_i - mole fraction of component i in gas phase
n - total number of components in composition

Once the compressibility factors of each phase are determined from the iterative procedure, all the required vapor and liquid properties can be determined. These include densities, viscosities, enthalpies, conductivities, heat capacities and surface tension.

2 Dynamic Flow Simulation Model

2.1 General

This model is a transient two-phase flow model based on conservation equations. Two separate mass and momentum equations for gas and liquid and one energy equation. Estimation of gas release rates is based on flashing, integration, choking effects and fluid flow behavior in the system. Total volume released is calculated from:

- Rate variation and release time,
- Leak detection time and production rates,
- Shutdown time for each component in the system,
- Location of rupture,
- Property changes with pressure and temperature,
- Frictional and hydrostatic pressure drop,

2.2 Data requirements

To provide the release results, the software needs the following information:

- Geometrical description of the flow lines
- Compositional input of the hydrocarbon fluid
- Receiving pressure at the outlet of the system
- Leak position and size

2.3 Geometrical discretization

Pipeline length and diameter must be specified. It might be of importance to specify dips and peaks along the pipeline where condensate could accumulate. Generally, finer grid results in more accurate calculations. Each user specified pipeline is discretized into a number of sections in the model and calculations are done for each of the section elements in the system. The computational time increases with the number of sections, and a short single pipeline is much faster to simulate than a complex network with many internal sections.

2.4 Leak modeling

The leak/rupture in a pipeline is modeled by implementation of a critical choke model with a diameter equal the equivalent diameter of the leak. The model handles both sub critical and critical flow. If the gas velocity in a choke exceeds the critical velocity, critical flow conditions are used.

2.5 Nomenclature for a pipeline layout

The physical elements used to define a pipeline layout in the model are as follows:

Pipe	-	an element with a given diameter, length, height, roughness and u value
Branch	-	one or more connecting pipes in series (Figure A.1)
Connection	-	connects two pipes
Junction	-	connects two or more braches.
Network	-	two or more connected branches (Figure A.2)

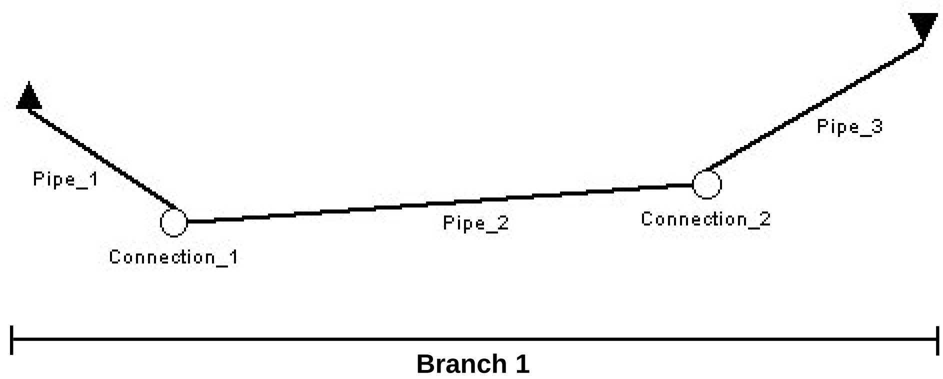


Figure A.1 Example sketch of a branch

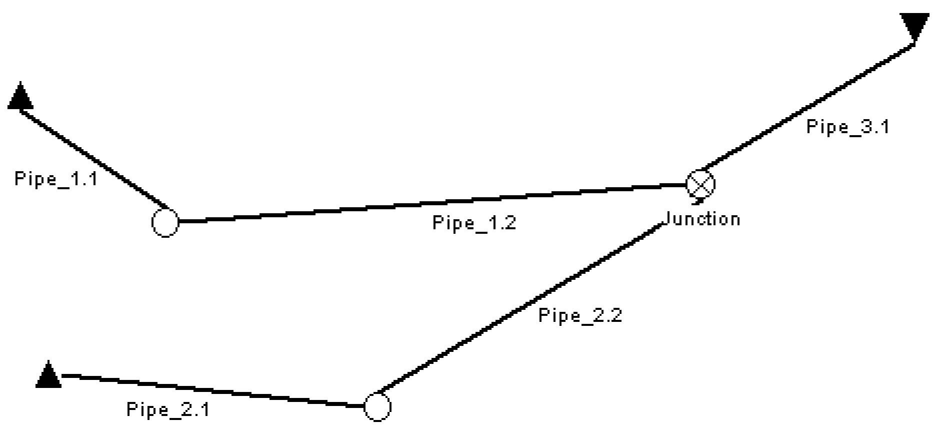


Figure A.2 Example sketch of a network

A network can only have one outlet and one leak/rupture, but may have several inlets.

3 References

Peng, D. and Robinson, D.B. 1976. "A New Two Constant Equation of State", Ind. Eng. Chem. Fund.

Appendix B: Gas Bubble Plume Algorithm Details

1 Plume Modelling

1.1 Sub sea gas bubble plume calculations

The gas bubble plume calculations are based on the following input data:

Discharge depth H_0, m
Gas mass flux q, kg/s
Gas density ρ , kg/Sm^3 (@ 1 atm and 15 ^{o}C)
Sea temperature θ_s , ^{o}C

Here, the gas mass flux is presumed to be delivered by the sub sea gas leak module in terms of a table of leak rates and corresponding times from the start of the leak. The gas mass flux is used together with discharge depth, sea temperature, and gas density to determine the volume flow rate V_0 (m^3/s) at the discharge depth:

$$V_0 = q / \rho_0 \tag{1}$$

where $\rho_0 = \rho \dfrac{H_0 + 10}{10} \dfrac{273 + 15}{273 + \theta_s}$, assuming ideal gas

In the expression above, the number 10 corresponds to 10 m water column, which equals a hydrostatic pressure of one atmosphere. The volume flux at the discharge depth is used to define the buoyancy flux parameter $\phi_0 = gV_0 / \pi$

The bubble plume calculations are based on Fanneløp's general non-dimensional solution for underwater gas releases, shown in graphical form at Figure B.1 (Fanneløp and Sjøen 1980, Fanneløp 1994). The critical assumption in the development of the solution is that the mass flux of gas is conserved, while the gas volume varies with hydrostatic pressure according to the ideal gas law. The expansion of the gas is assumed to be isothermal. Moreover, the initial momentum of the discharged gas is neglected, as well as possible effects of crossflow and stratification (due to vertical temperature and salinity gradients). This implies that the solution is valid for large gas leaks at moderate depths, but may be less reliable for small leak rates and large water depths due to enhanced influence of factors such as cross flow, stratification and dissolution of gas in the water masses (Johansen 2000).

The plume is defined by three variables – plume radius b_p, centerline velocity w_p, and plume rise time t_p – all functions of the vertical distance z from the discharge point. These variables may be expressed in terms of non-dimensional variables, X, B, W and T:

$$X = z / H \text{ , } B = b_p / 2\alpha H \text{ , } W = w_p / M \text{ and } T = t_p M / H \tag{2}$$

where $H = H_0 + 10$ and $M = \left[\phi_0 \dfrac{\lambda^2 + 1}{2\alpha^2 H} \right]^{1/3}$

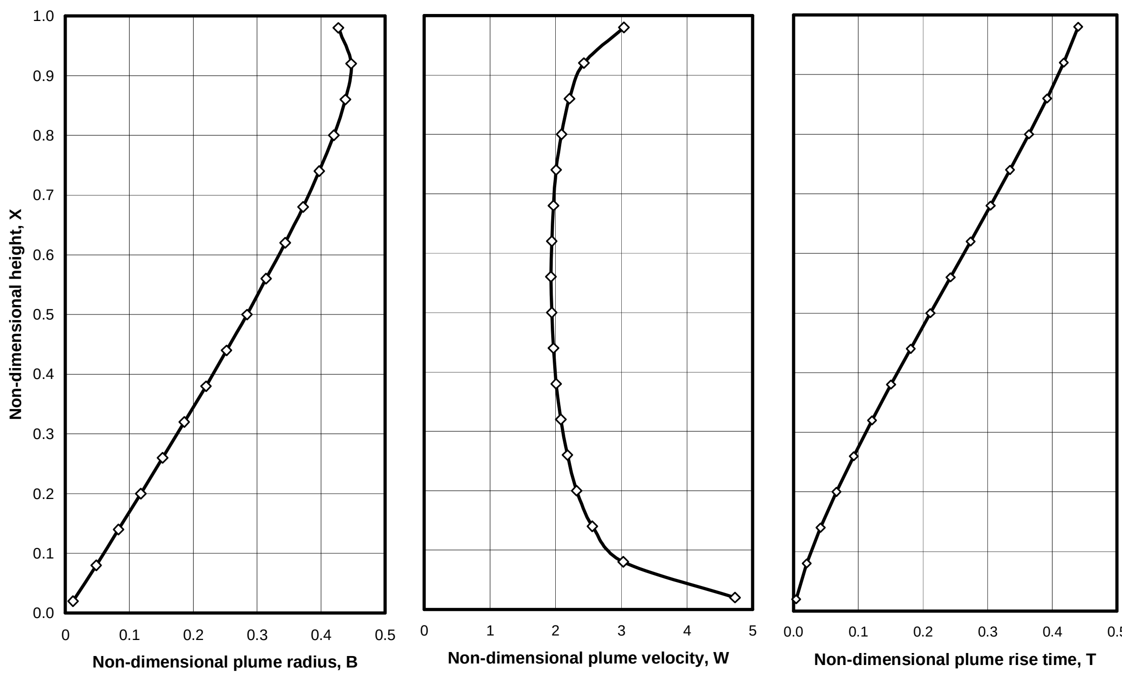


Figure B.1 Fanneløp's general gas bubble plume solution in non-dimensional form. Note that the non-dimensional rise time T is derived from the non-dimensional plume velocity W.

The non-dimensional plume rise time *T* is derived from the non-dimensional plume velocity by the integral

$$T = \int_0^X dX / W \tag{3}$$

The parameter α is the entrainment coefficient ($\alpha = 0.1$), and λ is a shape factor representing the ratio between the buoyancy and velocity profiles ($\lambda = 0.65$), both assumed constant with depth.

2 Surfacing of gas

For the present purpose, the general solution presented in Chapter 1 may be curve fitted or interpolated from tabulated values and used to determine the plume variable b_p, w_p and t_p on the basis of the input variables q, H_0, ρ and θ_s. The plume variables are used to estimate the time dependent gas flow rates q_a (kg/s) to the atmosphere and the corresponding radius R_B (m) of the boiling zone.

2.1 Surfacing rate

The time of surfacing is determined from the time of discharge and the plume rise time corresponding to a given gas discharge rate. Thus, with gas flow rates $q(i)$ tabulated at consecutive time steps (i = 1, 2,..), the corresponding list of times of surfacing t_s will represent the sum of the release time t_r and the rise time t_p:

$$t_s(i) = t_r(i) + (1+\beta)t_p(i) \qquad (4)$$

where the factor β is introduced to account for the fact that the computed rise time t_p is derived from the centerline plume velocity, while the rise time of a certain fraction of the gas flow will be longer due to the presumed Gaussian velocity distribution in the plume. Calculations based on a plume shape factor $\lambda = 0.65$ show that the Gaussian velocity profile will causes a time lag in the surfacing gas flow rate of about 1/3 of the center line plume rise time, i.e. $\beta = 0.333$ (Figure B.2).

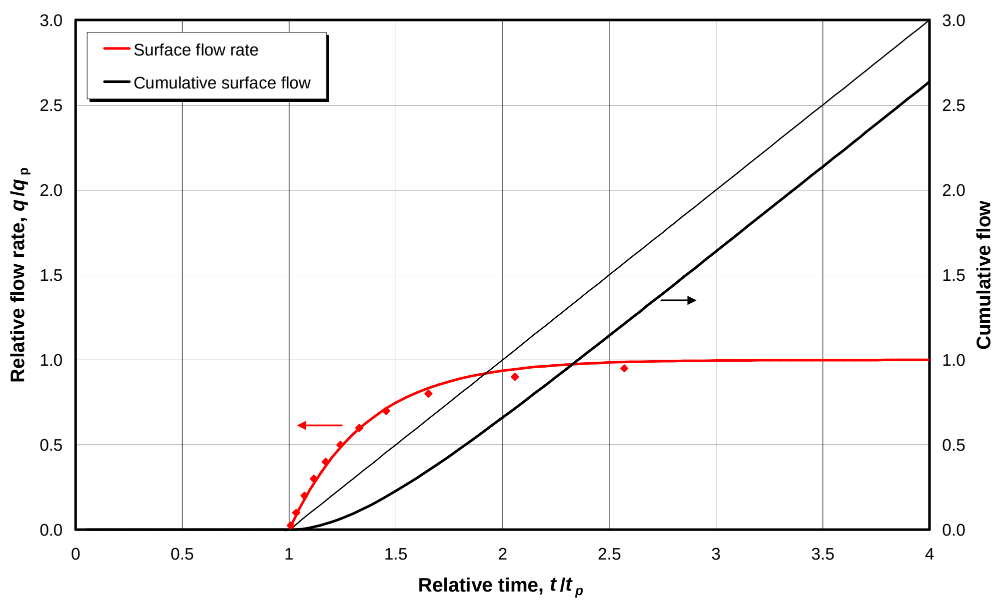


Figure B.2 Surfacing gas flow computed for a Gaussian plume velocity profile with shape factor $\lambda = 0.65$. The red line shows the surface flow rate q (kg/s) relative to the gas flow rate q_p in the plume, approximated with an exponential formula. The red markers show computed values for a plume with Gaussian velocity and density profiles and shape factor $\lambda = 0.65$. The thick black line shows the cumulative gas flow Q, found by time integration of the red line. The thin black line is drawn for comparison and shows the cumulative gas flow without reduction, i.e. $Q_p = q_p t$ (kg).

Figure B.2 is based on the assumption that the time development of the surface flow rate can be approximated by an exponential function of the form

$$q(t) = q_p \left(1 - \exp\left(-t/\tau\right)\right), \tag{5}$$

where τ is the time constant. Computations made for a plume with Gaussian velocity and density profiles support this assumption, and indicates a time constant of about of 1/3 of the centerline plume rise time (see red markers on Figure B.2). Time integration of this exponential function gives the following expression for the cumulative surfacing gas flow:

$$Q(t) = q_p \left[t - \tau\left(1 - \exp\left(-t/\tau\right)\right)\right] \tag{6}$$

For large times, $t >> \tau$, this equation can be approximated by $Q \approx q_p (t - \tau)$, which can be seen to imply a time lag τ in the cumulative surface gas flow.

The time dependent gas flow rate to the atmosphere is determined from the discharged mass of gas $\Delta Q = q\,\Delta t_r$ (kg) in the time interval $\Delta t_r = t_r(i) - t_r(i-1)$, divided by the corresponding surfacing time period $\Delta t_s = t_s(i) - t_s(i-1)$:

$$q_a = \Delta Q / \Delta t_s = q \Delta t_r / \Delta t_s \tag{7}$$

A gas leak from a pipeline rupture will in general imply a sharp decrease in leak rate with time. Since the plume rise time t_p will increase with decreasing gas discharge rates, this equation implies that the gas flow rate (kg/s) to the atmosphere will tend to be reduced relative to the gas discharge rate at the leak point. This also implies that the gas release to the atmosphere will last longer than the release period at the discharge point.

2.2 Boiling zone

The surface flow generated by a surfacing gas bubble plume has been investigated by Fanneløp and Sjøen (1980) and Milgram and Burgess (1984). Fanneløp and Sjøen derived a model for the zone where the flow is predominantly horizontal, while Milgram and Burgess focused on the turning region. In the present context, however, we need a continuous representation of the flow pattern. For this purpose, an algebraic solution has been derived that fulfils the continuity equation for volume flow, based on an assumed exponential reduction of the vertical velocity as the plume approaches the surface where the vertical velocity will be zero.

The centerline velocity in the turning zone is thus specified as $w(h) = w_p \left[1 - \exp(-h/h_0)\right]$, where h is the depth and h_0 is a characteristic depth of the radial flow of entrained water.

A Gaussian velocity profile is assumed in the undisturbed cross section of the plume with a centerline velocity w_p and a characteristic radius b_p.

The algebraic model gives radial and vertical velocities $u, w(r,h)$ at a certain radius r and depth h:

$$u(r,h) = 0.5 \frac{w_p\, b_p^2}{r\, h_0} \left[1 - \exp\left(-\frac{r^2}{b_p^2}\right)\right] \exp\left(-\frac{h}{h_0}\right) \tag{8 a}$$

$$w(r,h) = w_p \exp\left(-\frac{r^2}{b_p^2}\right)\left[1-\exp\left(-\frac{h}{h_0}\right)\right] \qquad (8\text{ b})$$

The characteristic depth $h_0 = a\,b_p$ is related to the plume radius by a parameter $a = 0.37$ which has been tuned to match the initial conditions in the zone of radial flow derived by Fanneløp and Sjøen (1980). The corresponding flow field is visualized in terms of flow lines in Figure B.3, top frame.

The radial distribution of the surfacing gas flux may be determined by computing trajectories of gas bubbles rising with a slip velocity w_b in the flow field generated by the surfacing plume (see Figure B.3, bottom frame).

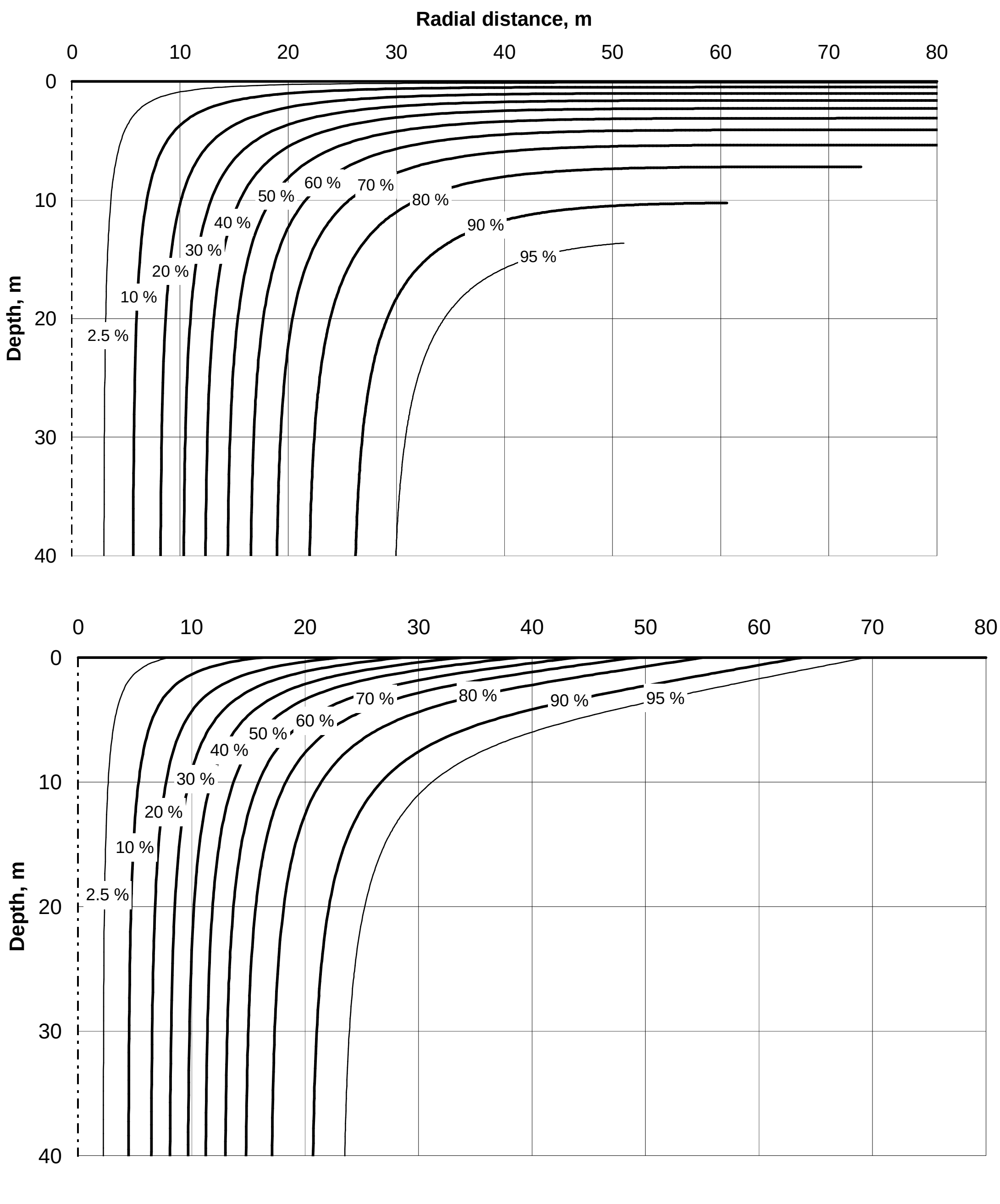


Figure B.3 Flow field generated by a surfacing gas bubble plume. The top frame shows flow lines in the water, while the bottom frame shows flow lines for gas, presuming a bubble rise velocity of 0.3 m/s.

Here, the slip velocity for gas bubbles is assumed to be 0.3 m/s in correspondence with Fanneløp and Sjøen's assumptions. Each flow line shown in the graph is enclosing a certain fraction of the gas flow in the undisturbed plume as indicated by the legend on the graph. For the present purpose, we have chosen to define the radius enclosing 90 % of the gas flow as the radius of the boiling zone, i.e. $R_B = R_{90}$.

In order to facilitate the computation of the boiling zone, we have calculated the radius of the boiling zone for an arbitrary set of the plume parameters b_p and w_p. A curve fit of the results in non-dimensional form is shown at Figure B.4. The thin line represents a best fit power law function based on the data points:

$$R_{90} / b_p - 1 = 0.29 \left(w_p / w_b \right)^{0.68} \qquad (9)$$

where w_p and w_b (m/s) are the plume velocity computed at the surface and the bubble slip velocity.

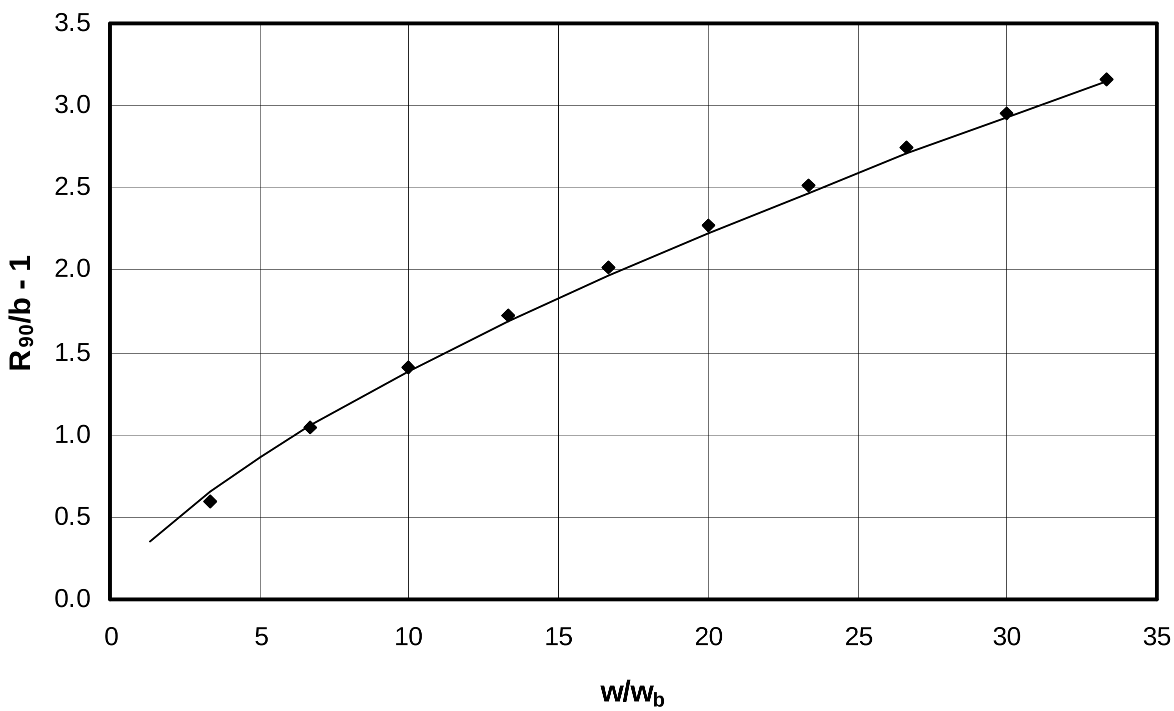


Figure B.4 Normalized plot of the radius of the boiling zone R_{90} computed with the flow line approach described above. The plume parameters w and b are varied, while the slip velocity w_b is kept constant (w_b = 0.3 m/s). The thin line represents the best fit power law function (Eq. 9)

3 Transient leaks

As all integral plume models, Fanneløp's general solution for sub sea gas bubble plumes is based on the assumption of a stationary source. In the present context, this stationary solution is applied to instantaneous gas leak rates which vary with time. In general, such a quasi-stationary approach is presumed to be valid for slowly varying sources as long as the rise time is short relative to the time scale for the change in flow rate. However, in case of pipeline ruptures, strong transients may be expected at the start of the leak, with high initial leak rates tailing off with time as the internal pressure in the pipeline is reduced to the ambient hydrostatic pressure.

One important issue in conjunction with transient leaks is the starting plume phenomenon – i.e. the gradual build up of a plume from a source which is turned on suddenly and then maintained at a constant rate. A theory for starting plumes which has been proposed by Bettelini and Fanneløp (1993) indicates that in the initial phase, the front of the plume will develop as a nearly spherical cap attached to a "normal" coned plume below. The cap will rise slower than the plume, and thus accumulate gas as it rises towards the surface. Thus, gas may be expected to be released into the atmosphere in a strong burst as the cap reaches the sea surface. However, with the rapidly diminishing leak rates which can be expected in case of a pipeline rupture, it is not obvious that a cap can be maintained: the diminishing leak rate at the source will cause the plume to slow down, and possibly lose speed relative to the cap.

Neglecting the starting plume issue, we expect that the main effects of a diminishing leak rate will be (1) a reduction in the mass flow rate of gas through the sea surface relative to the mass flow rate at the source, and (2) an extension of the time period when gas is leaking into the atmosphere relative to the leak period at the source. These effects are demonstrated at Figure B.5 which show surfacing gas flow computed from a gas leak from an assumed pipeline rupture at 400 m depth.

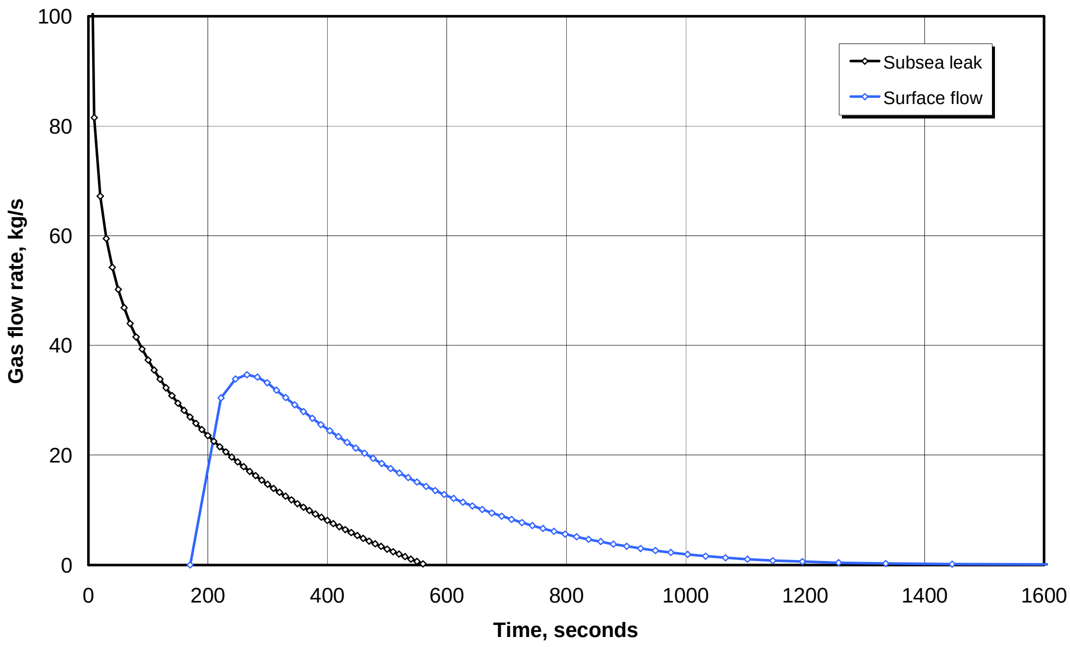


Figure B.5 Surface gas flow computed for a major sub sea gas pipe rupture at 400 m depth. The curves show the sub sea leak rate (black) and the corresponding surface flow rate (blue). The sub sea leak rate is sampled at 10 seconds intervals.

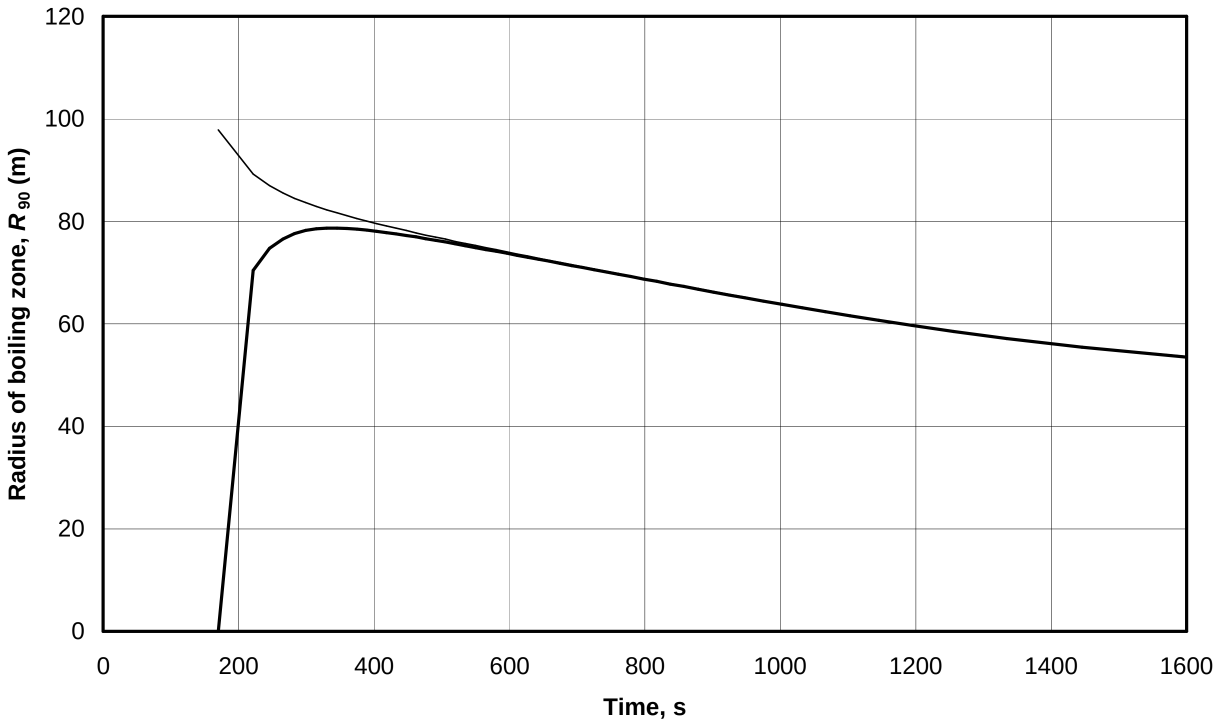


Figure B.6 Radius of boiling zone R_{90} computed for the same case as shown in Figure B.5. Thin line shows R_{90} computed by equation 9, while the thick line accounts for a gradual build up of the boiling zone (see text).

Figure B.5 shows that in this case, the surfacing of gas will be delayed by about 3 minutes (170 seconds) due to the rise time of the initial plume, and also reduced considerably in strength due to increasing rise times caused by a continuous reduction in the sub sea leak rates. For the same reason, the surface gas flow will also last for a considerably longer period than the sub sea leak.

Figure B.6 shows the radius of the boiling zone for the same case. The thin line shows the boiling zone computed directly from the plume radius and rise velocity by equation 9, while the thick line includes a gradual growth of the area of the boiling zone with time corresponding to the build up of the gas flow rate, i.e. $\pi R^2(t)/\pi R_{90}^2 = q(t)/q_p$, which implies

$$R(t) = R_{90}\left(1 - \exp\left(-t/\tau\right)\right)^{1/2} \qquad (10)$$

where τ is the time constant introduced in section 2.

4 Summary of model concept and formulas

This chapter summarizes the model concepts and formulas to be used in the programming of the model of gas behaviour in the water column as a result of the previous discussion. Note that the equations listed in this chapter are numbered in brackets, to be distinguished from equation numbers used in the previous chapters.

4.1 Sub sea gas bubble plume

Input variables

- Discharge depth H_0, m
- Gas mass flux q, kg/s
- Gas density ρ, kg/Sm^3 (@ 1 atmosphere and 15 ^oC)
- Sea temperature θ_s, ^oC

Volume flow rate V_0 (m^3/s) at the discharge depth

$$V_0 = q / \rho_0 \qquad [1]$$

where $\rho_0 = \rho \frac{H_0 + 10}{10} \frac{273 + 15}{273 + \theta_s}$, assuming ideal gas

The number 10 corresponds to 10 m water column, which equals a hydrostatic pressure of one atmosphere. The volume flux at the discharge depth is used to define the buoyancy flux parameter:

$$\phi_0 = g V_0 / \pi \qquad [2]$$

Fanneløp's general bubble plume model

Plume variables, all given as a function of the distance z (m) above the leak point:

b_p: plume radius, m

w_p: plume velocity, m/s

t_p: rise time, s

Non-dimensional variables:

$$X = z / H , \; B = b_p / 2\alpha H , \; W = w_p / M \text{ and } T = t_p M / H \qquad [3]$$

where $H = H_0 + 10$ and $M = \left[\phi_0 \frac{\lambda^2 + 1}{2\alpha^2 H} \right]^{1/3}$

The parameter α is the entrainment coefficient ($\alpha = 0.1$), and λ is a shape factor representing the ratio between the buoyancy and velocity profiles $(\lambda = 0.65)$, both assumed constant with depth.

Values of *B*, *W* and *T* are given in Table B.2 as a function of the non-dimensional depth X.

Table B.2 Fanneløp's general bubble plume solution for isothermal expansion. Dimensionless plume variable B, W and T as a function of dimensionless height X.

X	**B**	**W**	**T**
0.02	0.012	4.73	0.004
0.08	0.048	3.03	0.020
0.14	0.083	2.56	0.042
0.20	0.118	2.32	0.067
0.26	0.152	2.18	0.093
0.32	0.186	2.08	0.122
0.38	0.22	2.01	0.151
0.44	0.252	1.97	0.181
0.50	0.284	1.94	0.212
0.56	0.314	1.93	0.243
0.62	0.344	1.94	0.274
0.68	0.372	1.97	0.304
0.74	0.397	2.01	0.335
0.80	0.42	2.09	0.364
0.86	0.438	2.21	0.392
0.92	0.447	2.43	0.418
0.98	0.427	3.04	0.440

4.2 Surfacing of gas

Input variables

Time series of leak rates $q = f(t_r)$, where t_r is release time. The leak rate values $q(i)$ should preferably be tabulated at fixed time increments $t(i) = i \times \Delta t$.

Surfacing time

Compute surfacing times from release time t_r and plume rise time t_p:

$$t_s(i) = t_r(i) + (1+\beta)t_p(i) \quad [4]$$

where the shape factor $\beta = 0.333$

Surfacing rate

Compute surfacing rates from

$$q_a = \Delta Q / \Delta t_s = q \Delta t_r / \Delta t_s \quad [5]$$

where $\Delta t_r = t_r(i) - t_r(i-1)$ and $\Delta t_s = t_s(i) - t_s(i-1)$

Boiling zone

Compute radius of boiling zone (R_{90}) from:

$$R_{90} / b_p = 1 + 0.29\left(w_p / w_b\right)^{0.68} \quad [6]$$

where w_p and w_b (m/s) are the plume velocity computed at the surface and the bubble slip velocity (0.3 m/s).

For transient leaks, the gradual increase in the radius if the boiling zone may accounted for by use of the following equation:

$$R(t) = R_{90}\left(1 - \exp\left(-t/\tau\right)\right)^{1/2} \qquad [7]$$

where the time constant $\tau = t_p / 3$ and t is the cumulative surfacing time (time of surfacing counted from start of leak).

4.3 Computational procedures

	Procedure to be applied for each subsequent leak rate in the time series	*Eq.*
1	Compute volume flow rate V_0 at discharge depth from gas mass flux q, gas density ρ and water depth H_0, corrected for sea temperature θ_s.	[1]
2	Compute buoyancy flux parameter ϕ_0 from V_0.	[2]
3	Determine non-dimensional plume variables B, W and T at sea surface, $X=H_0/H$ by interpolation in the general solution.	*Table B.2*
4	Compute plume variables b_p, w_p and t_p at sea surface from B, W and T via the scaling variables H and M.	[3]
5	Compute surfacing time t_s from release time t_r and plume rise time t_p	[4]
6	Compute surfacing rate q_a from leak rate q and incremental release and surfacing times	[5]
7	Compute radius of boiling zone R_{90} from plume radius b_p and plume rise velocity w_p, corrected for transients with time constant τ derived from plume rise time t_p	[6, 7]

5 Testing and validation of the gas bubble plume model

The bubble plume model chosen for this project is based on the work of Fanneløp and Sjøen, published in 1980 (Fanneløp and Sjøen, 1980). The authors developed the governing equations for a bubble plume in stagnant and homogeneous water, and solved them in a non dimensional form. The results were presented as tables of the non dimensional plume rise velocity and diameter, W and B as a function of the non dimensional plume height X. The non dimensional plume variables where defined as

$$\mathrm{X} = z/H,\ \mathrm{B} = b/2\alpha H,\ \mathrm{W} = w/\mathrm{M}\,,$$

where $M = \left[\dfrac{\phi_0(1+\lambda^2)}{2\alpha^2 H}\right]^{1/3}$, $H = D + H_0$ and $\phi_0 = g V_0/\pi$.

Here, D is the discharge depth and V_0 is the volume flow of gas at the discharge point.

The solution contains two empirical constant, the entrainment coefficient α and the profile parameter λ, the latter defining the ratio between the length scale of the buoyancy profile and the velocity profile. These parameters were determined from gas plume experiments conducted by Fanneløp and Sjøen in a 5 meter deep basin. The experiments indicated that the entrainment coefficient was depending on the gas flow rate. By including experimental results from other sources, they concluded that for small gas flow rates, the values were in the range $\alpha \approx 0.07$ - 0-08, and for larger flow rates the value approaches $\alpha \approx 0.1$ or larger (> 10 L/s at standard conditions). The profile parameter was estimated to $\lambda = 0.65$. The values for large gas flow rates have been confirmed by recent research, but smaller values have been found for the entrainment coefficient in small scale tests (Seol et al. 2007).

Fanneløp's general solution for subsea bubble plumes was developed for homogeneous water with no cross flow. For such conditions, the model has been verified against experiments. However, Socolofsky and Adams (2002) identified two factors that could change the plume behaviour in stratified waters with crossflow; the first is the possible separation of bubbles from an inclined plume, and the second is the possible trapping of the plume due to a stable stratification (the plume reaches a level of neutral buoyancy). They proposed expressions for the separation height h_S and the trapping height h_T based on experimental studies:

$$h_S = 5.1 F_B / \left(u\, u_S^{2.4}\right)^{0.88} \text{ and } h_T = 2.8\left(F_B / N^3\right)^{1/4}$$

Here, u is the strength of the cross flow and u_S is the rise velocity of gas bubbles, $F_B = V_0\, g(\rho - \rho_G)/\rho$ is the buoyancy flux, and $N = \left[-\left(g/\rho\right)\left(\partial\rho/\partial z\right)\right]^{1/2}$ is the Brunt-Vaisälä buoyancy frequency. The density of sea water, ρ is in general much larger than the density of the gas ρ_G.

These equations may be used as a check of the possible influence of cross flow and stratification: If the smallest of the resulting heights are larger than the release depth, the plume is likely to be under no influence of the crossflow or stratification. However, since both the strength of the cross flow and the stratification will vary with depth in real cases, practical application of this criterion is not obvious. As a demonstration, we have used Socolofsky's equation for the separation height to estimate the lower limit of the gas flow rate as a function of discharge depth (Figure B.7). The curves for 25 and 50 cm/s current speed show the gas flow rate that will give a separation height equal to the discharge depth. Smaller rates may cause separation of gas bubbles during plume rise, causing a change in the plume behaviour (eventually complete loss of buoyancy).

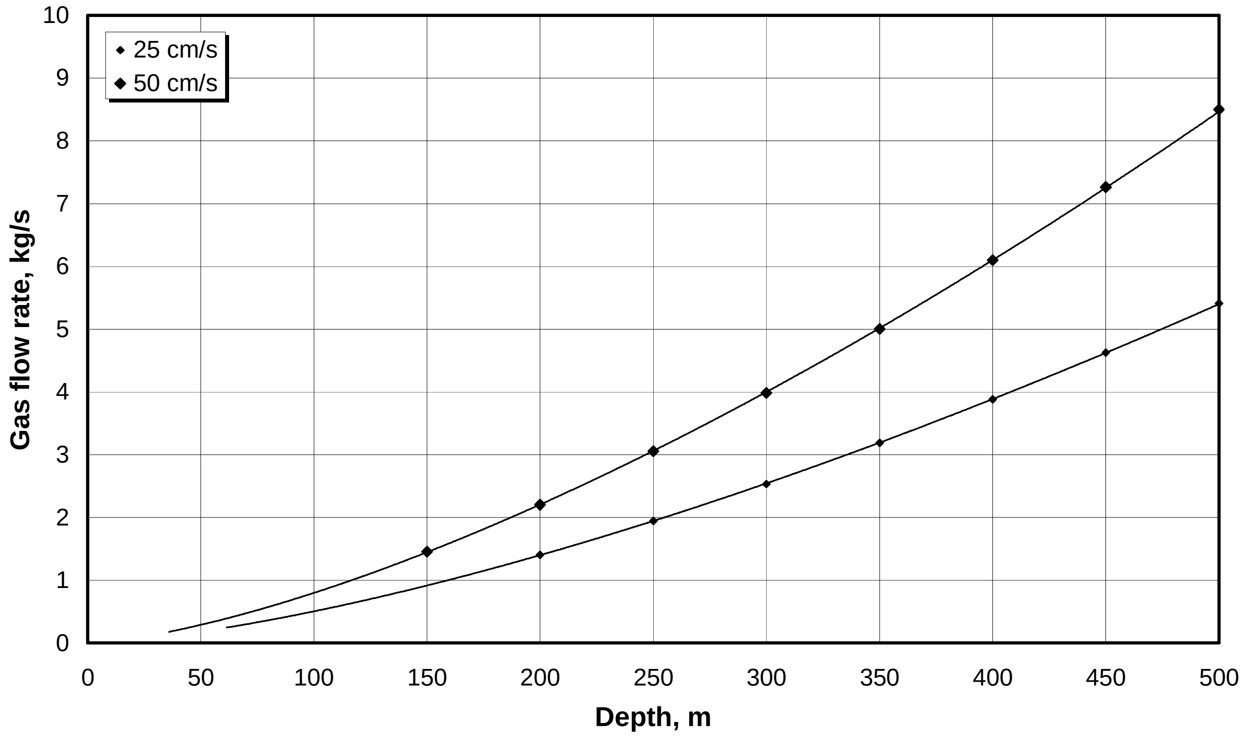


Figure B.7 Limiting gas flow rate as a function of discharge depth. The values are computed by use of Socolofsky's separation height formula.

The results in Figure B.7 show that with gas leak rates larger than 10 kg/s, the bubble plume can be expected to rise to the surface even from 500 m depth without separation of gas bubbles in cross flows up to 50 cm/s. It should be noted that in pipeline ruptures, gas leak rates can be one or more magnitudes above this limit. Moreover, due to gas expansion, the buoyancy flux generated by a pipeline rupture at the sea bed will increase as the plume approaches the surface. The present calculations, based on the buoyancy flux at the discharge level are thus on the conservative side.

A similar presentation might be made for the trapping height, but the equation for the trapping height presumes a constant density gradient. In reality, mainly the surface layers in the ocean tend to show any clear stratification (50 meter and shallower), while sea temperature and salinity gradients normally will be small (and negligible) near the sea bed. This, and the strong gain in buoyancy flux due to gas expansion as the plume rises to the surface, makes it very unlikely that a gas bubble plume from a major sub sea pipeline rupture will be trapped before it reaches the sea surface.

6 References

Bettelini, M.S.G. and T.K. Fanneløp, 1993: Underwater plume from an instantaneously started source. Applied Ocean Research, Vol. 15, pp. 195-206.

Fanneløp, T.K, and K. Sjøen, 1980: Hydrodynamics of underwater blowouts. *Norwegian Maritime Research*, No. 4, 1980, pp. 17-33.

Fanneløp, T.K., 1994: *Fluid Mechanics for Industrial Safety and Environmental Protection*, Industrial Safety Series, Vol. 3, Elsevier Amsterdam, pp. 296-305.

Johansen, Ø, 2000: DeepBlow – a Lagrangian Plume Model for Deep Water Blowouts. *Spill Science & Technology Bulletin,* Vol. 6, pp. 103-111.

Milgram, J.H. and J.J. Burgess, 1984: Mearsurements of the surface flow above round bubble plumes. *Applied Ocean Research*, Vol. 6, pp. 40-44.

Seol, D-G., T. Bhaumik, C. Bergman and S.A. Socolofsky, 2007: Particle Image Velocimetry measurments of the Mean Flow Charactersistics in a Bubble Plume. Journal of Engineering Mechanics, Vol. 133, pp. 665-676.

Appendix C: Summary of OCD/5 Source Code Modifications

1 Source Code and Compiler

The fortran source code provided with the OCD/5 download from the following US EPA web site (http://www.epa.gov/scram001/dispersion_prefrec.htm) was used as a starting point for the code modifications.

The G95 Fortran compiler available from http://www.g95.org was used to recompile the fortran code for the main simulation module OCD.for.

The following compile options were used to successfully compile the code:

G95 –freal-loops -fsloppy-char -ftrace=full ocd.for

2 Code Modifications

The modified OCD.for code has been delivered on CD with the final digital report copies. Modifications to the code have been identified by inserting “SL Ross” in the fortran code comments prior to the code modifications.

The primary changes made to the code include:

1. Removal of the requirement that the emissions.dat date stamp match that of the LMET and WMET meteorological datasets. The software as delivered now requires that the number of hourly emissions lines present in the emissions.dat file is at least as large as the Length of the Run (number of averaging periods) entered in the Run Information Dialog of OCD/5. (Lines 2250 to 2256 and 2748 to 2753 commented out in OCD.for)
2. Modification of the software so the Starting Day and Hour of the run no longer have to be hour 1. This was an apparent ‘bug’ in the original software. Any starting day and hour can be selected in the current compile so long as the length of the run does not extend past the end of a given day. In other words, if a simulation has a 4-hour run length then the starting hour must be less than 20. (Lines 507& 508 in OCD.for)

3. Modified the code so the output concentration is in mg/m^3 rather than μg/m^3 and output is generated only until concentrations reach 1 mg/m^3. This was implemented because natural gas concentrations below 35000 mg/m^3 (Lower Explosive Limit for natural gas) are not hazardous and there is no need to track

extremely low concentrations in this application. (Lines 1774, 1775 & 1789 in OCD.for)

4. Modified the code so the year data in the LMET.dat file can be entered in either 2-digit or Y2K compliant format. The LMET files generated using PCRAMMET and those pre-developed for the Gulf of Mexico Region can be used without modification with this change (Lines 5598 to 5611 in OCD.for)
5. Addition of a system call to GNUPLOT to plot the simulation results at the end of an OCD/5 modeling Run. Added subroutine 'rungnuplot' and a call to the subroutine to plot the data present in the secondary output summary file ('extra.out') generated by OCD/5. (Lines 9313 to 9363 lines 582 to 584 in OCD.for)

The instance of GNUPLOT called within OCD/5 uses the 'emiss.gpl' script file reproduced below to generate the plot. Modifications to the plot can be made by modifying this script. The script can also be called using the 'replot filename' command to plot any simulation results that have been previously run and archived.

'emiss.gpl" script file

```
set autoscale
unset log
unset label
set style line 1 linetype rgb "red" lw 2
set style line 2 linetype rgb "yellow" lw 1
set style line 3 linetype rgb "blue" lw 2
set style line 4 linetype rgb "violet" lw 2
set style line 5 linetype rgb "cyan" lw 2
set xtic 0.5
set ytic auto
set ztic auto
set xzeroaxis linetype 3 linewidth 2.5
set yzeroaxis linetype 4 linewidth 2.5
set zzeroaxis linetype 5 linewidth 2.5
set title "Left Click on Graph - Hold Click and Drag Mouse to Change Graph
        View"
set xlabel "Down Wind Distance X(km)"
set ylabel "Cross Wind Distance Y(km)"
set zlabel "Gas Conc. (mg/m3)"
set view 80,17,1,1
splot "extra.out" using 5:6:23 with lines 2,"nglel.dat" using 1:2:3 w l 1
set label 1 'Lower Explosive Limit for Natural Gas' at 2,0,40000 tc rgb "red"
set label 2 'Sea Level Gas Concentrations' at 0,0,-5000 tc rgb "green"
pause -1
```

Appendix D: Guide for Preparation of LMET and WMET Data Files for OCD/5

LMET and WMET data files are available for the Gulf of Mexico Region (Douglas, 2008) for five years (2000 to 2004). Sample files for use in this project were acquired from the MMS contact provided below.

Holli Ensz, Physical Scientist
Minerals Management Service
Office of Leasing and Environment
1201 Elmwood Park Blvd.
New Orleans, LA 70123
504-736-2536

Data files for other regions can be developed using the procedures identified below.

1 Overland Meteorology Files – LMET

The overland meteorology (LMET) data sets required by OCD/5 are generated from two data sources using the PCRAMMET.exe program. Hourly overland wind and twice daily mixing height data files are used by the program. These files are available through the EPA's SCRAM database located at http://www.epa.gov/scram001/surfacemetdata.htm.

Data files containing the mixing height data available from EPA's archive have been included with the deliverables for this project. The names of these files are:

- Camix.zip (California)
- Akmix.zip (Alaska)
- Ormix.zip (Oregon)
- Txmix.zip (Texas)
- Wamix.zip (Washington)

These files contain yearly data sets of mixing height data, for one or more locations within the region, for the years from 1984 to 1992.

Only one mixing height station is available for California. The station number is 23230 with a latitude of 37.75, longitude of 122.2 and a time zone designation of 8. A full list of the mixing height stations in the United States is provided in Table D1.

Data files containing the hourly overland wind data available from EPA's archive for the state of California have been included with the deliverables for this project. The names of these files are:

- Ca23161.zip
- Ca23174.zip
- Ca23188.zip
- Ca23190.zip
- Ca23232.zip

- Ca24216.zip
- Ca24257.zip
- Ca24283.zip
- Ca93193.zip

A complete list of the over-land surface meteorological stations in the United States is available on the EPA web site and is reproduced here as Table D2. The positions of the California sites can be found in Table D2. The most logical choice for most pipeline release modeling in California will be station 23174.

The 1991 data for station 23174 (Los Angeles International Airport) with latitude of 33.933, longitude of 118.383 and a time zone designation of 8 has been used in the example data sets generated for this project.

The PCRAMMET.exe program is executed from a Command Prompt window to generate the final LMET data file used by OCD/5. When the program is run it prompts the user for various input information. Respond with the following inputs:

- Wet or Dry deposition calculations? - None
- Output filename? - LMET????.DAT (user specified output name)
- Output File type? - ASCII
- Mixing Height Data File Name? – 23230-89.txt (for California region in 1989 from camix.zip)
- Hourly Surface Data File Name? – 23174-89.DAT (1989 hourly wind data)
- Surface data format? – SCRAM
- Latitude? – 33.933 (data for station 23174)
- Longitude? – 118.383 (data for station 23174)
- Time zone? – 8 (data for station 23174)

The program generates a data file compatible with the OCD/5 dispersion model.

2 Over-water Meteorology Files – WMET

The over-water meteorology (WMET) data sets required by OCD/5 are generated from data collected at offshore buoys. These files are available through NOAA's National Data Buoy Center database located at http://www.ndbc.noaa.gov/. Historical data can be downloaded from this site for specific offshore buoys located in the region of interest. The web site presents a worldwide map of available offshore buoys. The user zooms into the region of interest and selects a buoy to see the general description of the buoy. Details regarding the buoy's temperature and wind sensor heights that are required by OCD/5 can be obtained by accessing the 'View Details' option provided in the pop-up for the buoy. Selecting the 'View History' option accesses the actual buoy data. This presents the user with a number of data options. The option appropriate for the WMET file creation is 'Historical data – Standard meteorological data'. The user selects the year of historical data of interest and the data can be downloaded directly as a text file and then saved by the user. It is best to rename the data file to one with a maximum eight-character filename and 3-character extension (txt) as the OCD/5 data input can only handle filenames with the old DOS naming limitations. This text file requires additional modification prior to use in OCD/5. A program called Buoymet.exe has been developed as part of this project to add over-water mixing zone height information to the data set and to convert temperature data to Kelvin units (as required by OCD/5). The program is executed in a Command Prompt window by typing "Buoymet infilename outfilename 500" at the system command prompt. The buoymet.exe file and the buoy data text file (infilename) must be in the same directory or folder for this program to function. The infilename is the name of the offshore buoy text data file downloaded from NOAA's web site (renamed to DOS file name convention). The outfilename (again use DOS filename convention) is the WMET file name to be used in OCD/5. The '500' is a default mixing zone height, in meters, used for over-water dispersion modeling.

Table D1 SCRAM MIXING HEIGHT STATIONS

Station #	Station Name	State	Lat	Lon	Zone
26409	ANCHORAGE	AK	61.217	149.833	9
26617	NOME/MUNICIPAL ARPT	AK	64.500	165.433	9
26411	FAIRBANKS/INT'L ARPT	AK	64.817	147.867	9
27502	BARROW/W POST-W ROGERS ARPT	AK	71.300	156.783	9
03952	NORTH LITTLE ROCK	AR	34.833	92.250	6
13963	LITTLE ROCK/ADAMS FIELD	AR	34.733	92.233	6
23160	TUCSON/INT'L ARPT	AZ	32.133	110.933	7
23230	OAKLAND/WSO AP	CA	37.750	122.200	8
23066	GRAND JUNCTION/WALKER FIELD	CO	39.117	108.533	7
23062	DENVER/STAPLETON INT'L ARPT	CO	39.767	104.867	7
12844	WEST PALM BEACH/INT'L ARPT	FL	26.683	80.117	5
12842	TAMPA/INT'L ARPT	FL	27.967	82.533	5
12832	APALACHICOLA/MUNICIPAL ARPT	FL	29.733	85.033	5
13861	WAYCROSS/WSMO	GA	31.250	82.400	5
13873	ATHENS/MUNICIPAL ARPT	GA	33.950	83.317	5
21504	HILO/GENERAL LYMAN FIELD	HI	19.717	155.067	10
22536	LIHUE/ARPT	HI	21.983	159.350	10
24131	BOISE/AIR TERMINAL	ID	43.567	116.217	7
03879	SALEM	IL	38.633	88.950	6
14842	PEORIA/GREATER PEORIA ARPT	IL	40.667	89.683	6
13985	DODGE CITY/MUNICIPAL ARPT	KS	37.767	99.967	6
13996	TOPEKA/MUNICIPAL ARPT	KS	39.067	95.633	6
03816	PADUCAH/WSO AIRPORT	KY	37.067	88.767	6
12884	BOOTHVILLE/WSCMO CITY	LA	29.333	89.400	6
03937	LAKE CHARLES/MUNICIPAL ARPT	LA	30.117	93.217	6
53813	Slidell	LA	30.333	89.820	6

14684	CHATHAM/WSMO	MA	41.667	69.950	5
14764	PORTLAND/INT'L JETPORT	ME	43.650	70.317	5
14607	CARIBOU/MUNICIPAL ARPT	ME	46.867	68.017	5
14826	FLINT/BISHOP ARPT	MI	42.967	83.750	5
14847	SAULT STE MARIE/NWSO	MI	46.467	84.350	5
14926	ST CLOUD/MUNICIPAL ARPT	MN	45.550	94.067	6
14918	International Falls/INT'L ARP	MN	48.567	93.383	6
03946	MONETT/WSMO	MO	36.883	93.900	6
03940	JACKSON/THOMPSON FIELD	MS	32.317	90.083	6
24143	GREAT FALLS/INT'L ARPT	MT	47.483	111.367	7
94008	GLASGOW/INT'L ARPT	MT	48.217	106.617	7
93729	CAPE HATTERAS/WSO	NC	35.267	75.550	5
13723	GREENSBORO,HIGH POINT /WINSTO	NC	36.083	79.950	5
24011	BISMARCK/MUNICIPAL ARPT	ND	46.767	100.750	6
24023	NORTH PLATTE/LEE BIRD FLD	NE	41.133	100.683	6
94918	NORTH OMAHA/NWSFO ARPT	NE	41.367	96.017	6
93755	ATLANTIC CITY	NJ	39.750	74.667	5
23050	ALBUQUERQUE/INT'L ARPT	NM	35.050	106.617	7
03160	DESERT ROCK	NV	36.617	116.017	8
24128	WINNEMUCCA/WSO AIRPORT	NV	40.900	117.800	8
14735	ALBANY/COUNTY ARPT	NY	42.750	73.800	5
14733	BUFFALO/GREATER BUFFALO INT'L	NY	42.933	78.733	5
13840	WRIGHT PATTERSON/AFB	OH	39.817	84.050	5
03948	NORMAN	OK	35.233	97.467	6
13967	OKLAHOMA CITY/WILL ROGERS WOR	OK	35.400	97.600	6
24225	MEDFORD/JACKSON COUNTY ARPT	OR	42.383	122.883	8
24232	SALEM/MCNARY FIELD	OR	44.917	123.000	8
94823	PITTSBURGH/WSCOM 2 AIRPORT	PA	40.500	80.217	5
11641	SAN JUAN/ISLA VERDE INT'L ARP	PR	18.433	66.000	4
13880	CHARLESTON/INT'L ARPT	SC	32.900	80.033	5
14936	HURON/REGIONAL ARPT	SD	44.383	98.217	6
24090	Rapid City	SD	44.050	103.066	6
13897	NASHVILLE/METRO ARPT	TN	36.117	86.683	6
12919	BROWNSVILLE/INT'L ARPT	TX	25.900	97.433	6
12924	CORPUS CHRISTI/INT'L ARPT	TX	27.767	97.500	6
12912	VICTORIA/WSO AIRPORT	TX	28.850	96.917	6
22010	DEL RIO/INT'L ARPT	TX	29.367	100.917	6
23044	EL PASO/INT'L ARPT	TX	31.800	106.400	7
23023	MIDLAND/REGIONAL AIR TERMINAL	TX	31.950	102.183	6
13901	STEPHENVILLE/WSMO	TX	32.217	98.183	6
03951	LONGVIEW/WSMO	TX	32.350	94.650	6

23047	AMARILLO/INT'L ARPT	TX	35.233	101.700	6
24127	SALT LAKE CITY/INT'L ARPT	UT	40.783	111.950	7
93739	WALLOPS ISLAND	VA	37.850	75.483	5
93734	STERLING	VA	38.983	77.467	5
24157	SPOKANE/INT'L ARPT	WA	47.633	117.533	8
94240	QUILLAYUTE/WSO AIRPORT	WA	47.950	124.550	8
14898	GREEN BAY/AUSTIN STRAUBEL FIE	WI	44.483	88.133	6
03860	HUNTINGTON/TRI-STATE ARPT	WV	38.367	82.550	5
24021	LANDER/HUNT FIELD	WY	42.817	108.733	7

Table D2 SCRAM SURFACE DATA STATIONS

Station #	Station Name	State	Lat	Lon	Zone
25624	COLD BAY/ARPT	AK	55.200	162.717	9
25501	KODIAK/U S C G BASE	AK	57.750	152.500	9
25309	JUNEAU/INT'L ARPT	AK	58.367	134.583	9
25503	KING SALMON/ARPT	AK	58.683	156.650	9
25339	YAKUTAT/STATE ARPT	AK	59.517	139.667	9
25507	HOMER/ARPT	AK	59.633	151.500	9
26615	BETHEL/WSO AIRPORT	AK	60.783	161.800	9
26442	VALDEZ/WSO	AK	61.133	146.350	9
26451	ANCHORAGE/WSMO AIRPORT	AK	61.167	150.017	9
26409	ANCHORAGE	AK	61.217	149.833	9
26510	MC GRATH/ARPT	AK	62.967	155.617	9
26617	NOME/MUNICIPAL ARPT	AK	64.500	165.433	9
26411	FAIRBANKS/INT'L ARPT	AK	64.817	147.867	9
26616	KOTZEBUE/RALPH WEIN MEMORIAL	AK	66.867	162.633	9
26533	BETTLES/BETTLES FIELD	AK	66.917	151.517	9
27401	BARTER ISLAND/WSO AIRPORT	AK	70.133	143.633	9
27502	BARROW/W POST-W ROGERS ARPT	AK	71.300	156.783	9
13894	MOBILE/WSO AIRPORT	AL	30.683	88.250	6
13895	MONTGOMERY/WSO ARPT	AL	32.300	86.400	6
03881	CENTERVILLE/WSMO	AL	32.900	87.250	6
13876	BIRMINGHAM/MUNICIPAL ARPT	AL	33.567	86.750	6
03856	HUNTSVILLE/MADISON COUNTY JET	AL	34.650	86.767	6
13963	LITTLE ROCK/ADAMS FIELD	AR	34.733	92.233	6
13964	FORT SMITH/MUNICIPAL ARPT	AR	35.333	94.367	6
23160	TUCSON/INT'L ARPT	AZ	32.133	110.933	7
23183	PHOENIX/SKY HARBOR INT'L ARPT	AZ	33.433	112.017	7
23184	PRESCOTT/MUNICIPAL	AZ	34.650	112.433	7
23188	SAN DIEGO/LINDBERGH FIELD	CA	32.733	117.167	8
23174	**LOS ANGELES/INT'L ARPT**	**CA**	**33.933**	**118.383**	**8**
23190	SANTA BARBARA/FAA AIRPORT	CA	34.433	119.833	8
23161	DAGGETT/FAA AIRPORT	CA	34.867	116.783	8
93193	FRESNO/AIR TERMINAL	CA	36.767	119.717	8
23234	SAN FRANCISCO/INT'L ARPT	CA	37.617	122.383	8
23232	SACRAMENTO/EXECUTIVE ARPT	CA	38.517	121.500	8
24216	RED BLUFF/MUNICIPAL ARPT	CA	40.150	122.250	8
24257	REDDING/AAF	CA	40.500	122.300	8
24283	ARCATA/ARPT	CA	40.983	124.100	8
93037	COLORADO SPRINGS/MUNICIPAL AR	CO	38.817	104.717	7
23066	GRAND JUNCTION/WALKER FIELD	CO	39.117	108.533	7
23062	DENVER/STAPLETON INT'L ARPT	CO	39.767	104.867	7
93010	Limon	CO	39.266	103.700	7
14740	HARTFORD/BRADLEY INT'L ARPT	CT	41.933	72.683	5
13781	WILMINGTON/GREATER WILMINGTON	DE	39.667	75.600	5
12836	KEY WEST/INT'L ARPT	FL	24.550	81.750	5
12839	MIAMI/INT'L ARPT	FL	25.800	80.300	5
12835	FORT MYERS/PAGE FIELD	FL	26.583	81.867	5
12844	WEST PALM BEACH/INT'L ARPT	FL	26.683	80.117	5
12843	VERO BEACH/MUNICIPAL AIRPORT	FL	27.650	80.417	5

12842	TAMPA/INT'L ARPT	FL	27.967	82.533	5
12815	ORLANDO/INT'L ARPT	FL	28.450	81.317	5
12834	DAYTONA BEACH/REGIONAL ARPT	FL	29.183	81.050	5
12816	GAINESVILLE/MUNICIPAL AIRPORT	FL	29.683	82.267	5
12832	APALACHICOLA/MUNICIPAL ARPT	FL	29.733	85.033	5
93805	TALLAHASSEE/MUNICIPAL ARPT	FL	30.383	84.367	5
13899	PENSACOLA/REGIONAL ARPT	FL	30.467	87.200	6
13889	JACKSONVILLE/INT'L ARPT	FL	30.500	81.700	5
13861	WAYCROSS/WSMO	GA	31.250	82.400	5
03822	SAVANNAH/MUNICIPAL ARPT	GA	32.133	81.200	5
93842	COLUMBUS/METROPOLITAN ARPT	GA	32.517	84.950	5
03813	MACON/LEWIS B WILSON ARPT	GA	32.700	83.650	5
03820	AUGUSTA/BUSH FIELD	GA	33.367	81.967	5
13874	ATLANTA/ATLNA-HARTSFIELD INT'	GA	33.650	84.433	5
13873	ATHENS/MUNICIPAL ARPT	GA	33.950	83.317	5
21504	HILO/GENERAL LYMAN FIELD	HI	19.717	155.067	10
22521	HONOLULU/INT'L ARPT	HI	21.333	157.917	10
22536	LIHUE/ARPT	HI	21.983	159.350	10
14933	DES MOINES/INT'L ARPT	IA	41.533	93.650	6
14943	SIOUX CITY/MUNICIPAL ARPT	IA	42.400	96.383	6
94910	WATERLOO/MUNICIPAL ARPT	IA	42.550	92.400	6
14940	MASON CITY/FAA AIRPORT	IA	43.150	93.333	6
24156	POCATELLO/MUNICIPAL ARPT	ID	42.917	112.600	7
24131	BOISE/AIR TERMINAL	ID	43.567	116.217	7
93822	SPRINGFIELD/CAPITAL ARPT	IL	39.850	89.683	6
14842	PEORIA/GREATER PEORIA ARPT	IL	40.667	89.683	6
14923	MOLINE/QUAD-CITY ARPT	IL	41.450	90.500	6
94846	CHICAGO/O'HARE INT'L ARPT	IL	41.983	87.900	6
94822	ROCKFORD/GREATER ROCKFORD ARP	IL	42.200	89.100	6
93817	EVANSVILLE/DRESS REGIONAL ARP	IN	38.050	87.533	6
93819	INDIANAPOLIS/INT'L ARPT	IN	39.733	86.267	5
14827	FORT WAYNE/BAER FIELD	IN	41.000	85.200	5
14848	SOUTH BEND/MICHIANA REGIONAL	IN	41.700	86.317	5
03928	WICHITA/MID-CONTINENT ARPT	KS	37.650	97.433	6
13985	DODGE CITY/MUNICIPAL ARPT	KS	37.767	99.967	6
93997	RUSSELL/FAA AIRPORT	KS	38.867	98.817	6
13996	TOPEKA/MUNICIPAL ARPT	KS	39.067	95.633	6
23065	GOODLAND/RENNER FIELD	KS	39.367	101.700	7
13984	CONCORDIA/BLOSSER MUNICIPAL A	KS	39.550	97.650	6
03816	PADUCAH/WSO AIRPORT	KY	37.067	88.767	6
03889	JACKSON/JULIAN CARROLL ARPT	KY	37.600	83.317	5
93820	LEXINGTON/BLUEGRASS FIELD	KY	38.033	84.600	5
93821	LOUISVILLE/STANDIFORD FIELD	KY	38.183	85.733	5
93814	COVINGTON/GREATER CINCINNATI	KY	39.050	84.667	5
12916	NEW ORLEANS/INT'L ARPT	LA	29.983	90.250	6
03937	LAKE CHARLES/MUNICIPAL ARPT	LA	30.117	93.217	6
13970	BATON ROUGE/RYAN ARPT	LA	30.533	91.133	6
13957	SHREVEPORT/REGIONAL ARPT	LA	32.467	93.817	6
14739	BOSTON/LOGAN INT'L ARPT	MA	42.367	71.033	5
93721	BALTIMORE/BLT-WASHNGTN INT'L	MD	39.183	76.667	5

14764	PORTLAND/INT'L JETPORT	ME	43.650	70.317	5
14606	BANGOR/FAA AIRPORT	ME	44.800	68.817	5
94847	DETROIT/METROPOLITAN ARPT	MI	42.233	83.333	5
14822	DETROIT/CITY AIRPORT	MI	42.417	83.017	5
14836	LANSING/CAPITAL CITY ARPT	MI	42.767	84.600	5
94860	GRAND RAPIDS/KENT CO INT'L AR	MI	42.883	85.517	5
14826	FLINT/BISHOP ARPT	MI	42.967	83.750	5
14840	MUSKEGON/COUNTY ARPT	MI	43.167	86.233	5
14850	TRAVERSE CITY/FAA AIRPORT	MI	44.733	85.583	5
94849	ALPENA/PHELPS COLLINS AP	MI	45.067	83.567	5
14847	SAULT STE MARIE/NWSO	MI	46.467	84.350	5
14925	ROCHESTER/MUNICIPAL ARPT	MN	43.917	92.500	6
14922	MINNEAPOLIS-ST PAUL/INT'L ARP	MN	44.883	93.217	6
14913	DULUTH/INT'L ARPT	MN	46.833	92.183	6
14918	INTERNATIONAL FALLS/INT'L ARP	MN	48.567	93.383	6
13995	SPRINGFIELD/REGIONAL ARPT	MO	37.233	93.383	6
03966	ST LOUIS/SPIRIT OF ST LOUIS	MO	38.650	90.633	6
13994	ST LOUIS/LAMBERT INT'L ARPT	MO	38.750	90.367	6
03945	COLUMBIA/REGIONAL ARPT	MO	38.817	92.217	6
13988	KANSAS CITY/FAA AIRPORT	MO	39.117	94.600	6
03947	KANSAS CITY/INT'L ARPT	MO	39.317	94.717	6
03940	JACKSON/THOMPSON FIELD	MS	32.317	90.083	6
13865	MERIDIAN/KEY FIELD	MS	32.333	88.750	6
93862	TUPELO	MS	34.250	88.717	6
24033	BILLINGS/LOGAN INT'L ARPT	MT	45.800	108.533	7
24037	MILES CITY/MUNICIPAL ARPT	MT	46.433	105.867	7
24144	HELENA/ARPT	MT	46.600	112.000	7
24153	MISSOULA/JOHNSON-BELL FLD	MT	46.917	114.083	7
24036	LEWISTOWN/FAA ARPT	MT	47.067	109.450	7
24143	GREAT FALLS/INT'L ARPT	MT	47.483	111.367	7
94008	GLASGOW/INT'L ARPT	MT	48.217	106.617	7
24146	KALISPELL/GLACIER PK INT'L AP	MT	48.300	114.267	7
13748	WILMINGTON/NEW HANOVER COUNTY	NC	34.267	77.900	5
13881	CHARLOTTE/DOUGLAS INT'L ARPT	NC	35.217	80.933	5
93729	CAPE HATTERAS/WSO	NC	35.267	75.550	5
03812	ASHEVILLE/REGIONAL ARPT	NC	35.433	82.550	5
13722	RALEIGH/RALEIGH-DURHAM ARPT	NC	35.867	78.783	5
13723	GREENSBORO,HIGH POINT /WINSTO	NC	36.083	79.950	5
24011	BISMARCK/MUNICIPAL ARPT	ND	46.767	100.750	6
14914	FARGO/HECTOR FIELD	ND	46.900	96.800	6
94014	WILLISTON/SLOULIN INT'L ARPT	ND	48.183	103.633	6
24013	MINOT/FAA AIRPORT	ND	48.267	101.283	6
14939	LINCOLN/MUNICIPAL ARPT	NE	40.850	96.750	6
14935	GRAND ISLAND/ARPT	NE	40.967	98.317	6
24023	NORTH PLATTE/LEE BIRD FLD	NE	41.133	100.683	6
14942	OMAHA/EPPLEY AIRFIELD	NE	41.300	95.900	6
94918	NORTH OMAHA/NWSFO ARPT	NE	41.367	96.017	6
24028	SCOTTSBLUFF/COUNTY AIRPORT	NE	41.867	103.600	7
14941	NORFOLK/KARL STEFAN MEM ARPT	NE	41.983	97.433	6
14745	CONCORD/MUNICIPAL ARPT	NH	43.200	71.500	5

93730	ATLANTIC CITY/AIRPORT NAFEC	NJ	39.450	74.567	5
14734	NEWARK/INT'L ARPT	NJ	40.700	74.167	5
23009	ROSWELL/INDUSTRIAL AIR PARK	NM	33.300	104.533	7
23050	ALBUQUERQUE/INT'L ARPT	NM	35.050	106.617	7
23081	GALLUP/FAA AIRPORT	NM	35.517	108.783	7
23169	LAS VEGAS/MCCARRAN INT'L ARPT	NV	36.083	115.167	8
03160	DESERT ROCK	NV	36.617	116.017	8
23154	ELY/YELLAND FIELD	NV	39.283	114.850	8
23185	RENO/CANNON INT'L ARPT	NV	39.500	119.783	8
24121	ELKO/MUNICIPAL ARPT	NV	40.833	115.783	8
24128	WINNEMUCCA/WSO AIRPORT	NV	40.900	117.800	8
24172	LOVELOCK/DERBY	NV	40.066	118.550	8
23153	TONOPAH	NV	38.066	117.133	8
94789	NEW YORK/J F KENNEDY INT'L AR	NY	40.650	73.783	5
14732	NEW YORK/LAGUARDIA ARPT	NY	40.767	73.900	5
04781	ISLIP	NY	40.783	73.100	5
04725	BINGHAMTON/EDWIN A LINK FIELD	NY	42.217	75.983	5
14735	ALBANY/COUNTY ARPT	NY	42.750	73.800	5
14733	BUFFALO/GREATER BUFFALO INT'L	NY	42.933	78.733	5
14771	SYRACUSE/HANCOCK INT'L ARPT	NY	43.117	76.117	5
14768	ROCHESTER/ROCHESTER-MONROE CO	NY	43.117	77.667	5
94725	MASSENA/FAA AIRPORT	NY	44.933	74.850	5
93815	DAYTON/INT'L ARPT	OH	39.900	84.200	5
14821	COLUMBUS/PORT COLUMBUS INT'L	OH	40.000	82.883	5
14895	AKRON/AKRON-CANTON REGIONAL	OH	40.917	81.433	5
14852	YOUNGSTOWN/MUNICIPAL ARPT	OH	41.250	80.667	5
14820	CLEVELAND/HOPKINS INT'L ARPT	OH	41.417	81.867	5
94830	TOLEDO/EXPRESS ARPT	OH	41.600	83.800	5
13967	OKLAHOMA CITY/WILL ROGERS WOR	OK	35.400	97.600	6
13968	TULSA/INT'L ARPT	OK	36.200	95.900	6
24225	MEDFORD/JACKSON COUNTY ARPT	OR	42.383	122.883	8
24284	NORTH BEND/FAA AIRPORT	OR	43.417	124.250	8
24221	EUGENE/MAHLON SWEET ARPT	OR	44.117	123.217	8
24230	REDMOND/FAA AIRPORT	OR	44.267	121.150	8
24232	SALEM/MCNARY FIELD	OR	44.917	123.000	8
24229	PORTLAND/INT'L ARPT	OR	45.600	122.600	8
24155	PENDLETON/MUNICIPAL ARPT	OR	45.683	118.850	8
94224	ASTORIA/CLATSOP COUNTY ARPT	OR	46.150	123.883	8
13739	PHILADELPHIA/INT'L ARPT	PA	39.883	75.250	5
14751	HARRISBURG/CAPITAL CITY ARPT	PA	40.217	76.850	5
94823	PITTSBURGH/WSCOM 2 AIRPORT	PA	40.500	80.217	5
14737	ALLENTOWN/BETLEHEM-EASTON ARP	PA	40.650	75.433	5
14778	WILLIAMSPORT-LYCOMING /COUNTY	PA	41.250	76.917	5
14777	WILKES-BARRE/WB-SCRANTON WSO	PA	41.333	75.733	5
04751	BRADFORD/FAA AIRPORT	PA	41.800	78.633	5
14860	ERIE/INT'L ARPT	PA	42.083	80.183	5
14711	MIDDLETOWN/OLMSTEAD ST	PA	40.200	76.766	5
11641	SAN JUAN/ISLA VERDE INT'L ARP	PR	18.433	66.000	4
14765	PROVIDENCE/T F GREEN STATE AR	RI	41.733	71.433	5
13880	CHARLESTON/INT'L ARPT	SC	32.900	80.033	5
13883	COLUMBIA/METRO ARPT	SC	33.950	81.117	5

03870	GREER/GREENV'L-SPARTANBRG AP	SC	34.900	82.217	5
14944	SIOUX FALLS/FOSS FIELD	SD	43.567	96.733	6
24090	RAPID CITY/REGIONAL ARPT	SD	44.050	103.067	7
14936	HURON/REGIONAL ARPT	SD	44.383	98.217	6
24025	PIERRE/FAA AIRPORT	SD	44.383	100.283	6
13882	CHATTANOOGA/LOVELL FIELD	TN	35.033	85.200	5
13893	MEMPHIS/INT'L ARPT	TN	35.050	90.000	6
13891	KNOXVILLE/MC GHEE TYSON ARPT	TN	35.800	84.000	5
13897	NASHVILLE/METRO ARPT	TN	36.117	86.683	6
13877	BRISTOL/TRI CITY AIRPORT	TN	36.483	82.400	5
12919	BROWNSVILLE/INT'L ARPT	TX	25.900	97.433	6
12924	CORPUS CHRISTI/INT'L ARPT	TX	27.767	97.500	6
12912	VICTORIA/WSO AIRPORT	TX	28.850	96.917	6
12962	HONDO/WSMO AIRPORT	TX	29.350	99.167	6
12921	SAN ANTONIO/WSFO	TX	29.533	98.467	6
12917	PORT ARTHUR/JEFFERSON COUNTY	TX	29.950	94.017	6
12960	HOUSTON/INTERCONTINENTAL ARPT	TX	29.967	95.350	6
13958	AUSTIN/MUNICIPAL ARPT	TX	30.283	97.700	6
93987	LUFKIN/FAA AIRPORT	TX	31.233	94.750	6
23034	SAN ANGELO/WSO AIRPORT	TX	31.367	100.500	6
13959	WACO/MADISON-COOPER ARPT	TX	31.617	97.217	6
23044	EL PASO/INT'L ARPT	TX	31.800	106.400	7
23023	MIDLAND/REGIONAL AIR TERMINAL	TX	31.950	102.183	6
03969	STEPHENVILLE	TX	32.217	98.183	6
13962	ABILENE/MUNICIPAL ARPT	TX	32.417	99.683	6
03927	DALLAS/FORT WORTH/REGIONAL AR	TX	32.900	97.033	6
23042	LUBBOCK/REGIONAL ARPT	TX	33.650	101.817	6
13966	WICHITA FALLS/MUNICIPAL ARPT	TX	33.967	98.483	6
23047	AMARILLO/INT'L ARPT	TX	35.233	101.700	6
93129	CEDAR CITY/FAA AIRPORT	UT	37.700	113.100	7
24127	SALT LAKE CITY/INT'L ARPT	UT	40.783	111.950	7
13737	NORFOLK/INT'L ARPT	VA	36.900	76.200	5
13741	ROANOKE/WOODRUM ARPT	VA	37.317	79.967	5
13740	RICHMOND/R E BYRD INT'L ARPT	VA	37.500	77.333	5
13743	WASHINGTON DC/NATIONAL ARPT	VA	38.850	77.033	5
93738	WASHINGTON DC/DULLES INT'L AR	VA	38.950	77.450	5
14742	BURLINGTON/INT'L ARPT	VT	44.467	73.150	5
24243	YAKIMA/AIR TERMINAL	WA	46.567	120.533	8
24227	OLYMPIA/ARPT	WA	46.967	122.900	8
24233	SEATTLE/SEATTLE-TACOMA INT'L	WA	47.450	122.300	8
24157	SPOKANE/INT'L ARPT	WA	47.633	117.533	8
94240	QUILLAYUTE/WSO AIRPORT	WA	47.950	124.550	8
14839	MILWAUKEE/GENERAL MITCHELL FI	WI	42.950	87.900	6
14837	MADISON/DANE CO REGIONAL ARPT	WI	43.133	89.333	6
14920	LA CROSSE/MUNICIPAL ARPT	WI	43.867	91.250	6
14898	GREEN BAY/AUSTIN STRAUBEL FIE	WI	44.483	88.133	6
14991	EAU CLAIRE/FAA AIRPORT	WI	44.867	91.483	6
03872	BECKLEY/RALEIGH CO MEMORIAL A	WV	37.783	81.117	5
13866	CHARLESTON/KANAWHA ARPT	WV	38.367	81.600	5
03860	HUNTINGTON/TRI-STATE ARPT	WV	38.367	82.550	5
24018	CHEYENNE/MUNICIPAL ARPT	WY	41.150	104.817	7

24027	ROCK SPRINGS/FAA AIRPORT	WY	41.600	109.067	7
24021	LANDER/HUNT FIELD	WY	42.817	108.733	7
24089	CASPER/NATRONA CO INT'L ARPT	WY	42.917	106.467	7
24029	SHERIDAN/COUNTY ARPT	WY	44.767	106.967	7

Appendix E: Software Installation, Removal and Operating Instructions

1 Initial Software Installation

The CD delivered with the project contains three separate subdirectories with installation utilities that must be run in sequence to properly install the software. The OCD/5 installation routine has been established by other researchers and could not easily be modified for this project. This has resulted in the requirement for the multiple installation procedure. The installation procedure is as follows:

1) Run the Setup.exe file in subdirectory 1OCD5setup. You may need to be logged on as an administrator for this step.
   a) Follow the on-screen prompts for installation.
   b) To simplify the setup procedure and final operation of all software components it is recommended that the default drive and directory (C:\OCDMENU) be used in this installation. If a different drive must be used, the same drive must be used in the installations described in steps 2 and 3 below. Do not change the directory name.
2) Run the WCDgas_2-0_Setup.exe file in the subdirectory 2WCDgasSetup.
   a) Be sure to change the installation location to C:\OCDMENU or to the drive and directory specified in step 1. This is accomplished by using the "Browse" button and selecting the new installation location from the directory tree.
   b) Once the proper installation location has been selected the default menu items can be used in the remainder of this installation.
   c) If you receive an error in registering OCX files, record the files names and use the regsvr32 application to manually register the file: e.g.

   ```
   regsvr32 c:\windows\system32\mschrt20.ocx
   ```
3) Run the installSLRaddIns.exe file in the subdirectory 3slrAddInstall.
   a) Again, be sure that the installation drive specified matches the one used in step 1 above. The directory name used in this portion of the install should be "OCDDATA".
   b) Say yes to the "del Samples ?" prompt in the command window.

note to the installer- all users must have full control over the C:\ocddata directory and it's contents.

2 Software Removal

The following steps can be taken to remove the software from the computer, should this be required.

1) Run the "WCDgas_2-0_Setup.exe" file in the subdirectory 2WCDgasSetup and select the "remove software" option.
2) Run the "uninstall.exe" program located in the C:\OCDMENU (or the drive and directory chosen for the software installation in step 1). At the end of this uninstall a window will appear indicating that a number of files were added after the install and were not be automatically deleted. These files can be deleted to completely clean the installed components from the system.

3 Example Use of Software Components

The two programs WCDgas.exe and OCDMENU.exe are run individually from the default install directory (C:\OCDMENU or the menu specified in step 1 of the software installation). The programs can be run independently of each other. WCDgas is used to build the pipeline networks and model the behavior of the gas from sub sea leaks through the water column to the water surface. OCDMENU, the atmospheric dispersion model, uses the *.dat gas emissions file generated by WCDgas along with over-water and over-land meteorological data to predict the downwind concentrations of the gas being released at the surface. The following steps are provided as a guide to familiarize new users with the basic use of these two software programs using example data generated during the project.

1) Run the WCDgas program by double clicking on the program icon present in the installation directory (C:\OCDMENU).
2) Select the File->Open option and choose Pac36dpG.wcd from the OCDDATA directory. The *.wcd files contain the pipeline definitions generated for the project. Pac refers to Pacific Region (Gom – Gulf of Mexico), 36 refers to the pipeline diameter in inches, dp refers to a deep rupture location (sh – shallow) and G refers to a guillotine break (1 – 1 inch puncture).
3) Initiate the Scenario->Calculate All option to calculate both the sub sea pipeline discharge and the bubble plume rise.
4) Use the "Result-> Release or Nearfield Plot to review the gas behavior.
5) Use Window-> New Summary Window to get a text summary of some of the inputs and outputs of the recent simulation. This window provides an average gas boil zone diameter which can be used in subsequent air dispersion modeling.
6) The "Scenario->Calculate All" option also generates an output gas emissions summary file for use in OCD/5. For this scenario it is named Pac36dpG.dat. This is an ASCII text file that can be viewed in any text editor.
7) OCDMENU is run after WCDgas has been used to generate the water surface gas emissions summary file.
8) Run the OCD/5 program by double clicking on the OCDMENU.exe program icon present in the installation directory (C:\OCDMENU).
9) Click on the initial screen that shows a graphic of a plume and the MMS logo to initiate the main menu view.
10) Select the File-> Open option and select either Pacific.DAO or GOMEX.DAO. These files contain the study area definitions developed for the Pacific and Gulf of Mexico Regions, respectively.
11) The remaining discussion assumes that the Pacific Region has been selected.
12) Open the "Input-> Run Information dialog".
13) Note the year, Julian day and hour of the simulation setting. These can be changed to determine the effect of different meteorological conditions on the dispersion modeling outcome. For now leave them as they are set.
14) Note the "Length of Run" and the "length of Averaging Period". The length of Run must be no greater than the number of lines (or hours) of emissions data present in the emissions file generated by WCDgas in step 6. The Length of Averaging Period should always be set to 1 for this application.
15) Open the "Input->Sources" option and select the "Define Sources" option. Only one source can be defined at a time or the software generates an error. Use the default source location for now. If a different spill location is desired in the future, edit the XY locations as described in the main body of the report to change the release point. Exit this menu option without making any changes.

16) The “Significant Sources” dialog appears to get corrupted occasionally when using OCDMENU. The problem is fixed by un-checking and re-checking the “Specify Significant Sources” box, then clicking on the source name (Pacific) to set the “Number of Significant Sources to zero and finally clicking on the Source name again to set the number to 1. These steps are described here because experience has shown this to be a recurring “bug” with the OCD/5 software.
17) Open the “Run-Run OCD” option.
18) Enter “b4602391.dat” in the ASCII Overwater Met Data File box, “Lmet91.dat” in the ASCII Over land Met Data File box, “Pac36dpg.dat” in the Hourly Emission File box, “Pac36dpg.out” in the Output Listing File Name, and “Pac36dpg.txt” in the Secondary Output Summary File Name box.
19) “Run” the simulation using the button at the bottom of the dialog.
20) If the simulation is successful a graph of the results will appear. “Right click and hold” on the graph and move the mouse to get different views of the plume concentration plot. Once the plot is closed it can be regained either by re-Running the simulation in OCDMENU or by using the “replot filename” option from a command window. The filename used is Pac36dpg.txt (or the secondary output file name specified in the Run OCD dialog).
21) Once the data has been entered as described above a new simulation using Met data starting from a different hour or day of the year can be run by opening the “Input->Run Information” dialog and changing the starting Julian day or hour. Once the change has been made go back to the “Run-> Run OCD” option and re-run the simulation with the same Met input file names. Change the input files if Met data from a different year or location is of interest. The “number of significant sources” error often creeps into the picture after changing the starting day or hour of the simulation. Use the procedure described in step 16 to fix the problem if it is encountered.