

AERflare

A Model for Temporary Flaring Permits, Non-Routine Flaring and Routine Flaring Air Dispersion Modelling for Sour Gas Facilities

User Guide, AERflare Version 2.01

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User Guide, AERflare Version 2.01

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Alberta Energy Regulator (AER)

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Minimum System Requirements for *AERflare*

AERflare is a Windows® based software application requiring Microsoft® Excel as a user interface. The minimum system requirements* are:

- Windows®8; Windows®7
- Microsoft® Excel. (Office 2010, Office 2013)
- x64 or x86
- 1024x768 minimum resolution recommended
- 2 GHz processor minimum recommended
- 4 GB RAM minimum recommended
- Windows® - compatible mouse
- Optional: colour or b/w printer (300 dpi or better recommended)

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1. INTRODUCTION

AERflare, A Model for Temporary Flaring Permits, Non-Routine Flaring and Routine Flaring Air Dispersion Modelling for Sour Gas Facilities

The Alberta Energy Regulator (AER) has developed *AERflare* for evaluating non-routine and routine flaring for sour gas facilities. This User Guide is for the *AERflare* modelling spreadsheet and associated modules. The User Guide outlines how to install the files, use the model and provides examples on the use of the model.

The *AERflare* model was designed to perform state of the art source estimates for flares and perform screening level air dispersion modelling using state of the art techniques. The user must have a good understanding of the following documents:

1. AER Directive 060 (requirements for temporary flaring permits, non-routine and routine flaring air dispersion modelling expectations, AER 2013),
2. ESRD Air Quality Model Guideline (2013),
ESRD Non-Routine Flaring Management: Modelling Guidance (2013),
3. *AERSCREEN* and *AERMOD* (U.S. EPA 2011)

The *AERflare* model documentation is comprised of four components that are described in the following table.

| Module | Description |
|--|---|
| <i>AERflare.xlsm</i> | a Microsoft®-Excel (Office 2013) application software for Windows® containing macros and a user interface to external calculation modules. |
| <i>Screening Meteorological Data Files (*.sfc and *.pfl)</i> | A set of sixteen data files created using the AERSCREEN modelling system component MAKEMET for the eight basic land use groups described in the AERMOD user guide. For each land use type, there is a surface and a profile meteorological file. Each file is an AERMOD-ready meteorology file containing a full range of meteorological conditions using three month seasons and the range of conditions found in Alberta. |
| <i>MakeMet.exe</i> | Modified source code and executable adapted from AERSCREEN (v11126). <i>MakeMet</i> was modified to read inputs from a file as opposed to the original version which prompted the user for inputs. <i>MakeMet</i> can be used to create screening meteorological data files. |
| User Guide Version 2.01.pdf | this User Guide |

All of these documents and programs are available as a single download from the AER website. For the latest updates visit the AER website (see Directive 060):

<http://www.aer.ca/rules-and-regulations/directives/>

Also required is the AERMOD air dispersion model. The AERMOD source code, documentation and executable files are available at the U.S. EPA Technology Transfer Network website:

http://www.epa.gov/ttn/scram/dispersion_prefrec.htm#aermod

Model Changes

Version 2.01

- Bug Fixes and look-feel updates
- Added explicit gas composition of air using GPSA 13th Edition, SI. The molar mass for air is based upon: N₂ 78,12%; O₂ 20.96% and Ar 0.92%.

- Added argon (AR) to gas composition inputs.
- Added MPOSTBAT setting on **iSTART** page. The MPOSTBAT allows an advanced user to create a command line batch or script file to be inserted in the run stream during batch processing. The MPOSTBAT file is inserted after each batch run job.
- Added MMETUSTAR, MLOWWIND1 and MLOWWIND2 advanced switch settings. These settings are used to control how the *AERMET* meteorological processing and *AERMOD* processing for low wind speeds is conducted. See also the associated user adjustable SVmin and WSmin settings.
- Allow UTM entry for world UTM locations. Land use classification processing, however, remains available only for Canada. DEM processing for world locations available through generic file (XYZ) inputs.
- Added ‘Read User Receptor Grid’ option to the **iUSERTER** page. When selected the user is prompted for a generic XY file containing space or comma separated receptor grid points. The terrain processing will determine the elevations from DEM data.
- Removed the ‘re starting’ and ‘re ending’ controls from the user terrain files created by AERflare to be compatible with typical AERMOD insert files.
- Added options for radius for roughness (rrough) and radius for albedo (ralbbow) for *AERSurface* meteorology. rrough is set to the older *AERSurface* 3 km methodology rather than the new 1 km methodology as a balanced compromise between near-field and far-field turbulence effects. ralbbow is set at the *AERSurface* default of 5 km.
- Added the option for flag pole receptor heights.
- Added the option for nsources, the number of virtual sources used to model a time varying flare source in *AERMOD*. The default is nsources=9 with a maximum of 20.
- Added the option for flagging the minimum number of data points representing a valid dataset to use risk based criteria. In concept, a single year of meteorology is required with 8760 hours. However, regulations allow for a percentage of these data to be missing or calibration. Therefore, AERflare allows risk based criteria use for data sets with a minimum of 7884 points.

Version 1.x to 2.00

- Added annual and monthly air dispersion modelling predictions. The monthly predictions are based upon the month of the proposed flaring plus the month before and after. Using a 5-year data set, this allows for $N > 8760$ and thus the Risk Based Criteria can be applied.
- Added inefficiency by-products stream for air dispersion modelling impacts of products of inefficiency. These products are modelled as raw H_2S whereas combustion products are modelled SO_2 . The H_2S source differs from the SO_2 source; the H_2S has a lower heat component based upon convective stripping of energy from the flame and momentum is calculated from the mass flow not combusted.
- Added lift gas stream effects to combustion calculations.
- Added flare assist streams for air and/or steam flaring assist. The flare assist streams impact the combustion calculations by adding momentum, energy and reducing the combustion efficiency of the flare.
- Added conversion of sub-hourly emissions predicted concentrations to hourly average concentration.
- Added transient blowdown calculations. The spreadsheet prompts for volume, pressure and temperature of vessel to blowdown and calculates the exponential blowdown curve for the inputs. The curve is divided into three steps for modelling. The modelling predictions determine the maximum hourly concentration from the curve based upon the duration of each step and the maximum predicted concentrations for each step.
- Added **oFIGURE 1** page to display in a graphical format the predictions as a function of distance from the facility. The graphic shows max concentration, wind speed producing the maximum concentration, PG atmospheric stability leading to maximum concentration as a function of distance.
- Added **oFIGURE 2** page to display in a graphical format the statistical summary of emissions and combustion efficiency for hour-by-hour flaring analysis
- Added a **DEFINITIONS** reference page as per D060
- Added a **LAHEE** reference page. Linked the Lahee reference page to the flaring inputs for the determination of the maximum flaring volume allowance as per D060.

- Changed the summary page to reflect the numerous changes below. Also added a check-list style table at the top of the page to summarize how the inputs compare to D060 requirements for approvals.
- Changed the **ATTACHMENTS** page to **iNOTES** page. **iNOTES** page has specific prompts for questions that AER approval reviewers may consider in the review of the application.
- Added **iBATCH** and **oBATCH** pages for batch operation of spreadsheet. Users can save the input page to the batch page. Inputs and outputs are saved. Added **oBATCHVIEW** to **review modelling results**.
- Added NON-DEFAULT flag for all output pages when a non-default setting is selected.
- Added **iSTART** page for the selection of type of assessment, advanced program operations and non-default settings
- Non-routine flaring uses the hour-by-hour variation in source parameters. This is implemented in *AERMOD* using a time varying emissions file and a co-located source. Nine sources are defined based upon an estimate of the final rise of the hourly variation.
- Routine flaring uses the average meteorological wind speed and temperature.
- Added the prediction of concentrations based upon the non-routine flaring Risk Based Criteria.
- Added distinction between non-routine flaring and routine flaring. Both are modelled at 9-emission rates. Non-routine flaring results are compared to risk based criteria and routine flaring results are compared to ESRD established modelling objectives.
- Added *AERSCREEN/AERMOD* air dispersion modelling. Associated with this change are the following additions:
 - added 8-screening meteorological data sets corresponding to the 8-land use types in the Alberta Air Quality Model Guideline. The meteorological data sets represent 100% land cover for the respective land cover type.
 - added a mapping of Alberta, British Columbia and Saskatchewan for land cover reduced to the 8-land use types. The spreadsheet prompts for a location and the nearest land cover cell value is used to represent the air dispersion modelling.

- allowance for coordinates in geographical coordinates, UTM zones 8,9,10,11,12,13 and 10TM
 - air dispersion modelling is performed for the parallel air-flow and elevated terrain from 100m to 10km. The spreadsheet prompts for terrain elevations from the base elevation to the maximum terrain elevation.
 - Screening assessment using the *AERSCREEN* approach with the 8-screening meteorological data sets is intended for rapid assessment.
- Added *AERMOD* air dispersion modelling for refined analysis. Following a step-wise progression from screening to refined analysis, *AERflare* can create a refined dispersion modelling input files for *AERMOD*, run *AERMOD*, and post-process the results for non-routine, routine and blowdown sources.
 - Removed *SCREEN3*; removed the 99% percentile concentration prediction based upon *ISCST3* air dispersion modelling; fuel gas log; and minimum fuel calculation based upon the 99% concentration.
 - Added digital terrain processing for inputs to the **iTERRAIN** page. Digital elevation data (DEM) is downloaded from the internet site automatically or pulled from a user's local library. The terrain processing extracts worst case terrain contour elevations as would be done if performed manually; therefore, manual entry of worst case terrain remains an applicable option.
 - Added **iUSERMET** page to develop a site specific meteorological data set suitable for refined dispersion modelling using *AERMOD*. The meteorological data set is composed of data from the ESRD MMEU Meteorological Processor extraction of MM5 data for the province of Alberta. The **iUSERMET** page processing also downloads land use classification code (LCC) files for Canada from the internet or the user's local library. The LCC files are processed using *AERSURFACE* methodology to determine an average Bowen Ratio, albedo and surface roughness for the user's assessment site. The *AERMET* processor is subsequently used to create a site specific meteorological file.
 - Added **iUSERTER** page to develop a site specific receptor grid suitable for refined dispersion modelling using *AERMOD*. Digital elevation data (DEM) is downloaded from the internet site automatically or pulled from a user's local library. The user can create an ESRD standard assessment grid or modify the receptor spacing. Terrain and hill scale factors are determined from the DEM data and output to an *AERMOD* formatted insert file.

- Added **oPOSTPROCESS** page to post process external *AERMOD* output for the determination of AER D060 risk based criteria. Similar to the post-processing provided by the *AERflare* spreadsheet automated assessment, the **oPOSTPROCESS** page allows a user to process output created external to the *AERflare* interface. The **oPOSTPROCESS** page allows for advanced statistics for graphical presentation or in-depth analysis.

User Qualifications

AERflare is freely distributed to assist in D060 temporary flaring permitting, non-routine and routine flaring air dispersion modelling within Alberta. *AERflare* performs both screening level calculations (uses only a few user inputs to create a realistic and conservative estimate of flare emissions and concentrations) and also refined level calculations. Although relatively few inputs are required through the interface, it is a complex tool. *AERflare* requires inputs that may require sound engineering judgement or other technical expertise. It uses site-specific thermodynamics, fluid dynamics, and air dispersion modelling. Flare dispersion assessment is a multidisciplinary and iterative task with many assumptions and judgments.

The *AERflare* model was created so that a minimal amount of technical background is required to run the models. However, there remains some technical knowledge required to supply suitable inputs and the ability to understand whether the output is appropriate for the inputs and meets the needs of stakeholders. The user must recognise that the models are technical in nature and the correct interpretation of the result may require technical expertise that proceeds from consequences of the inputs. In any modelling assessment, high quality input data is very important.

The model has been created with a professional commitment to environmental protection and safeguarding the well-being of the public. It is the responsibility of the software user to accept and continue this commitment in their application of the software. The software is supplied as a tool to assist the user to comply with applicable statutes, regulations and bylaws. Neither the software nor application of the software is intended to replace statutes, regulations or bylaws.

Suitable Technical Background

Environmental issues are interdisciplinary in nature. The practice of environmental science requires the integration of diverse disciplines and philosophies; many projects will require a team of appropriate specialists to address complex environmental issues. Persons doing the assessment should undertake only that aspect of environmental work that they are competent to perform by virtue of training and experience. Thus they should seek out and use appropriate Environmental Specialists to provide expert advice on certain environmental issues.

The basis of the models is technical with expertise required in chemistry, thermodynamics, atmospheric physics, meteorological processes, industrial processes and regulatory affairs. While the full technical background is not a requirement to execute the models, the user of the software is required to have a general engineering and environmental science background; a general knowledge of the emission sources: wells, pipelines, and pipeline networks; and a working knowledge of the most current version of:

- *AER Directive 060* –
- Alberta ESRD Air Quality Model Guideline and Non-Routine Flaring Management: Model Guidance.
- *AERMOD/AERMET/AERSCREEN/AERSURFACE* user guides



There are many technical inputs required by *AERflare* to perform the calculations. Some have been prescribed by the AER as mandatory default entries. Others are input by the user for the specific flaring scenario.

Use of *AERflare* and understanding whether the predictions are appropriate for the user inputs still, however, requires some specific technical understanding.

How this Document is Organized

This User Guide is organized as both an instructional guide and a tutorial. This guide is divided into the following chapters:

| Chapter | Description |
|---------------------------------|--|
| 1 Introduction | Backgrounder for <i>AERflare</i> |
| 2 Installation and Setup | How to install the <i>AERflare</i> program |

| | |
|--|--|
| 3 AERflare Inputs | Description of the program prompts and user entries |
| 4 Air Dispersion Modelling and Output | Description of the program output calculations and graphics |
| 5 Transient Blowdown Flaring | Description of inputs and modelling for flaring from the depressurization of vessels and pipelines |
| 6 Advanced Techniques | A description of the modelling that can be performed using <i>AERflare</i> going beyond screening air dispersion modelling |
| 7 AERflare Batch Operation | Description of the operation of <i>AERflare</i> for multi-scenario operation |
| 8 Examples | Tutorial with four examples to demonstrate the features |

About this Guide

The following symbols and conventions are used in this guide

Bold Used for menu, command, and keyboard selections you make and screens you will see.

Italics Used for emphasis and to identify new terms

text User typed responses or entries

variable A named variable that is used in the spreadsheet to reference a cell location, equation variable or specific technical term

PAGE A worksheet page name



Helpful information about a particular topic.



Important information to prevent problems and ensure that you are successful in using the software.

link A hyperlink to a section within the User Guide, an internet web site or email address

Where to Go for Help

AER welcomes your feedback. Comments on the current version, suggestions for features in future versions, or bug reports in the User Guide or *AERflare* software can be submitted to the email below. Please provide information on the version of Windows you are using, version of Excel, and enough information to duplicate the issue. Thank you.

Directive060Inbox@aer.ca

What is *AERflare* all about?

The *AERflare* spreadsheet tool was created to provide consistency in the calculation of flare-type source parameters for use with standard air quality dispersion models that are based upon chimney-type sources parameters. The basic premise of *AERflare* is to determine the momentum and energy released during a flaring event; this energy is released to the atmosphere giving buoyancy and momentum plume rise for the flare-type source. *AERflare* then uses the buoyancy and momentum energy and back-calculates chimney-type equivalent source parameters that can be used as inputs in typical air dispersion models. These parameters are the height, diameter, velocity and temperature of the source. The equivalent source parameters are frequently called pseudo-parameters. The parameters are called pseudo-parameters because they are not real-world dimensions, but only calculated inputs that represent the flare-type source so that the correct plume height is used in the standard dispersion model. Standard dispersion models determine the plume rise based upon the calculation of buoyancy and momentum from the entered chimney source parameters (height, diameter, velocity and temperature.)

Flaring can be loosely divided into three types: continuous, short-term steady and transient. Continuous flaring is flaring when the emissions occur hour after hour for long periods of time (weeks, months or years). The flared gas for continuous emissions can vary from zero flow rates, to low flow rates and to high flow rates over the course of the flare duration. Short-term steady flaring is similar to continuous flaring but flaring occurs only for prescribed period of time. Transient flaring is similar to short-term steady flaring where the flare is operated for a prescribed period of time, but the flow rate to the flare originates from a high pressure blow down resulting in a scientifically well-defined change in flow rates from very high to low over a specific period of time. In each of the flare types, it is important to examine the range of low flow rates to high flow rates and the pollutants released during these periods. Low flow rates are associated with low plume rise and high flow rates are associated with higher plume rise.

From a regulatory standpoint, flaring is divided into two broad categories: continuous (including short-term steady) flaring for routine operations; and, non-routine flaring (including short-term steady and transient flaring). Non-routine flaring has special regulations because it is associated with specific disposal of large amounts of gas and typically high pollutant emissions. Non-routine flaring is divided into two categories: planned flaring (including well test flaring, maintenance and turn-around operations); and, unplanned flaring (including upsets and emergency flaring). The distinction between routine, non-routine (planned) and non-routine (unplanned) is the frequency of the flaring events and the inherent risk to environmental harm (consequence). Planned non-routine flaring from temporary flares requires a permit from the AER.

ERCBflare version 1.x was originally created to specifically address the concerns related to the applications to AER for non-routine flaring associated with well test flaring. Because non-routine flaring events are often associated high energy and high levels of pollutant emissions, it was necessary to update the calculation tool to incorporate the more complex source conditions demanded by industry users, operations and high impact but low risk predictions. *AERflare* version 2.x was created to specifically address these complex questions and therefore *AERflare* is inherently more complex than its predecessors (*ERCBflare* version 1.x and ESRD flare tool). An important change also included in the *AERflare 2.x* is the updated air quality dispersion model used to predict environmental harm (*AERMOD*), and it too is more complex than its relatively simplistic predecessor (*SCREEN3*).

The purpose of *AERflare* version 2.x is to provide a relatively easy-to-use user interface tool to assist the user in the complex analysis of routine and non-routine flaring. The goal of *AERflare* is to predict a rapid (within minutes), conservative estimate of flaring impacts. It also provides next-step analyses methods to bridge the gap between rapid screening analysis and full-refined air quality dispersion modelling.

2. INSTALLATION AND SETUP

This chapter describes how to install the *AERflare* software. The *AERflare* modelling package includes a user interface (a Microsoft®-Excel Office 2013 spreadsheet) that prompts the user for inputs and controls operation of the air dispersion modelling stand-alone programs (specifically *AERMOD*).



Microsoft Excel must be installed on your computer in order to use the *AERflare* tool.

Recommended version for *AERflare* are Office 2010 and Office 2013. *AERflare* currently works with Office XP, but is not supported.

Overview of the Installation Process

If you have not already done so, download the installation software from the AER website (see below).

The single install ZIP file contains all of the software required for the *AERflare* program to run within the users existing Microsoft Office (including Excel) environment.

STEP 1: The *AERflare* tool is packaged as a downloadable ZIP file which the user can unpack to form a folder tree and access directly. Download the file *AERflare* package from:

<http://www.aer.ca/rules-and-regulations/directives/>

There are two download files provided

| File | Intent | Recommended Download Destination Folder |
|--------------------------------|----------|---|
| AERflare_vxxxxxx.zip | Required | c:\myfiles\AERmodels\AERflare\ |
| AERflare_UserGuide_vxxxxxx.pdf | Required | c:\myfiles\AERmodels\AERflare\docs\ |

The AERflare_vxxxxxx.zip file contains the necessary user-interface and meteorological data files used in the flaring assessment. It is recommended that the users download and read this user guide for *AERflare*.

The MAKEMET.zip file contains a modified version of the U.S. EPA MAKEMET program. The U.S. EPA version of MAKEMET is command line driven, requiring the user to enter data and several prompts. The modified version of MAKEMET uses input files, and therefore is more readily useable for batch operations, and is less entry-error prone. MAKEMET is an optional processing that is required only if the user wishes to create a site-specific screening meteorological data file.



The files may be installed to the user's choice of alternate folder locations during the installation. The **iBIN** page within *AERflare* is used to locate the required file locations

STEP 2: Using the Windows explorer (Windows Key + e) locate the AERflare_vxxxx.zip file that you downloaded in **STEP 1**. Right click on the file and select 'unzip to here' (if you have the WINZIP utility) or 'unpack' (if you are using the embedded unzip functionality within Windows). The following folders and files will be created (where [mydir] is the folder used in **STEP 1**):

| | |
|--|---|
| [mydir]AERflare_vxxxxxx.xlsm | The <i>AERflare</i> spreadsheet tool |
| [mydir]metfiles\(\conif.x;cult.x; decid.x;desert.x;grass.x,swamp.x; urban.x;water.x) | The screening meteorological data files created using <i>MAKEMET</i> . These 8-meteorological files are used to determine screening level concentrations using <i>AERflare</i> in the screening modes. For each meteorological file name there is a *.SFC and *.PFL file representing an AERMOD ready surface profile meteorology file, respectively. |
| [mydir]metfiles\test_AERflare\(\aermod.sfc; aermod.pfl) | This folder contains an example site specific meteorological file. There is a *.SFC and *.PFL file representing an AERMOD ready surface and profile meteorology file, respectively |



The test_AERflare example site specific meteorological data file is provided as an example for use in the tutorials provided in this User Guide. User's should not use the example site specific meteorological data for their air quality evaluations or permit applications.

STEP 3: User's will also require files that are updated and distributed by the U.S. EPA: *AERMOD* and *AERMET*. The *AERMOD* source code, documentation and

executable files are available at the U.S. EPA Technology Transfer Network website:

http://www.epa.gov/ttn/scram/dispersion_prefrec.htm#aermod

The *AERMET* source code, documentation and executable files are available at the U.S. EPA Technology Transfer Network website:

http://www.epa.gov/ttn/scram/metobsdata_procaccprogs.htm#aermet



The files may be installed to the user's choice of locations during the installation.

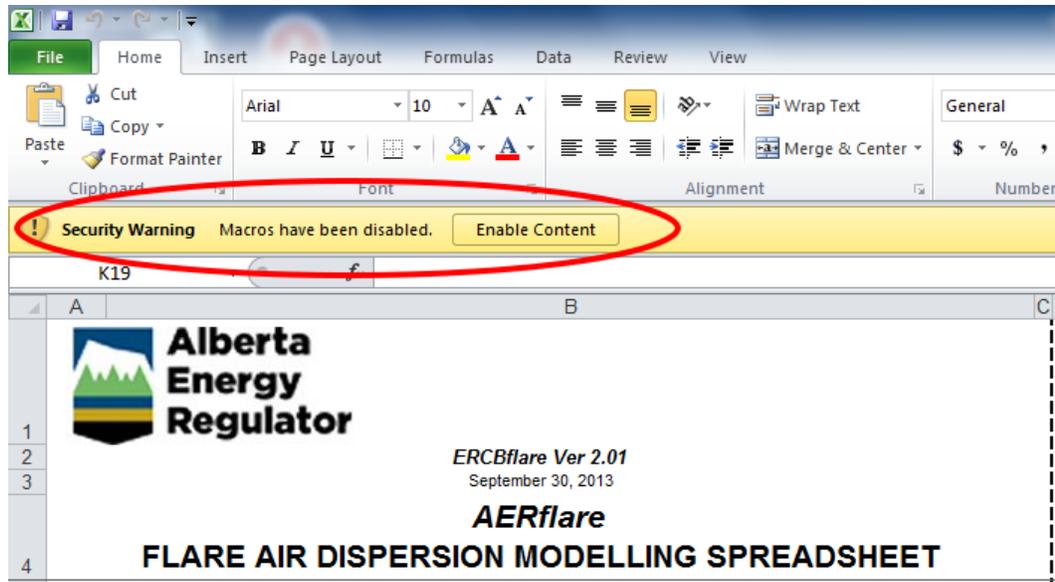


AERMOD must be installed on your machine in order to use all of the features of *AERflare* for air dispersion modelling screening.

Initial Setup

Now that you are finished installing the *AERflare* spreadsheet tool, meteorological files and *AERMOD* program, you can complete the installation by loading the *AERflare* spreadsheet and following the steps below.

1. From the select Windows START->Microsoft Office XXXX->Microsoft Excel XXXX; this will launch Excel. Then using the Excel menu option File->Open or use the Windows Explorer to navigate to the installation folder for *AERflare* and [mydir] and double-click on the *AERflare_vxxxxx.xlsm* file. This will load the *AERflare* tool into Excel.
2. The *AERflare* spreadsheet is an XLSM file that contains typical spreadsheet-like calculations as well as program macros. This is the “M” part of the “.xlsm” filename extension. When the file is opened, your computer and office security settings may display a warning. Select ‘Trust this document’, ‘Enable Macros for this document’ or ‘Enable Content’ depending on your version of Windows if prompted when the file is opened. Failing to do so will prevent *AERflare* from operating.



3. Click on the **iSTART** page. Select “Show” for the *Hide iBIN Page* option.
4. Click on the **iBIN** page. For the entry for **AERMOD**, type the full path and file name of the AERMOD.exe file (previously installed). The **Browse...** button can be used to navigate your file folder tree using common Windows Explorer methods.
5. For the entry for **METFILES**, type the full path and file name of the folder location where the screening meteorological files were stored. By default this will be:

[mydir]\metfiles

The files can be placed anywhere on your network. *AERflare* requires read access to the files only.

6. If the **BROWSE...** button was used to select the files or the **SAVE** button pressed, then *AERflare* stores the entry for your computer setup. If you load an uninitialized *AERflare* spreadsheet or a spreadsheet initialized to another users folder locations, *AERflare* synchronizes the settings to your computer setup. You have the option of saving the file when you have completed the calculations. You can force *AERflare* to synchronize by pressing the **SYNC** button.
7. Click on the **iSTART** page. Select “Hide” for the *Hide iBIN Page* option. Typically, you shouldn’t have to revisit the **iBIN** page. However, use the **iSTART** page to show the **iBIN** page to make any changes to your system as required.



Select 'Trust this document' or 'Enable Macros for this document' if prompted when the file is opened. Failing to do so will prevent AERflare from operating.



AERflare spreadsheets must be saved as an XLSM file type to preserve the macro (Visual Basic for Applications) functionality.

This completes the mandatory components initialization of the *AERflare*. The user may wish to also initialize several optional components of *AERflare*.

AERMET: On the **iBIN** page, for the row entry for *AERMET*, enter the full path for the location of the AERMET.exe file or use the **BROWSE** button to navigate to the installation folder and click on the AERMET.exe.

MAKEMET: On the **iBIN** page, for the row entry for *MAKEMET*, enter the full path for the location of the MAKEMET.exe file or use the **BROWSE** button to navigate to the installation folder and click on the MAKEMET.exe.

DEMLIB: On the **iBIN** page, for the row entry for **DEMLIB**, enter the full path for the location of where digital elevation files should be stored when downloaded from the internet. **DEMLIB** represents a library or cache to save time on subsequent analyses to avoid download times. Also, the **DEMLIB** provides a library of files for repeatability of *AERflare* predictions.

LCCLIB: On the **iBIN** page, for the row entry for **LCCLIB**, enter the full path for the location of where land-use classification code (LCC) files should be stored when downloaded from the internet. **LCCLIB** represents a library or cache to save time on subsequent analyses to avoid download times. Also, the **LCCLIB** provides a library of files for repeatability of *AERflare* predictions.

POSTBAT: [OPTIONAL] on the **iBIN** page is used to define the full pathname of a batch file (an advanced feature, the file is created by the user) that is run after each run job.

DEMURL: on the **iBIN** page lists the internet URL where DEM files are downloaded from. This entry is not editable.

LCCURL: on the **iBIN** page lists the internet URL where LCC files are downloaded from. This entry is not editable.

To test your system you can follow the example on the Chapter 7: Batch Operations to load the provided example or follow these basic steps.

1. Click on the **iSTART** page. Select “Show” for the *Hide iBATCH Page* option.
2. Click on any cell on the first data row (row 9) below the titles. This selects this row as the active Batch operation row.
3. Click the **Load Current Row** button at the top of the page. Clicking the button copies the inputs from the **iBATCH** page to the respective inputs on the **iFACILITY**, **iFLARING**, **iTERRAIN**, **iNOTES**, and mode selections on the **iSTART** page.
4. Click on the **iFLARING** tab to confirm that the **iBATCH** entries were copied to the **iFLARING** and other pages.
5. Click on the **Recalculate** button at the top of the **iFLARING** page. This will re-direct you to the **oMODELLING** page and the location where the modelling option buttons are placed. The modelling options area shows two streams of buttons. On the left are Non-Routine flaring modelling options and on the right are Routine flaring modelling options. These are discussed in more detail in a later chapter of this guide. Above the modelling buttons are the summarized routine source inputs to be used in the modelling based upon average meteorological wind and temperature conditions. Below the buttons area, the results of the air dispersion modelling will be summarized once complete.
6. For this example, it doesn't matter if the Non-Routine mode or Routine mode was selected. Click on the **5. AERSCREEN-MAX** button. This will create input files based upon the screening meteorological files and will execute the *AERMOD* program. If you properly installed both of these and pointed the **iBIN** page to their proper location, then the *AERflare* program should loop through 6-scenarios of calculations. The screen may flash and update during the calculation sequence. A status of the calculations is shown at the bottom of the screen. It is recommended that you **DO NOT** continue to use your computer for other concurrent Windows applications because this can cause interference and instability within the calculations.



It is recommended that you **DO NOT** continue to use your computer for other concurrent Windows applications because this can cause interference and instability within the calculations.

3. *AERflare* INPUTS

This chapter provides the following information about the general operation of the *AERflare* program:

- what inputs are and how they work together
- what the buttons/menu items do
- overview of the calculation processes

Introduction

The *AERflare* program uses the familiar Microsoft Excel as host for the calculations. *AERflare.xlsxm* contains the user-interface for the calculations, allowing the user to input information and view calculation results. The *AERflare* application consists of the *AERflare.xlsxm* macro enhanced spreadsheet. The spreadsheet uses external files (read only meteorological files and the *AERMOD.exe* executable air dispersion model).



The *AERflare* spreadsheet is a stand-alone spreadsheet containing all of the necessary macros and programming to load and process input and output from the modules



AERflare.xlsxm is an Excel spreadsheet file (.xlsxm) containing macros (programming) that acts as a user interface for input files and output from the processing modules.



All inputs and outputs are stored within the spreadsheet. Temporary files are created in the parent folder for the spreadsheet during air dispersion modelling calculations. The user can preserve intermediate modelling files or create modelling files to the folder of choice when those options are selected.

Graphical User-Interface

Overview – The AERflare GUI in Excel

All user input and output are controlled using an *AERflare.xlsxm* file for Microsoft Excel. The Graphical User-Interface (GUI) file (.xlsxm) contains several Excel worksheets (**pages**). At the bottom of each page is a title on a tab. You can change to a page using the mouse by clicking on a tab or using the keyboard using ctrl+pgup or ctrl+pgdn. The pages are shown in Figure 1 and shows the typical linkage of sheets. Typical operations are linked with bold lines; the user may wish to view operations linked with solid lines; and technical or optional operations are linked with dashed lines. Typical operations include:

- Selection of Permit (Non-Routine Planned Flaring) mode or Evaluation (Air Quality Evaluation of Flaring) mode.
- Inputs are entered on several pages. All input pages start with “i” and the tabs are coloured green.
- Air dispersion modelling options are available for low-level screening (maximum predictions are compared to objectives), screening (percentile concentration predictions are compared to objectives or risk based criteria) and refined air dispersion modelling (recommended methods to be used if screening doesn’t pass).
- Outputs are provided in a summary table and graphics are provided that may be useful in reporting.
- Technical pages display the detailed source calculations and intermediate calculation steps.

The *AERflare.xlsxm* spreadsheet can be used as a stand-alone input/output calculation for each project/scenario or it may be used as a central database of inputs. Both systems have advantages and disadvantages.

Stand-Alone

When the user uses *AERflare* in a stand-alone framework, the user would load a copy of the spreadsheet into EXCEL; user inputs are entered on the input pages; and following the completion of the air dispersion modelling the outputs are displayed on the output pages. The user would save the *AERflare* spreadsheet in a

sub-folder of the project or scenario being assessed. In this manner, the exact inputs and outputs are maintained for later verification or reference.

Central Database

When the user uses the *AERflare* in a central database framework, a single copy of the *AERflare* spreadsheet is used to input, perform calculations and save summary output. Detailed output information for the inputs are lost, when new information is input, but the inputs can be restored from the database and the outputs readily re-created. This framework is advantageous to perform sensitivity testing or design scenarios where specific output results are required and not all of the details. The central database framework corresponds closely with the batch operation of *AERflare* (see Section 7: Batch Operations)

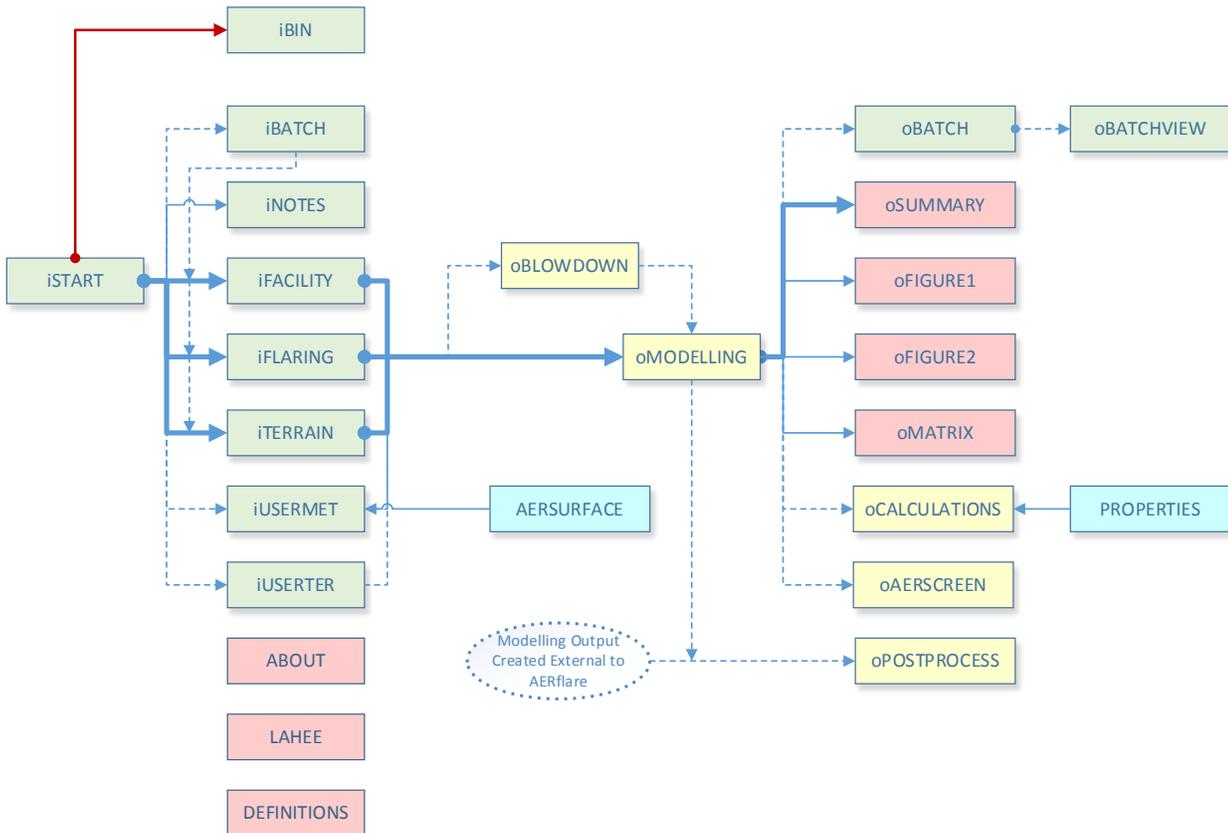


Figure 1: AERflare Page Name and Typical Linkage

The AERflare Excel Pages

AERflare has 25 GUI Excel pages representing informational, input, output and technical output. Pages for input have tabs that are green, output and information pages are pink, and technical output pages are yellow (coloured tabs on pages are visible for Office 2002 and newer versions of Excel only).



Tabs for the page types are colour coded **for Office 2002 and newer** versions of Excel (earlier versions do not display the page colours).

Input pages are *green*; output pages are *pink*; and technical pages are *yellow*.



Input pages start with “i”

Output pages start with “o”

All calculations are performed in the Excel pages for complete transparency of all calculations. The programming and macros imbedded in the *AERflare* tool are security locked to protect the integrity of the user interface. The programming and macros do not perform any of the calculations with the exception of: equation root solvers; thermodynamic equations of state solvers; and thermodynamic property from gas composition matrix operations. These calculations are described in the Appendix B.

A complete list of user-interface pages are described in the following table:

| Page Name | Purpose | Description |
|-------------|------------------|---|
| ABOUT | User Information | General information and instructions for use of the spreadsheet. Use this sheet to link to the latest information regarding AERflare. |
| LAHEE | User Information | A list of the LAHEE well classifications. The LAHEE system has been adopted by AER to classify well operations. The LAHEE classification is linked to AER D060 non-routine planned flaring maximum flare rates. |
| DEFINITIONS | User Information | A list of AER D060 terminology related to routine and non-routine flaring. |
| iSTART | Input | All flare calculations must start at this page to specify the mode of the screening calculations. Also on this page are several non-default operation selections and inputs. |
| iBIN | Input | The <i>AERflare.xls</i> GUI needs to know where the user has stored meteorological files and the location of the AERMOD executable. |
| iBATCH | Input | The iBATCH page is used as a database of inputs and summary outputs. The user can use the iBATCH to run sensitivity tests or a running list of wells for a field of operations |
| oBATCH | Output | The oBATCH page contains the output for matching row numbers on the iBATCH page. |
| oBATCHVIEW | Output | The oBATCHVIEW page allows the user to load output from the batch page and display the summary information in a page-view format. |
| iFACILITY | Input | The iFACILITY page is used to enter facility level inputs such as owner and operator, location of the flare and emergency planning. Many of these inputs are important inputs for the non-routine planned flaring temporary |

| Page Name | Purpose | Description |
|--------------|--|--|
| | | permit process. If the routine flaring mode is selected, then many of iFACILITY entries are greyed-out and are not required entries. |
| iFLARING | Input | The iFLARING page is used to enter flare level inputs such as source flow rates and gas compositions. The iFLARE page is also used to select between a steady release and a transient blowdown release. |
| oBLOWDOWN | Input (Normally Hidden) | The oBLOWDOWN page is normally hidden unless the selection on the iFLARING page for MBLOWDOWN=1. In this case, the transient blowdown calculations are invoked. The oBLOWDOWN page contains the calculations for the exponential blowdown approximation for source flow rate and conservation of mass. |
| iLOCATION | Input | The iLOCATION page is used to check the entered flare location. Two graphics are provided on the page to illustrate the entries. |
| iTERRAIN | Input | The iTERRAIN page is used to enter the worse terrain elevations surrounding the well location. A graphic is provided on the page to illustrate the entries. The graphic is a good way to confirm the user entries are correct. |
| iUSERMET | Input (Technical) | The iUSERMET page is a step-by-step entry and tutorial page for creating a site specific (user-created) refined meteorological data set. The output will be 5-year data set with site specific land use characterization. AERMOD ready surface and profile files are created. |
| iUSERTER | Input (Technical) | The iUSERTER page is a step-by-step entry and tutorial page to create a site specific (user receptor) refined receptor grid. The output will be an AERMOD formatted file that can be inserted into an AERMOD ready inputs control file. |
| iNOTES | Input | The iNOTES page has two purposes. First, the AER approval reviewers specifically request a descriptive response for the first four questions to assist in their understanding of the application and approval decision. Secondly, the page allows the user keep track of assumptions or information regarding the assessment. |
| oSUMMARY | Output | The oSUMMARY page provides a summary check list of the flaring inputs against the limits and requirements outlined in AER D060. The oSUMMARY page also summarizes the important source and air dispersion modelling predictions the reviewer will consider in approval/application process. Many of the fields are not applicable for routine flare air dispersion modelling but the page can be a useful summary of the air dispersion modelling results. |
| oFIGURE 1 | Output (Technical) | The oFIGURE 1 page displays the air dispersion modelling as a function of distance from the source. The graphic can provide useful information for flaring management. |
| oFIGURE 2 | Output (Technical) | The oFIGURE 2 page display the source emissions and combustion efficiency calculation results when using the hour-by-hour source model. |
| oMATRIX | Output (Technical) | The oMATRIX page displays a screening matrix summary of the concentrations and predicted distances as a function of wind speed and atmospheric stability class. |
| oMODELLING | Summary of Technical Output and Location of Modelling Calculation Option Buttons | The oMODELLING page is a technical output page that displays the calculated pseudo-parameters for the flare source that are suitable for refined air dispersion modelling outside of the AERflare model based upon average meteorological temperature and wind speeds. It also presents air dispersion modelling options depending upon the flare Non-Routine or Routine flaring mode selected on the iSTART page. The results of the air dispersion modelling are summarized for each scenario at the bottom of the page. |
| oAERSCREEN | Technical Output of Air dispersion modelling Intermediate Results (Technical) | The oAERSCREEN page is used to configure the AERMOD air dispersion model to perform AERSCREEN style screening air dispersion modelling. The detailed output of the air dispersion modelling are listed on this page as well as the oFIGURE 1 page. The user can use this page to determine seasonal or annual exceedance of the objectives for each model scenario. |
| oPOSTPROCESS | Technical Output of Air dispersion modelling EXTERNAL Results (Technical) | The oPOSTPROCESS page can be used to post-process air dispersion modelling result files (POSTFILE) to create tabulated and graphical statistical summaries. This page is included because the risk based criteria cannot be calculated using the standard AERMOD output. |

| Page Name | Purpose | Description |
|---------------|--|---|
| oCALCULATIONS | Technical Output of Intermediate Source Calculations | The oCALCULATIONS page is a technical listing of the combustion calculations. It also lists the source mass and energy balance intermediate calculations. The results of these calculations are summarized on the oMODELLING page. |
| PROPERTIES | Reference (Technical) | The PROPERTIES page displays a technical reference listing of the chemical and thermodynamic properties used in the calculations. |
| AERSURFACE | Reference (Technical) | The AERSURFACE page displays a technical reference listing of the Bowen ratio, albedo and surface roughness used by AERSURFACE and used in the land-use classification processing by AERflare to create the site specific meteorological data file on the iUSERMET page |



The pages flagged having a Purpose of (Technical) may be hidden from view using the **iSTART** hide technical pages option. These pages are not required for screening level modelling

iSTART

Fundamentals

The **iSTART** page is the starting point for all *AERflare* modelling.

The **iSTART** page fundamental entries are illustrated in the figure below. These options specify cosmetic or convenience modes (i.e., hide or don't hide technical information) but also control how the screening calculations are to be performed (i.e., Permit or Evaluation of air quality). If *AERflare* is operated in the non-routine flaring mode, then the AER risk-based criteria will be used to evaluate air dispersion modelling predictions. Otherwise, routine flaring air dispersion modelling mode uses the establish ESRD risk based criteria to evaluate air dispersion modelling.

iSTART Page Program settings and switches

| | | |
|---|---|-------------|
| Are these flaring calculations for an ambient air quality evaluation or for a temporary permit application? | <input checked="" type="radio"/> Permit <input type="radio"/> Evaluation | S P S |
|---|---|-------------|

Permit or Evaluation Mode

This selection is used to toggle the visibility of input cells, technical pages and operations based upon whether the intent of the calculations is to be used for an AER temporary flaring permit or any other purpose for evaluating air quality concentrations. If the intent is for a permit, then specific information related to the permitting process is gathered from the user as well as restricting the calculations to the AER mandated flaring assessment calculations using hour-by-hour variability. An AER temporary flaring permit is by definition a non-routine planned flaring event, therefore the flaring classification is locked to this setting when **PERMIT** is selected.

When the *AERflare* calculation mode is set to **EVALUATION**, many of the inputs and emissions restrictions are grayed-out and are not required to be filled in. The **EVALUATION** mode can be used for what-if analyses, ESRD facility approval analyses or other flaring investigations. In **EVALUATION**, routine, non-routine planned or non-routine emergency flaring classifications can be selected.

Flaring Classification

The flaring classification setting is an important selection since it prescribes the modelling methods to be used as well as the objectives to be used for evaluation of the results of the modelling.

A non-routine flaring assessment is intended to accompany an AER D060 non-routine flaring approval application. Non-routine flaring has strict guidelines on the intended purpose of the flaring, timing of the flare event, and the ability to predict emissions and design the stack. Non-routine flaring is typically associated with higher than normal flare volumes with rare intermittent occurrence or very-rare occurrence. Non-routine flaring is divided in two types of non-routine flaring. Because of the variable nature of non-routine flare events, non-routine flare emissions and air dispersion modelling are analyzed using a mandatory maximum, average and low flaring rate. All three flow rates must be analyzed because of the non-linearity between the energy released and resulting plume rise,

flaring emissions and terrain impacts. It can occur that worst case impacts result from low flaring rates.

A routine flaring assessment is intended to analyze steady or continuous emissions from a flare stack. Routine flaring assessments are performed using a single flaring rate that is representative of the maximum emissions rate. If the flare is used for multiple scenarios or multiple emission rate events, the user should assess each flaring event and flow rate independently to verify that flaring under all scenarios will meet the ambient air quality objectives.

In the example shown in the figure below, the user has previously selected the **PERMIT** mode on the **iSTART** page. Only the Non-routine—Planned Flaring is available.

| Flaring Classification | | The flaring classification defines what the Risk Based Criteria (RBC) will be used to assess acceptable modelling predictions. The classification also sets limits on the maximum acceptable concentration for modelling. | | | | | |
|--|----------------------------------|---|-----------------|--|--|---|---|
| | | RBC % (Limit 1) | Max % (Limit 2) | SO ₂ RBC (µg/m ³) | SO ₂ Max (µg/m ³) | H ₂ S RBC (µg/m ³) | H ₂ S Max (µg/m ³) |
| Routine -- Continuous or Intermittent Flaring for more than 720 hours per year | <input type="radio"/> Locked | 99.9 | -- | 450 | -- | 14 | -- |
| Non-Routine -- Planned Flaring | <input checked="" type="radio"/> | 99 | 99.9 | 450 | 900 | 14 | 7652 |
| Non-Routine -- Unplanned Flaring | <input type="radio"/> Locked | 90 | 99.9 | 450 | 9923 | 14 | 7652 |

(see also to the right, an extension of the table with ppm equivalents)

| SO ₂ RBC (ppm) | SO ₂ Max (ppm) | H ₂ S RBC (ppm) | H ₂ S Max (ppm) |
|---------------------------|---------------------------|----------------------------|----------------------------|
| 0.172 | -- | 0.010 | -- |
| 0.172 | 0.344 | 0.010 | 5.493 |
| 0.172 | 3.789 | 0.010 | 5.493 |

Note:

- conversion at 25 °C, 101.325 kPa
- 3.789 ppm is derived from SO₂ evacuation criteria of 5 ppm over 15 minutes adjusted to 60 minutes= $5 \times (15/60)^{0.2}$
- 5.493 ppm is derived from H₂S evacuation criteria of 10 ppm over 3 minutes adjusted to 60 minutes= $10 \times (3/60)^{0.2}$

Only the Non-routine flaring assessments can make use of the risk based criteria (RBC). The RBC used for Non-Routine planned and emergency/upset flaring classifications are listed to the right of each option. For planned flaring, the modelled 99% 1h average SO₂ concentration at each receptor must be less than or equal 450 µg/m³ (or 0.172 ppm). The 99.9% 1h average SO₂ concentration at each receptor must be less than or equal to 900 µg/m³ (or 0.344 ppm). The same RBC is applied for predictions of H₂S, the modelled 99% 1h average H₂S concentration at each receptor must be less than or equal 14 µg/m³ (or 0.01 ppm). The 99.9% 1h average H₂S concentration at each receptor must be less than or equal to 7652 µg/m³ (1h equivalent concentration for the threshold of 10 ppm for

3min). The upper limit of the H₂S is based upon the evacuation criteria for H₂S used in the *AERH2S* emergency response planning.

For emergency/upset flaring, air dispersion modelling uses the 90% RBC 1h average SO₂ concentration at each receptor must be less than or equal to 450 µg/m³ (0.172 ppm). The emergency/upset flaring maximum concentration (99.9%) 1h average SO₂ concentration at each receptor must be less than or equal to 9923 µg/m³ (1h average or 3.789 ppm; based upon 5 ppm for 15min). The maximum SO₂ represents the evacuation criteria for SO₂ used in the *AERH2S* emergency response planning. For H₂S, the 90% RBC 1h average concentration at each receptor must be less than or equal to 14 µg/m³ (0.01 ppm) and the 99.9% maximum 1h average H₂S concentration must be less than or equal to 7652 µg/m³ (10 ppm) representing the evacuation criteria for H₂S.

Although *AERflare* uses RBC criteria for modelling and flare stack design purposes, the ESRD requires that any direct measurement of air quality outside of the facility fenceline (i.e., public area) must be less than or equal to the ambient air quality objectives which is protective of human and environmental health. These objectives do not prescribe that a human receptor must be present, but are protective to human and environment that could be or have the right to be present.

Hide Technical Pages

The hide technical pages option is cosmetic for *AERflare* operations. Hide technical toggles the visibility of **oCALCULATIONS** and **oAERSCREEN** pages. Although, **oMODELLING** is a technical page, it must remain visible because it displays the summarized source parameters, is home to the air dispersion modelling buttons, and displays the summary of the equivalent 1h average concentrations. The pages that are included as “technical” are listed on page 21.

Hide iBATCH & oBATCH Page

The hide **iBATCH** and **oBATCH** page option is cosmetic for *AERflare* operations. Hide **iBATCH** and **oBATCH** page toggles the visibility of the **iBATCH** and **oBATCH** pages. If the user is not using the batch mode features, then this page can be hidden from view.

Hide iBIN page

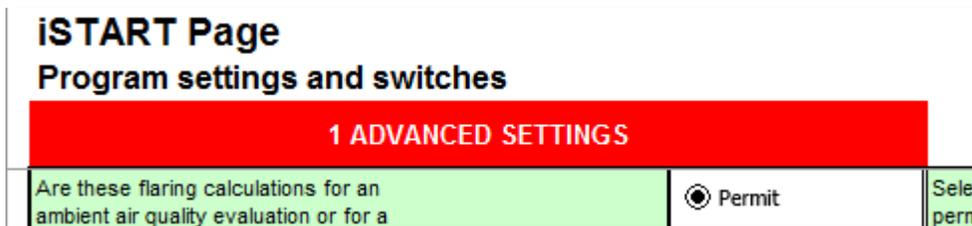
The hide **iBIN** page option is cosmetic for *AERflare* options. Hide **iBIN** is used to toggle the visibility of the **iBIN** page. Once the *AERflare* spreadsheet has been configured, typically operations will not require the page (see Chapter 2: Installation and Setup) and it can be hidden from view.

Advanced Switches

The advanced switches are useful for advanced users for debugging and for other automation links. The advanced switch block is shown in the figure below. The defaults are shown and the user can over-ride the default by entering a value in the **INPUTS** column. Entries different than the default are highlighted for convenience.

| Advanced Technical Switches | | | | |
|--|-----------|-------|--------|---------|
| Description | Variable | Units | Inputs | Default |
| Re-create run.bat file each time (1-Yes, 0-No) | mrunbat | -- | 1 | 1 |
| Add pause to run.bat file (1-Yes, 0-No) | mpause | -- | 0 | 0 |
| Run POSTBAT after each batch line (1-Yes, 0-No) | mpostbat | -- | 0 | 0 |
| Keep input files (1-Yes, 0-No) | mkeep | -- | 0 | 0 |
| Keep output files (1-Yes, 0-No) | mkeepout | -- | 0 | 0 |
| AERMOD input files- uses 0,0 origin (1-Yes, 0-No) | mrelloc | -- | 0 | 0 |
| AERMOD input files-export receptors (1-Yes, 0-No) | mexprec | -- | 1 | 1 |
| Apply BETA adjustment of u* in AERMET (1-Yes, 0-No) | mmetustar | -- | 0 | 0 |
| Use BETA adjustment of low winds method 1 (1-Yes, 0-No) (horizontal meander OFF; SVmin=0.5 m/s) | mlowwind1 | -- | 0 | 0 |
| Use BETA adjustment of low winds method 2 (1-Yes, 0-No) (horizontal meander ON; SVmin=0.3 m/s; FRAN=max 0.95) | mlowwind2 | -- | 0 | 0 |
| Force SCREEN AERMOD Control Setting (1-Yes, 0-No) | mscreen | -- | 0 | 0 |
| Force Site Elevation to DEM elevation (1-Yes, 0-No) | melev | -- | 1 | 1 |
| DEM always download files (1-Yes, 0-No) | mdemget | -- | 0 | 0 |
| LCC always download files (1-Yes, 0-No) | mlccget | -- | 0 | 0 |
| Synchronize settings between spreadsheets (1-Yes, 0-No) | msync | -- | 1 | 1 |

When an advanced setting has been selected the output pages are embossed with a warning message to notify the user. Example the message below was created when one of the advanced settings were used.



MRUNBAT

The *AERflare* model creates a small batch file that is used to call the *AERMOD* program and link it to the temporary file used as input to *AERMOD*. To save time, *AERflare* doesn't recreate the `RUN.BAT` file each time. The user may set the `mrunbat=1` to force `run.bat` to be created each run or 0 to prevent the file from being recreated. This option can be useful if the wizard user wants to add pre- or post-processing commands into `RUN.BAT` file.

MPAUSE

AERflare creates a synchronous secondary process using the command prompt. By default *AERflare* minimizes the command prompt to the task bar as a reference during the air dispersion modelling. The command prompt window is closed automatically after execution of *AERMOD* and control is returned to *AERflare* calculation process. For debugging, a PAUSE statement can be added to the RUN.BAT file to force the user to look at the command prompt window and enter an acknowledgment to proceed. Select `mpause=1` to include the PAUSE statement. The `mruntime=1` option should also be set to force the RUN.BAT file to be re-written.

MPOSTBAT

The `mpostbat` is an advanced setting that can be used by a wizard user to insert user processing following each batch line operation. The `mpostbat` works with the `POSTBAT` setting on the **iBIN** page. The POSTBAT batch or script file is inserted in to the run stream processing following the optional print option on batch operations. The `POSTBAT` can be configured, for instance, to rename output print jobs or copy files.

`POSTBAT` is appended with two command line variables:

```
[POSTBAT] [iBatchRow] [scenario name]
```

Where [POSTBAT] is the entry for POSTBAT on the iBIN page, [iBatchRow] is the spreadsheet row number for the batch operation on the **iBATCH** page, [scenario name] is the scenario name from column H on the **iBATCH** page (surrounded by quotes).

An example `POSTBAT` is shown below. The batch file is used in connection with **iBATCH** file run-time setting `RUN=2` (print required after run). With a default printer setting of “Adobe PDF” the required pages are printed to a pdf file for each batch job. The output file PDF file, however, has the same name as the spreadsheet. The `POSTBAT` file copies the file to a user define location, then deletes the original PDF if the copy is successful.

```
@echo %1
@echo %2
@copy "c:\user\me\my documents\aerflare.v201.pdf" doc_%1.pdf && del
"c:\user\me\my documents\aerflare.v201.pdf" /Q
```

MKEEP

The **mkeep** option prevents *AERflare* from deleting the temporary input files used to control and get results from individual *AERMOD* scenarios. The **mkeep=1**, the temporary files are not deleted. Note that this may create a large number of files. The files have a temporary name prefix created by the system. The **mkeep** option is useful for creating input files for further analysis external to *AERflare* or for debugging.

MKEEPOUT

The **mkeepout** option prevents *AERflare* from deleting the temporary output files used to control and get results from individual *AERMOD* scenarios. The **mkeepout=1**, the temporary files are not deleted. Note that this may create a large number of files. The files have a temporary name prefix created by the system. The **mkeepout** option is useful for debugging or for post-processing the advanced **oPOSTPROCESS** page.

MRELLOC

The **mrelloc** specifies whether the output files for the user specified *AERMOD* input files contain relative location coordinates or the absolute coordinates specified on the **iFACILITY** page. By default, *AERflare* performs its calculations using relative location coordinates with the flare located at (0, 0). When the user selects CREATE AERMOD INPUT files from the **oMODELLING** page, the user may be merging this input file with site specific terrain. To assist in this automation, the user can select **mrelloc=1** to force the flare location to the X,Y location rather than edit the created file. If a site specific receptor file is used, then this option has no effect.

MEXPREC

The **mexprec** switch is similar to the **mrelloc** switch. **mexprec** switch is used to prevent the export of the receptor locations used in the *AERflare* screening. By default, *AERflare* creates a list of discrete receptor locations and terrain elevations. When **mexprec=1**, *AERflare* only outputs the start header and end header for the AERMOD input file and the user automation can be insert the site-specific receptor grid and terrain elevations. If a site specific receptor file is used, then this option has no effect.

MMETUSTAR, MLOWWIND1 and MLOWWIND2

The `mmetustar`, `mlovwind1` and `mlovwind2` settings are used to control the beta configuration of AERMET and AERMOD low wind processing options. `mmetustar`, `mlovwind1` and `mlovwind2` are used in AERMET and `mmetustar` is also used in AERMOD. If `mmetustar` is used for AERMOD, then the user must select a meteorological data set that was processed using the `mmetustar` option. These settings use the AERMOD default settings for `svmin` and `wsmmin`, however, these latter values can be user selected for testing purposes in the Non-Defaults Settings area.

MSCREEN

The `msscreen` switch is used to force the *AERflare* modelling runs using AERMOD to use the SCREEN control option. This setting forces all wind directions to go to all receptors. This setting is a worst-case option and will lead to conservative predictions. This setting is useful to perform screening assessments using user-meteorological files, such as a user created screening file created using *MAKEMET*. By default, modelling performed using calculation buttons AERSCREEN-XXX (calculation buttons #1, #2, #5 or #6) use the SCREEN control setting and modelling performed using calculation buttons AERMOD-XXX do not use the SCREEN setting. Therefore, the `msscreen` setting only affects the AERMOD-XXX button calculations.

MELEV

The `melev` setting is used in connection with the button on the **iTERRAIN** page. On the **iFACILITY** page, the user is prompted to enter the location of the flare and its elevation. On the **iTERRAIN** page, DEM data is used to determine the surrounding terrain elevations and interpolates to determine the flare base elevation according to the DEM data. Due to grading or DEM variation, the **iFACILITY** elevation may be different than the DEM derived elevation creating an effective pedestal or pit effect. In either case, the flare stack height could be arbitrarily increased or decreased leading to incorrect ground level concentrations. If the difference between the two elevations is greater than 2 m, a warning is displayed and the user is required to justify the difference. By default, the `melev` switch is used to force the **iFACILITY** elevation entry to the DEM derived elevation. This makes the flare height consistent with the DEM data set.

MDEMGET

The `mdemget` setting is used to force *AERflare* to download digital terrain data without first looking within the saved library. This switch can be used to ensure that the most up-to-date data is being used in the analysis at the expense of repeated down load time. It is recommended that this setting is set to “0” to not automatically download. For repeatability of the assessment it is recommended that a Library be created. Updates, when available from the download site, can be included by starting a new library periodically.

MLCCGET

Similar to the `mdemget` option, the `mlccget` setting is used to force *AERflare* to download land classification data without first looking within the saved library. This switch can be used to ensure that the most up-to-date data is being used in the analysis at the expense of repeated down load time. It is recommended that this setting is set to “0” to not automatically download. For repeatability of the assessment it is recommended that a Library be created. Updates, when available from the download site, can be included by starting a new library periodically.

MSYNC

This switch is used to turn on or off the automatic synchronizing of the settings on the **iBIN** page. Setting `msync=0`, turns off synchronizing. With `msync=0`, when the *AERflare* spreadsheet opens it does not reset the spreadsheet values to the saved system values. Similarly, with `msync=0`, when files or folders are specified on the **iBIN** page, they are not saved to the system for later recall.

AERflare also synchronizes the **iSTART** page selections for [Hide Technical Pages](#), [Hide iBATCH page](#) and [Hide iBIN page](#).

Non-Default Settings

The non-default settings area is a listing of options the user can select to perform calculations outside of the AER (Alberta) regulatory requirements. When settings are entered different than the default setting, a warning message is displayed on all output pages indicating that the modelling is not appropriate for AER approval/applications. Some of the settings are explicit (e.g., average wind speed) and others are the result of selections on other input pages (example land cover). The non-default settings block is shown in the figure below.

Non-Default Settings

| Description | Variable | Units | Inputs | Default | Comment |
|--|-----------|-------------------|--------|---------|---------|
| Ambient Temperature | ta | °C | 5 | 5 | |
| Average Ambient Wind Speed | ua | m/s | 3.5 | 3.5 | |
| PG Stability Class | ipg | -- | 4 | 4 | |
| Wind Anemometer Reference Height | zref | m | 10 | 10 | |
| Qmin fraction of Qmax | qmin/qmax | -- | 0.125 | 0.125 | |
| SO ₂ 1h Air Quality Objective | obj_so2 | µg/m ³ | 450 | 450 | |
| H ₂ S 1h Air Quality Objective | obj_h2s | µg/m ³ | 14 | 14 | |
| Receptor Resolution for Maximum Concentration | dsmin | m | 20 | 20 | |
| Raw, Fuel and Lift Gas Temperature before Combustion | tginit | °C | 5 | 5 | |
| Minimum value of Sigma-V (0.01 to 1.0 m/s) | svmin | m/s | 0.2 | 0.2 | |
| Minimum wind speed (0.01 to 1.0 m/s) | wsmin | m/s | 0.2828 | 0.2828 | |
| Maximum meander parameter (0.5 to 1.0) (optional for MLOWWIND2) | franmax | -- | 0.95 | 0.95 | |
| Receptor hill height grid resolution | hhdx | m | 200 | 200 | |
| Modelling domain for receptor grid | rmaxdist | m | 10000 | 10000 | |
| Modelling domain buffer beyond receptor grid | dombuf | m | 5000 | 5000 | |
| Minimum number of data point in a period to apply RBC | mnData | -- | 7884 | 7884 | |
| Number of virtual sources for HbH modelling | nsources | -- | 9 | 9 | |
| Run Flags (see switch table to right) | myrun | -- | 0 | 0 | |
| User Period Selection (Annual or Month) | mflmon | -- | 1 | 1 | |
| Blowdown Distribution of Mass Option | mdist | -- | 2 | 2 | |
| Blowdown User Entry of Qmax | qmax | -- | blank | blank | |
| Blowdown User Entry of Qtotal | qtotal | -- | blank | blank | |
| Land Use around the site | well_lu | -- | 1 | 1 | |

Changes to these settings are intended for testing or calculations performed outside of Alberta, Canada

When an entry is made in the non-default inputs, the entry is highlighted to notify the user that the value is different than the default and a warning comment is displayed adjacent to the entry. In addition, all output pages (see below) are branded with a warning message that a non-default setting was used. For regulatory use in Alberta, all settings must have their default value.

START Page

1 NON-DEFAULT SETTINGS

Ambient Temperature

The average annual temperature for Alberta was determined to be $ta=5$ °C. The average temperature is used for routine flare modelling for determining combustion chemical properties and energy balance. The raw gas and fuel gas may originate (either in a pipeline, facility or below ground) at higher or lower temperatures. However, *AERflare* assumes there is sufficient piping length between the stream source and the flare tip that the flared gas temperature will be equal to the ambient temperature.

For non-routine flaring, the air dispersion modelling and combustion calculations make use of hourly meteorology. The ambient temperature is set to the ambient temperature in the meteorological data set on an hour-by-hour basis.

Average Ambient Wind Speed

The average ambient wind speed (m/s) for Alberta was determined to be $ua=3.5$ m/s. The wind speed is used for routine flare air dispersion modelling for determining the combustion efficiency based upon the ratio of stack velocity to ambient wind speed velocity. For routine flaring, air dispersion modelling is performed using the average meteorological conditions. Flare stacks should be designed to achieve good combustion efficiency under the full range of expected wind speeds to ensure that ambient air quality measurements would not exceed objectives.

For non-routine flaring, the air dispersion modelling and combustion calculations make use of hourly meteorology. The ambient wind speed is set to the ambient wind speed in the meteorological data set on an hour-by-hour basis.

PG Stability Class

The PG (Pasquill-Gifford) atmospheric stability class is used in conjunction with the ambient wind speed. The ambient wind speed is typically measured at the $zref=10$ m anemometer height and is converted to a flare stack tip height using wind profile exponent power-law. The average meteorological condition is assumed to be neutral stability. The PG stability class, ipg , entered here is not used for air dispersion modelling.

For non-routine flaring, the air dispersion modelling and combustion calculations make use of hourly meteorology. The PG stability is set to the ambient wind speed exponent power-law in the meteorological data set on an hour-by-hour basis.

| PG Stability | Class | Description | Wind Speed Exponent |
|--------------|---------|--------------------------------|---------------------|
| 1 | Class A | Extremely unstable conditions | 0.07 |
| 2 | Class B | Moderately unstable conditions | 0.07 |
| 3 | Class C | Slightly unstable conditions | 0.10 |
| 4 | Class D | Neutral conditions | 0.15 |
| 5 | Class E | Slightly stable conditions | 0.35 |
| 6 | Class F | Moderately stable conditions | 0.55 |

Ref: US EPA Industrial Source Complex Model (ISCST) rural wind speed exponents

Wind Anemometer Reference Height

The wind anemometer reference height is the height of the meteorological tower used to collect the wind speed and direction. *AERflare* adjusts the wind speed from the wind anemometer reference height ($zref$) to the stack height (Hs) for use

in the flare source calculations. References to wind speed in the output fields correspond to the wind speed in the original meteorological file and not the adjusted wind speed at stack height.

Qmin Fraction of Qmax

The flaring assessment provided within *AERflare* uses a three-flowrate analysis as opposed to the maximum design flowrate analysis. While the maximum flowrate is an important consideration to determine environmental consequence since it is frequently associated with maximum mass of pollutant emissions rates, typically flaring operations are well below the maximum rate. The high energy associated with the maximum design rate results in a high plume rise and is not necessarily the worst case consequence. Average flowrates or low flowrates from the same diameter flare tip may result in lower plume rise and downwash conditions producing high groundlevel concentrations. Typical operation of flares is about 1/8th of the maximum design flowrate. *AERflare* uses $q_{min}=q_{max}/8=0.125$ as the flow rate by default. For non-default assessments, a different value can be entered for the q_{min} flowrate.

SO2 1h Air Quality Objective

The one hour average ambient air quality objective for SO₂ in Alberta is 450 µg/m³ (ESRD 2011). For other jurisdictions, the ambient objective can be changed. This changes the linkages to references the objective in the RBC and graphics.

H2S 1h Air Quality Objective

The one hour average ambient air quality objective for H₂S in Alberta is 14 µg/m³ (ESRD 2011). For other jurisdictions, the ambient objective can be changed. This changes the linkages to references the objective in the RBC and graphics.

Receptor Resolution for Maximum Concentration

The *AERflare* analysis uses a logarithm distribution of 100-receptor points between 100 m and 10,000 m from the source. Near the source, the receptor to receptor distance is about 5 m whereas far from the receptor the receptor distance is about 500 m. *AERflare* will perform multiple iterations to determine the maximum concentration until a minimum receptor resolution has been achieved. The default resolution is set to 20 m. Therefore, if the predicted maximum concentration is near the source *AERflare* does not iterate, but if the predicted maximum concentration is far from source, *AERflare* may require multiple

iterations. A resolution of 20 m may require three iterations and will therefore increase run-times by a factor of three. A maximum of 5-iterations is used in the *AERflare* calculations.

To prevent *AERflare* from iterating to the maximum concentration and hence speeding up the calculation process, the `dxmin` setting can be set to a large number, e.g., `dxmin=5000`. Do not set `dxmin` to a large number before creating a user terrain grid on the **iUSERTER** page, since `dxmin` is also used as the default spacing around the fenceline (terrain ID=1).

Raw, Fuel and Lift Gas Temperature Before Combustion

The *AERflare* program makes the assumption that the Raw gas, Fuel gas and Lift gas temperature before combustion is at ambient temperature. This assumption is based upon the acknowledgement that there is a measurable length of piping between process operations and the flare tip at which the gases will start to achieve an equilibrium temperature; and, it is a reasonable conservative assumption for the starting point of the energy balance. The starting temperature will have a small effect on the energy balance of the energy contributing to plume rise. When the initial gas temperature is equal to the ambient temperature, more energy may be required to create the same plume rise at different times of the year (winter vs summer). Alternatively, if the initial gas temperature is a fixed value and not a function of ambient temperature, then the temperature difference between the initial gas temperature and the ambient temperature results in a net increase in plume rise.

In *AERflare*, the initial gas temperature (`tginit`) is set to be equal to the ambient temperature (`ta`). `tginit` can be selected to a non-default starting condition on the **iSTART** page. Setting `tginit` to a temperature different than the `ta` temperature setting, forces the initial temperature for the Fuel gas, Raw gas and Lift gas to be a constant temperature, even when the ambient temperature changes through a typical range of -40 °C to +30 °C.

Minimum Value of Sigma-V

The minimum value sigma-v, `svmin`, a horizontal wind speed fluctuation term, used in the processing of meteorology in the *AERMET* module and is set to the *AERMET/AERMOD* default value of 0.2 m/s. This value can be adjusted when used in conjunction with the `mlowwind1` or `mlowwind2` options.

Minimum Wind Speed

The minimum wind speed value, `wsm`, is the minimum wind speed used in the processing of meteorology in the *AERMET* module and is set to the default 0.2828 m/s. The default value is $\text{SQRT}(2 * \text{svmin} * \text{svmin})$ used in previous versions. *AERMOD* allows a range of `wsm`=0.01 to 1.001 m/s.

Maximum Meander Parameter

The maximum meander parameter, `franmax`, is the maximum value of the meander parameter used during *AERMOD* modelling. The default value is 1.0 and also adjusted when using the `mlo` or `mlo2` options. *AERMOD* controls the allowable range of meander parameter to 0.50 to 1.0.

Receptor Hill Height Grid Resolution

AERMOD uses a receptor hill height factor to determine the influence of nearby terrain on predicted concentrations. *AERflare* uses a default grid resolution of `hdx`=200m to determine the maximum terrain elevation near receptors. Therefore, small peaks (less than `hdx`) are assumed to minimally impact the plume path corrections to concentration. Using lower values increases the resolution for determining the maximum hill height and increase computation time to create a user terrain file.

Modelling Domain for Receptor Grid

The default modelling domain size for *AERflare* is 10km radius, `rmaxdist`, creating a rectangular domain of 20 km by 20 km. This domain size is considered the minimum starting distance in an assessment to determine the maximum concentrations from flares.

Modelling Domain Buffer Beyond Receptor Grid

When *AERflare* creates a user terrain grid file, the hill heights factors are determined for locations within the domain plus a domain buffer, `dombuf`. Therefore, hill height factors are determined using a domain size of $2 * (rmaxdist + dombuf)$ by $2 * (rmaxdist + dombuf)$.

Minimum Number Of Data Point In A Period To Apply RBC

The Risk Based Concentration (RBC) limits for routine and non-routine concentration predictions use a percentile concentration to compare to the ambient objective. For example, the routine air quality modelling in Alberta the 99.9th percentile modelled concentration must be less than the ambient objective. *AERflare* checks the meteorological data file and flags missing data (following *AERMOD* programmatic rules). Although the Alberta ambient objectives are based upon a complete year of predictions (8760 hours) a minimum of 90% meteorological data validity is used, `mndata=7884`. If the number of meteorological data points within a year is less than `mndata=7884`, warning flags are displayed and the meteorological data should be considered suspect for systematic errors. Calm periods are assumed to have zero concentration in *AERMOD* and are included as both valid meteorology and predictions in *AERflare*.

Number of Virtual Sources For Hour-By-Hour Modelling

The flare source parameters are a function of meteorology and therefore they change hourly with the meteorological data (typical meteorological data sets are hourly). *AERflare* uses a source that changes hourly with varying effective stack height, effective stack diameter, effective temperature, effective velocity and emission rate. However, *AERMOD* variable emission source control files don't allow for structural changes in the source on an hourly basis but only the variables like emission rate, temperature and velocity. *AERflare* models the variable emission source by discretizing the continuously variable source to fixed number of sources, `nsources`. A minimum of `nsources≥3` should be used and a maximum of 20 sources is allowed in *AERflare*. *AERflare* determines the source parameters and plume rise for all meteorological conditions in the meteorological data file being used. *AERflare* divides the plume rise predictions into `nsources` groups based upon the plume rise ranking, then determines the average source parameters for each group. *AERflare* then models `nsources` flare sources instead of a single flare source. The `nsources` are turned **on** and **off** according to the hourly meteorology and only a single source is on at any meteorological hour. Larger values of `nsources` marginally increases processing time. Lower values of `nsources` decreases the resolution.

Run Flags

The run flags are used to limit the number of scenarios run by *AERflare* when the air dispersion modelling buttons are clicked on the **oMODELLING** page. The

run flags are listed at the top of the table on the **oAERSCREEN** page (row 3). The run flags are set internally according to the Non-Routine flare air dispersion modelling (3 scenarios of SO₂ and 3 scenarios of H₂S are performed) or Routine flare air dispersion modelling (1 scenario of SO₂ and 1 scenario of H₂S are performed). Under all scenarios both a parallel and a terrain case scenario are always performed. Using the table below, run flags can be forced on or off post-reading of the run flags on the **oAERSCREEN** page. The entry for the run flags on the **iSTART** page is a bit-wise comparison.

To run all six scenarios, enter **myrun=63**. To run only scenario 1 and 4, enter the **myrun=9**. The default setting is **myrun=0** which forces *AERflare* to use the settings on the **oAERSCREEN** page.

| Scenario/Case | Typical | MYRUN setting |
|---------------|------------------|---------------|
| 1 | SO2 Max | 1 |
| 2 | SO2 Average | 2 |
| 3 | SO2 Low (Qmax/8) | 4 |
| 4 | H2S Max | 8 |
| 5 | H2S Average | 16 |
| 6 | H2S Low (Qmax/8) | 32 |

A small switch block is provided to the right of the Non-Default Settings entry area that can be used to simplify the entry of **myrun** values. Using the mouse to click on the tiles below each of the 1 through 6 cases, selects the case to be run. If all of the cases are blank, then all of the cases are run, default setting. In the example below, only Case 1 and Case 4 are selected to be run.

| MyRun Model Cases | | | | | |
|-------------------------------------|--------------------------|--------------------------|-------------------------------------|--------------------------|--------------------------|
| 1 | 2 | 3 | 4 | 5 | 6 |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

User Period Selection (Annual or Month)

The **mflmon** flag is automatically raised based upon the selection of the modelling period on the **iFLARING** page. If the user over-rides the default, option, then the result is displayed as a warning on the **iSTART** page.

Transient Blowdown Distribution Of Mass Option

The **mdist** flag is based upon the selection of the transient blow down exponential curve discretization option available on the **iFLARING** page. The default is to divide the exponential curve into steps of equal mass. However, the user may

choose to use steps of equal duration. When this non-default selection is used, the warning is summarized on the **iSTART** page.

Blowdown User Entry of Qmax

The *AERflare* transient source model is based upon the initial volume and conditions of the gas. The source model calculates the maximum release rate and the total volume to be released. Advanced users may use external source model that predict these two variables. The **qmax** (source maximum mass flowrate) and **qtotal** (source total volume) can be entered on the **iFLARING** page and overriding the *AERflare* source model. This non-default entry is summarized as a warning flag on the **iSTART** page.

Blowdown User Entry of Qtotal

The *AERflare* transient source model is based upon the initial volume and conditions of the gas. The source model calculates the maximum release rate and the total volume to be released. Advanced users may use external source model that predict these two variables. The **qmax** (source maximum mass flowrate) and **qtotal** (source total volume) can be entered on the **iFLARING** page and overriding the *AERflare* source model. This non-default entry is summarized as a warning flag on the **iSTART** page.

Land Use around the Well

The *AERflare* screening model requires the land use surrounding the well/facility to be categorized into one of 8-screening categories according to ERSD Air Dispersion Model Guideline (ESRD 2013). The land use is determined based upon the entry of the flare stack coordinates and the determined nearest associated land use point in the database. An advanced user may select a different land use category for assessment. However, this non-default selection is flagged on the **iSTART** page.

iFACILITY

The **iFACILITY** page is used to specify well-site or facility level inputs.

Administrative-Operator

In the Administrative input section, shown below, input is required to identify the licensee and contact information.

| Administrative | UNITS | ENTRY |
|-------------------------------|-------------------|--|
| DUTY HOLDER | Corporate Name | Energy Inc |
| | Mailing Address | 123-4ave, SW |
| | City and Province | Calgary, AB |
| | Postal Code | A1B 2C3 |
| | Contact Name | John Smith |
| | Phone | (403) 123-4567 |
| | Fax | (403) 123-4567 |
| | Email | email@co.com |
| CONSULTANT (if applicable) | Corporate Name | Air Consulting Co. |
| | Mailing Address | 978-6st NW |
| | City and Province | Calgary, AB |
| | Postal Code | A1B 2C3 |
| | Contact Name | A.B. Dunrite |
| | Phone | (403) 111-1111 |
| | Fax | xxx |
| | Email | dunrite@airco.com |

For evaluation mode flaring assessments, the modelling is not presented for an AER approval process unless the application is audited and therefore the Administrative section is not strictly required. However, the completion of these entries forms a good engineering practice of documentation.

Administrative-Consultant

The [consultant](#) or company personnel responsible for entering information in the *AERflare* is entered in the Consultant section. The AER permit review personnel may contact the consultant should a point of clarification be required during the review whereas any substantial deviation or information gap will be directed through the [duty holder](#) contact who submitted the flaring approval.

Well or Facility Details

The Well/Facility details section is required for a non-routine flaring application to the AER. The required details are described below. These details ensure that the flare [duty holder](#) and AER are referring to the same well for the permit.

Site Name

Existing sites have a licenced name. The licence name is often a combination of the reservoir, zone or other name followed by the surface or down-hole location. The exact name as it appears on the licence should be entered, since this name and licence number need to agree in the AER well database. New wells may have been given a temporary name by the AER.

Licence or Approval Number

The AER licence number of the well should be entered. This is typically a 5-digit numeric value. New wells may not have a licence number yet, in which case a suitable entry like “new well” may be entered. Alternatively, if the flare calculations are part of a facility approval, the approval number should be entered.

Unique Well Identifier (UWI)

The unique well identifier (UWI) is the standard well identification that was developed for the petroleum industry by the Geoscience Data Committee of the Canadian Petroleum Association (CPA) and has been adopted by the oil and gas regulatory agencies of the four western provinces and federal areas. It consists of 16 characters, which make up four basic components:

1. legal survey location
2. survey system code
3. location exception code
4. event sequence code

Together these define the approximate geographical location of the bottom of a drill hole and a specific drilling or producing event at the drill hole.

The unique well identifier, although based on the legal survey position of a well, is primarily for identification rather than location. The location component describes the bottomhole location of the well, not the surface position of the well.

Oil or Gas

The Oil or Gas flag is used by *AERflare* to check inputs for soundness. If the Gas is selected then the reservoir engineer would provide the *AERflare* Consultant with only expected gas flowrates and volumes. These are entered on the **iFLARING** page.

If the Oil well is selected, then the well will typically produce oil, solution gas and produced gas in various amounts. The reservoir and/or production engineer

would provide the *AERflare* consultant with oil production rate and maximum GOR (gas to oil ratio taking into account both produced gas and solution gas). The Oil selection is used by *AERflare* to check that the entered maximum flaring rate on the **iFLARING** page is not less than product of oil rate and GOR (these are entered on the **iFACILITY** page). Additionally, AER D060 has volume allowances for Oil versus Gas wells; these checks are made on the **oSUMMARY** page in the D060 Permit Conditions checklist group.

Critical Well Classification

A critical sour well is a sour gas well that could potentially release large quantities of hydrogen sulphide (H₂S), causing significant harm to nearby people.

All applications to the AER to drill oil or gas wells must take into account the possibility of encountering sour gas. If the AER's first evaluation shows that there may be H₂S, then the application is examined further.

The AER uses two major criteria to determine if a sour well is to be classified as critical:

- how close the well is to an urban centre or public facility, such as a major recreational facility, and
- the potential H₂S release rate during the drilling stage.

The potential H₂S release rate is determined by both the percentage of H₂S in the gas and the rate at which gas that can be delivered to the surface. This is measured in cubic metres per second at standard pressure and temperature.

For example, a well may have both a weak flow of gas with only 1 per cent H₂S content but still be critical if it is very close to a town. But a gas well with 10 per cent H₂S content located in a remote location without people nearby might not be classified as critical.

The Critical Well selection in *AERflare* is an important flag for both the Operator and the AER approval review process. However, the selection does not impact the calculations performed by *AERflare* and is therefore cosmetic.

Formation(s) and Zone(s) to be Tested

A well being drilled will have a target formation and zone. Wells being tested or enhanced may have multiple formations and zones. The AER database tracks the activities and gas compositions of the various zones and formations. This entry is used by AER to confirm the Operator activities correspond to *AERflare* assessment and to verify/validate basic information used in the assessment.

Number of Zones to be Tested

The *AERflare* prompts the user for the number of zones being tested. The number of zones tested is descriptive of the operations planned by the Operator for the well and flaring activities. The *AERflare* spreadsheet must be completed for each zone tested. The flaring activities associated with the well will be limited by total volume flared according to the number of zones to be tested. The total volume flared for each of the completed *AERflare* spreadsheets on the individual zone test must be less than or equal to the total allowable for all zones volume listed on the **oSUMMARY** page in the AER D060 Permit Conditions group.

Lahee Classification

The volume allowance for an individual zone is a function of the Lahee Classification for the well. A listing of the descriptions of the Lahee classifications are provided on the **LAHEE** page. Adjacent to each description is the Tier number corresponding to the AER D060 volume allowance. The **oSUMMARY** page in the AER D060 Permit Conditions group compares the volume flared for this zone to the Tier allowance.

Surface Location

The surface location of the well is entered as a legal land survey description according to the Dominion Land Survey System. The format of the surface location should be:

(LSD-SEC-TWP-RGE-W?M)

Corresponding to:

| | | |
|-----|-------------------|---|
| LSD | Legal subdivision | Legal subdivisions are numbered from 1 to 16. A legal subdivision measures 402 by 402 metres (1320 by 1320 feet). |
| SEC | Section | Sections are numbered 1-36. A section measures 1.609 by 1.609 km (1 mile by 1 mile). |
| TWP | Township | Townships are numbered 001-126. A township measures 9.7 km (6 miles) north to south. |
| RGE | Range | Ranges are numbered from 1 to 30. Note that West of the sixth meridian contains a maximum of 14 ranges only. A range measures 9.7 km (6 miles) east to west. |
| W?M | Meridian | For the purposes of survey locations, the province of Alberta is subdivided into three areas defined by the meridians of longitude. For unique well identifier purposes, these are referred to as west (W) of the fourth, fifth, and sixth meridians. Acceptable values: W4M, W5M, W6M |

Mapping Projection

Surface coordinates are entered for the flare. For well tests, the flare location is nominally assigned to the well location unless its specific location is known. In the latter case, the specific location should be used for the surface coordinates of the flare. The coordinates entered are associated with a mapping projection. *AERflare* accepts the mapping projections (datum) in the table below. The project is used to convert the user entered coordinates to geographic (latitude and longitude) for internal use in determining the closest land cover data in the *AERflare* database.

| |
|------------------------------|
| Geographic (spheroid: WGS84) |
| 10TM (spheroid: NAD83) |
| UTM (spheroid: NAD83) |

UTM Zone

If the Mapping Projection was selected to be UTM, the user is required to enter the UTM zone or use the dropdown selection tool. The UTM zones for Western Canada are illustrated in Figure 2.

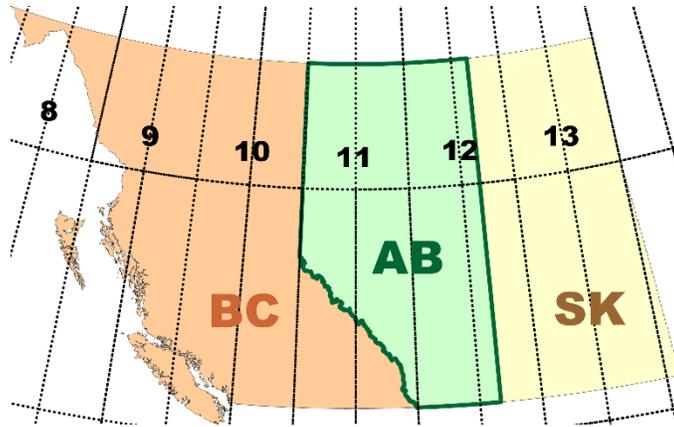


Figure 2: UTM Zones for Western Canada

Surface Coordinates of Flare

The (X,Y) pair of surface coordinates are entered for the flare location. If a well test flare is being assessed and the exact flare location is not known, then the well surface flare location can be entered. The coordinates must correspond to the mapping projection entered in the selection above.

The surface coordinates are an important entry for *AERflare* since they are used to determine the terrain and land use. The terrain and land use are critical inputs into the air dispersion model. Once the user has entered the coordinates on the **iFACILITY** page, the user can use the **iLOCATION** page to visually check if the coordinates were entered correctly. The **iLOCATION** converts the X,Y coordinates into Longitude/Latitude and UTMX/UTMY pairs.

| Flare Location | |
|--------------------------------------|-----------|
| X UTM | 481234 |
| Y UTM | 6112345 |
| UTM Zone | 11 |
| Conversion to Geographic Coordinates | |
| Longitude | -117.2945 |
| Latitude | 55.1574 |

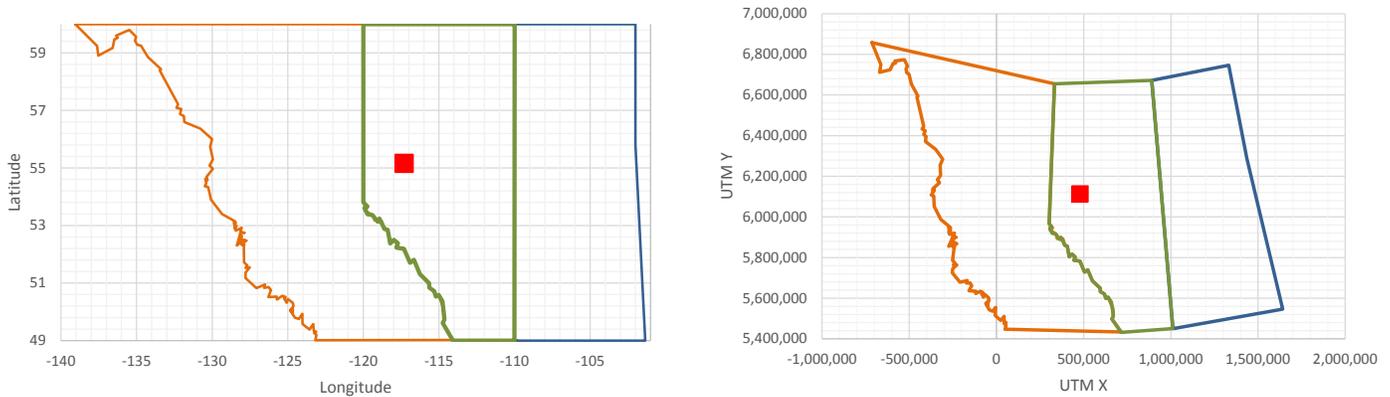


Figure 3: Visual check for X,Y Flare Location Entry in Longitude/Latitude (left) and UTMX/UTMY (right)

Flare Base Elevation

The base elevation of the well is the terrain elevation at the well surface (or flare location). The base elevation is an important variable since it is used to determine the atmospheric pressure for the combustion calculations. The terrain elevations vary dramatically across the province and can result in non-negligible changes in the emissions or source parameters. The flare base elevation is also an important entry relative to the terrain elevations used. Improper entries can result in artificial increase in effective stack height or lowering of stack height.

If the [melev](#) option is selected on the **iSTART** page, then the flare base elevation will be reset by the terrain processing. The flare base elevation is determined by triangulation of the nearest three DEM data points. If the [melev](#) option is not used, then *AERflare* will warn the user if the DEM determined elevation of the flare is different than the value the user has entered.

Land-use Characterization

The Land Cover is based upon available data for Canada (www.geobase.ca; circa 2000; based upon Canadian Forestry datasets and Canada Agriculture datasets). Land cover has been summarized for Alberta, B.C. and Saskatchewan based upon a gridded screening approach.

For screening level assessments, land cover (see Figure 4) was sampled within a cell size of 10km × 10km at nine locations. Land cover was reduced to the ESRD air dispersion modelling screening land cover sets (see Table 1 and Table 2). The most frequent land cover for the cell is represented at the location of the cell centre. This methodology creates a data set that is small enough to be easily contained within the spreadsheet while still well representing the dominant land

features. The coarse data is essentially pre-averaged therefore *AERflare* can just select the closest grid point as a representative LCC (see Figure 5).

AERflare uses the flare location coordinates to perform a search for the closest land cover sample in the database (see Figure 5). If the flare location falls outside of the database land cover range or if the user wishes to perform sensitivity testing on the flaring predictions using a different land cover, then the user can select a non-default land cover. For approvals using the *AERflare* spreadsheet, the default land cover is required.

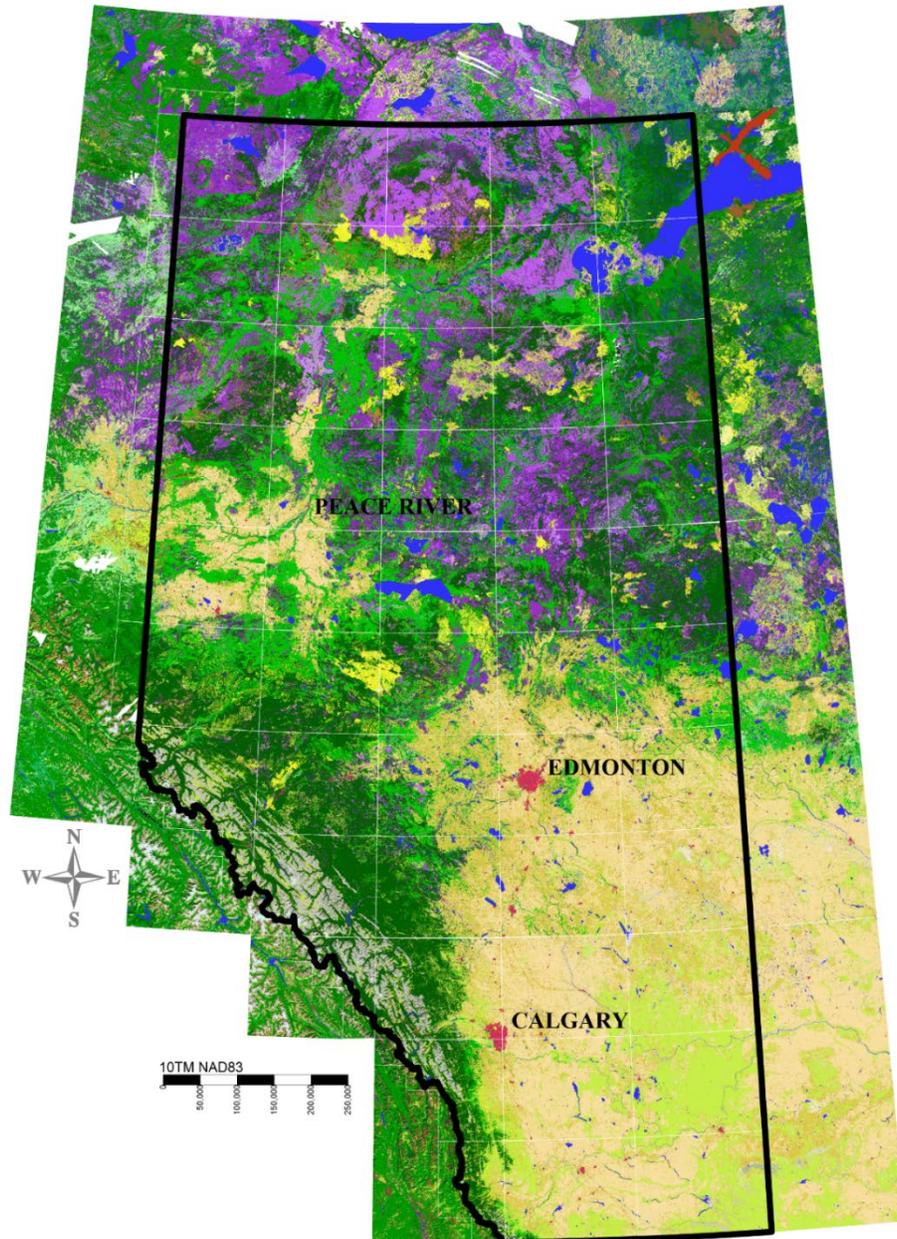


Figure 4: High Resolution Land Cover for Alberta

Table 1: Land Cover Classification

| | LCC | COUNT | Alberta Fraction | Description | Group | Description |
|---|-----|--------|------------------|---------------------|-------|-------------|
| ☐ | 11 | 460 | 0.1% | Cloud | 3 | Cultivated |
| ■ | 12 | 6657 | 0.9% | Shadow | | |
| ■ | 20 | 25952 | 3.7% | Water | 7 | Water |
| ■ | 30 | 1015 | 0.1% | Barren/NonVegetated | 3 | Cultivated |
| ■ | 31 | 3632 | 0.5% | Snow/Ice | | |
| ■ | 32 | 14096 | 2.0% | Rock/Rubble | | |
| ■ | 33 | 7078 | 1.0% | Exposed Land | | |
| ■ | 34 | 3287 | 0.5% | Developed | 5 | Urban |
| ■ | 50 | 1462 | 0.2% | Shrubland | 3 | Cultivated |
| ■ | 51 | 19413 | 2.7% | Shrub tall | | |
| ■ | 52 | 2906 | 0.4% | Shrub low | | |
| ■ | 80 | 1899 | 0.3% | Wetland | 6 | Swamp |
| ■ | 81 | 54525 | 7.7% | Wetland-treed | 1 | Coniferous |
| ■ | 82 | 46085 | 6.5% | Wetland-shrub | 6 | Swamp |
| ■ | 83 | 8258 | 1.2% | Wetland-herb | | |
| ■ | 100 | 18958 | 2.7% | Herb | 4 | Grassland |
| ■ | 110 | 45614 | 6.4% | Grassland | | |
| ■ | 120 | 43 | 0.0% | Cultivated | 3 | Cultivated |
| ■ | 121 | 90920 | 12.8% | Annual cropland | | |
| ■ | 122 | 61275 | 8.6% | Perennial/Pasture | | |
| ■ | 210 | 189 | 0.0% | Coniferous Forest | 1 | Coniferous |
| ■ | 211 | 149728 | 21.1% | Coniferous-Dense | | |
| ■ | 212 | 30832 | 4.3% | Coniferous-Open | | |
| ■ | 213 | 1166 | 0.2% | Coniferous-Sparse | | |
| ■ | 220 | 786 | 0.1% | Deciduous Forest | 2 | Deciduous |
| ■ | 221 | 99312 | 14.0% | Broadleaf-Dense | | |
| ■ | 222 | 3781 | 0.5% | Broadleaf-Open | | |
| ■ | 223 | 122 | 0.0% | Broadleaf-Sparse | | |
| ■ | 230 | 6 | 0.0% | Mixed Forest | 1 | Coniferous |
| ■ | 231 | 9470 | 1.3% | Mixed Wood-Dense | | |
| ■ | 232 | 857 | 0.1% | Mixed Wood-Open | | |
| ■ | 233 | 112 | 0.0% | Mixed Wood-Sparse | | |

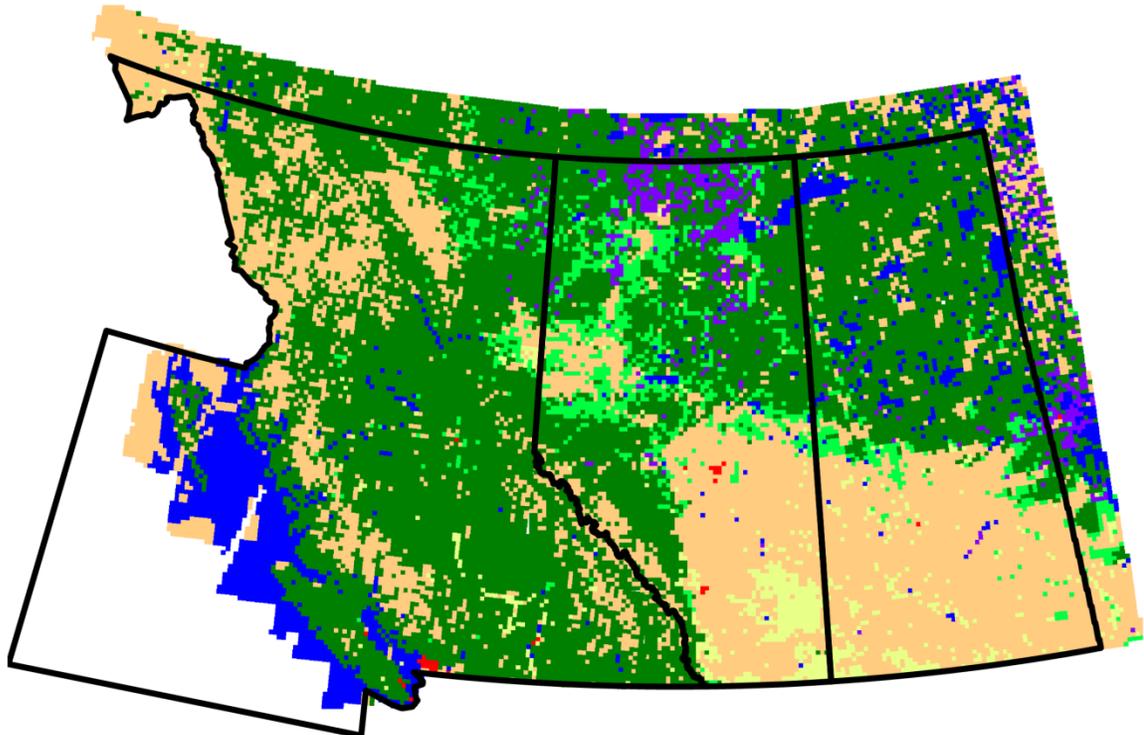


Figure 5: Screening Land Cover for Western Canada

Table 2: Screening Land Cover Classification

| | | Description | Alberta Fraction |
|---|----|-------------------|------------------|
| ■ | 10 | Coniferous Forest | 34.8% |
| ■ | 20 | Deciduous Forest | 14.7% |
| ■ | 30 | Cultivated Land | 29.4% |
| ■ | 40 | Grassland | 9.1% |
| ■ | 50 | Urban | 0.5% |
| ■ | 60 | Swamp | 7.9% |
| ■ | 70 | Water | 3.7% |
| ■ | 80 | Desert Shrubland | 0.0% |

The land cover is used to define the appropriate *AERSCREEN* meteorological data set to use in the air dispersion modelling. The *AERSCREEN* utility program *MAKEMET.exe* was used to prepare seasonal screening data sets according to Table 3. The set of screening meteorological data sets are included in the install package for *AERflare*. Each file contains approximately 2500 variations of

meteorology. Both *AERMOD* profile and surface files are provided so that they can be used for other assessments or sensitivity analysis.

Table 3: Screening Meteorological Variations Used for AERSCREEN- MAKEMET.exe

| Variable | Screening Meteorological File | | | | | | | |
|--------------------------------|-------------------------------|-------|--------|-------|-------|-------|--------|--------|
| | conif | decid | cultiv | grass | urban | swamp | water | desert |
| Minimum wind speed (m/s) | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Anemometer height (m) | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| SPRING -- Min Temp. (K) | 239.4 | 239.4 | 239.4 | 239.4 | 239.4 | 239.4 | 239.4 | 239.4 |
| Max Temp. (K) | 306.1 | 306.1 | 306.1 | 306.1 | 306.1 | 306.1 | 306.1 | 306.1 |
| Albedo | 0.12 | 0.12 | 0.14 | 0.18 | 0.14 | 0.12 | 0.12 | 0.3 |
| Bowen Ratio | 0.7 | 0.7 | 0.3 | 0.4 | 1 | 0.1 | 0.1 | 3 |
| Zo, roughness (m) | 1.3 | 1 | 0.03 | 0.05 | 1 | 0.2 | 0.0001 | 0.3 |
| SUMMER --.Min Temp. (K) | 271.9 | 271.9 | 271.9 | 271.9 | 271.9 | 271.9 | 271.9 | 271.9 |
| Max Temp. (K) | 310.5 | 310.5 | 310.5 | 310.5 | 310.5 | 310.5 | 310.5 | 310.5 |
| Albedo | 0.12 | 0.12 | 0.2 | 0.18 | 0.16 | 0.12 | 0.1 | 0.28 |
| Bowen Ratio | 0.3 | 0.3 | 0.5 | 0.8 | 2 | 0.1 | 0.1 | 4 |
| Zo, roughness (m) | 1.3 | 1.3 | 0.2 | 0.1 | 1 | 0.2 | 0.0001 | 0.3 |
| FALL -- .Min Temp. (K) | 238.9 | 238.9 | 238.9 | 238.9 | 238.9 | 238.9 | 238.9 | 238.9 |
| Max Temp. (K) | 306.5 | 306.5 | 306.5 | 306.5 | 306.5 | 306.5 | 306.5 | 306.5 |
| Albedo | 0.12 | 0.12 | 0.18 | 0.2 | 0.18 | 0.12 | 0.14 | 0.28 |
| Bowen Ratio | 0.8 | 1 | 0.7 | 1 | 2 | 0.1 | 0.1 | 6 |
| Zo, roughness (m) | 1.3 | 0.8 | 0.05 | 0.01 | 1 | 0.2 | 0.0001 | 0.3 |
| WINTER -- Min Temp. (K) | 226.5 | 226.5 | 226.5 | 226.5 | 226.5 | 226.5 | 226.5 | 226.5 |
| Max Temp. (K) | 290.0 | 290.0 | 290.0 | 290.0 | 290.0 | 290.0 | 290.0 | 290.0 |
| Albedo | 0.35 | 0.5 | 0.6 | 0.6 | 0.35 | 0.35 | 0.2 | 0.45 |
| Bowen Ratio | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 6 |
| Zo, roughness (m) | 1.3 | 0.5 | 0.01 | 0.001 | 1 | 0.05 | 0.0001 | 0.15 |

Operations to be Conducted

The AER approval review requires a description of the well test operations (cleanup/workover/testing/etc) to be performed. This is brief description of the work that will be completed and may include more than one zone.

Total Volume of Raw Gas to be Flared

During the operations to be conducted (see above description) the estimated total volume of raw gas to be flared during clean-up and testing of all zones is entered. The total volume is compared to the AER D060 Permit Conditions. This entry

provides a soundness check between the expectations of the Operator for the well clean up and the limits of prescribed by D060 for reducing flaring and conserving gas.

Total Estimated Days with Flaring for ALL Zones

The total work over of the well and cleanup is entered. The entry is compared to the D060 Permit Conditions limiting the duration of activities and flaring.

Well tied into Production Facilities

This entry is used by AER for consideration of future activities at the well, such as adding pipeline to tie the well or feasibility of performing in-line well testing. Additionally, this information is valuable in consideration of conservation of gas.

Information on the Feasibility of In-Line Well Testing Attached

If the well is tied into existing facilities, it may be possible to perform an in-line well test rather than a flared well test. An engineered feasibility report should be attached to the application for wells with a tie-in.

Previous Flaring/Incineration Permit

If the well is an existing well, then previous operations may provide a historical perspective on the necessity of the work over, flaring and emissions. Provide the previous permit number and date if the approval was acquired within the past twelve months.

Requested Approval Start Date/End Date

Scheduling non-routine well test flaring is often a moving target. *AERflare* requires a start date and end date when the flaring is forecast to occur. The duration may not exceed 60 days.

The start and end date are important conditions for the well test flare permit.

Emergency Response Details

In addition to consideration of energy conservation, flaring reduction and ensuring environmental objectives will be met, the AER requires that the Operator also plan sour gas emergency response plan (ERP) details. One step in the emergency response planning is the determination of the emergency planning zone. The *AERH2S* model is expected to be run to determine the emergency planning zone (EPZ) size.

H2S Release Rate

In the event of an accident at the well, gas can be released from the formation under its own pressure. Depending upon the operations, gas can reach the surface through the casing (casing diameter source) or through tubing (tubing diameter source). The release rate of H₂S is the product of the gas composition and the estimate absolute open flow (AOF) for the well.

$$[\text{H}_2\text{S Release Rate}] = [\text{AOF}] \times [\text{mole fraction of H}_2\text{S}]$$

Because there is no backpressure, the AOF is generally larger than the flaring rate for the well test or production flaring scenario. The AOF is calculated by *AERflare* using the above equation and is compared to the maximum flaring rate as a check of proper inputs. A warning message is displayed if the maximum flaring rate is greater than 80% of the calculated AOF. While in some circumstances, this ratio may be appropriate, a warning message is displayed for this atypical situation. The user should double check the data entered for consistency.

Emergency Response Planning Zone Distance

The emergency response planning zone distance is entered in *AERflare* to ensure that the Operator has considered ERP in advance of the planned operations.

Is an ERP Required?

The licensee or operator must meet emergency response plan requirements for sour wells. The plan must incorporate provisions for the temporary equipment as appropriate. (See AER D071: *Emergency Preparedness and Response Requirements*.)

The licensee must submit a sour well site-specific drilling and/or completion ERP to the AER for approval in accordance with Direction 071 or for any other situation in which the AER determines that a plan is required.

Surface development within the EPZ influences whether an ERP is required. Surface development includes residences that are required to egress through the EPZ and residences immediately adjacent to the EPZ.

In the event that a licence application requires a public hearing, the licensee is expected to develop and provide an ERP to the AER that has been deemed technically complete prior to issuing a notice of public hearing.

A sour well site-specific drilling and/or completion ERP may be used for testing, workover, or well servicing operations on that well for a period of up to one year after AER approval provided that those operations

ERP Reference Number

If an ERP is required, it has been completed and approved by the AER, then it will have been assigned an ERP reference number. Enter the reference number for the ERP.

Fluid Production Details

If Oil well was selected on the **iFACILITY** Well Details inputs, then the well will typically produce oil, solution gas and produced water in various amounts. The reservoir and/or production engineer would provide the *AERflare* consultant with oil production rate and maximum GOR (gas to oil ratio taking into account both produced gas and solution gas). The Oil selection is used by *AERflare* to check that the entered maximum flaring rate on the **iFLARING** page is not less than product of oil rate and GOR (these are entered on the **iFACILITY** page). Additionally, AER D060 has volume allowances for Oil versus Gas wells; these checks are made on the **oSUMMARY** page in the D060 Permit Conditions checklist group.

Anticipated Fluid Production

Enter the anticipated fluid production rate.

Gas to Fluid Ratio

The gas to fluid ratio for oil wells, **GOR**, is used to estimate the total gas available to be flared using

$$[\text{Gas Rate}] = [\text{Fluid Produced}] \times [\text{GOR}]$$

The maximum flaring rate used for the *AERflare* assessment should not be greater than [Gas Rate].

Careful attention should be applied to the estimate of maximum fluid production and maximum GOR. Since both values are *maximums* and inherently rare events, the product of the two is a very conservative estimate and a very rare event. The assessment of flaring based upon the extreme maximum gas rate may lead to an over-sized flare (a flare that has a large diameter to accommodate the worst case flow but is operated at much lower flowrates.) Oversized flares may lead to flaring combustion in-efficiency resulting in an exceedance of the ambient air quality objectives.

iFLARING

The **iFLARING** page is the page where the *AERflare* source parameters are entered for the specific flaring event being assessed. Whereas, the **iFACILITY** page contained global considerations of the overall work-over operations, the focus on the **iFLARING** page is on the conditions of an individual flaring scenario.

Flaring Details

The Flaring Details group is used by both Non-Routine and Routine flaring assessments.

| Flaring Details | UNITS | ENTRY |
|---|--|--|
| Subject Zone | | Leduc |
| Scenario Name | (operation such as cleanup or variable such as fuel gas) | 01-02 First Well |
| Time of Year to Model the Flare | -- | Annual  |
| Flare Stack Tip Exit Height | m | 27.432 |
| Flare Stack Tip Exit Diameter | mm | 102 |
| Requested Maximum Raw Gas H ₂ S Concentration for Subject Zone | % (for approvals round up to 0.5% increment) | 16.00% |

Subject Zone/Source

The well work over may involve several zones. On the **iFLARING** page enter the single zone that will be considered for the flare event. For sources other than wells, enter a brief description.

Scenario Name

The scenario name is descriptive name used by the Consultant to reference the flare event. It is also used to identify flaring events in the **iBATCH** database. In this case, it is helpful if the Scenario Name is unique, but it is not a requirement.

Time of Year to Model the Flare

The default assessment for *AERflare* is to consider the entire meteorological period so that a sufficient range of meteorological variations is considered in the screening assessment.

The *AERflare* assessment can be performed using a screening meteorological data set or a 5-year site-specific meteorological data set that may have been developed. If an annual assessment is selected, then either the screening or the site specific meteorological data set can be used in the modelling. Alternatively, to possibly take advantage of favourable meteorological conditions, the flaring assessment can be performed by limiting the meteorology to only the month of the expected flare event (the mid-point of the start and end dates for the flaring entered on the **iFACILITY** page). In this latter case, the assessment must be performed using the site specific meteorology data set, since the screening data set is not monthly but only seasonal and it does not contain sufficient number of variations. Whereas the 5-year site specific meteorological data can be reduced to five 3-month set of variations and provide more than 8760 variations. The number of variations tested is displayed on the **oAERSCREEN** output page. *AERflare* blocks output for monthly assessments and risk based output when the number of variations is less than 8760.

The default centre-month for the assessment is determined by the mid-point of the start and end dates for the flaring entered on the **iFACILITY** page. Sensitivity testing can be performed by modelling alternative months, but these months will be flagged as non-default.

For non-routine flaring, the **AERSCREEN-MAX(HbH)** modelling button (see **oMODELLING**) will be disabled when the monthly assessment option is used. Note that monthly assessment using the provided screening meteorological data sets will produce erroneous results since the format of the *AERSCREEN* date and

time do not match calendar dates. The option is available for future or advanced users.

Seasonal predictions are provided using the screening meteorological data sets when the Annual option is used. Although, the risk based criteria are displayed in this case when $N < mndata$, the screening meteorological dataset analysis uses the maximum concentrations only.

Flare Stack Tip Exit Height

The flare stack height above grade is entered.

The meteorological conditions at the flare stack height are used for combustion and source modelling with a minimum of 10m. The site specific meteorological data sets should be extracted at the flare stack exit height for the best estimate of the meteorology at that height when 3D wind fields are used. *AERflare* always corrects for the difference between the meteorological anemometer height and the stack. Therefore, if the site specific data was extracted at the stack height, then the correction in the wind speed will be zero.

Flare Stack Tip Exit Diameter

The inside diameter of the flare stack at the exit height are entered. If the flare stack exit is not circular, then an equivalent diameter can be entered based upon the exit area:

$$D = \sqrt{Area \times 4/\pi}$$

This assumption will maintain the proper momentum of the flare gas at the exit.

Requested Maximum Raw Gas H₂S Concentration

For the Subject Zone, the maximum H₂S concentration of the gas composition (entered in percent, %). The maximum H₂S concentration does not have to match the reference composition provided in the gas composition (lower portion of **iFLARING** page).

Continuous/Steady or Transient

The *AERflare* tool can be used to assess steady/continuous emissions or transient emissions resulting from a vessel or pipeline blowdown. The selection is made in

the Continuous/Steady or Transient data group. Transient flare inputs and modelling are discussed in Chapter 6.

| | |
|----------------------|--|
| Flaring Type? | <input checked="" type="radio"/> Continuous or Steady <input type="radio"/> Transient |
|----------------------|--|

Continuous or Short-Term Steady

For non-routine flaring assessments three emissions modelling scenarios are considered: maximum (Q_{max}), average (Q_{ave}) and a low rate ($Q_{max}/8$). Therefore two sets of inputs are required to define Q_{max} and Q_{ave} . The user must enter the Q_{max} and two of the three remaining fields. Only two of three remaining fields need entry because the third is function of the other two. The third value is calculated in the gray area to the right of then entry location.

In the example below, the required Q_{max} entry is $15 \times 10^3 \text{m}^3/\text{d}$. The user has entered two of the remaining fields, $\text{Average Flow Rate} = Q_{max}/2 = 7.5 \times 10^3 \text{m}^3/\text{d}$ and the duration of flaring, $\text{Duration} = 72$ hours. The total flared $\text{Volume} = 22.5 \times 10^3 \text{m}^3$ is calculated from Average Flow Rate and Duration .

| Continuous or Steady | UNITS | ENTRY | WARNINGS |
|--|--|-------|--------------------|
| Maximum Raw Gas Flow Rate for Source of Sour Gas | $10^3 \text{m}^3/\text{d}$ (15°C and 101.325 kPa) | 15 | |
| MUST enter any 2 of the fields: i) VOLUME of Raw Gas to be Flared ii) AVERAGE FLOW RATE of Raw Gas iii) DURATION of Flaring | i) Volume 10^3m^3 (15°C and 101.325 kPa) ii) Average Flow Rate $10^3 \text{m}^3/\text{d}$ (15°C and 101.325 kPa) iii) Duration hours | 7.5 | 22.500 -- -- |

Maximum Raw Gas Flow Rate

The maximum raw gas flow rate is the peak gas flow rate expected from the non-routine well test or upset/emergency scenario. For routine flare air dispersion modelling the maximum gas flow rate represents the scenario flow rate. Routine flare air dispersion modelling may require multiple assessments to ensure that the complete range of flare flow rates results in adequate combustion efficiency to avoid ground level exceedance of the ambient air quality objectives. Assessment of only the maximum flow rate, may result in an over-sized flare (a flare that has a large diameter to accommodate the worst case flow but is operated a much lower flowrates). Oversized flares may lead to flaring combustion in-efficiency

or flame instability and downwash resulting in an exceedance of the ambient air quality objectives.

Average Flow Rate Parameters

The average flow rate is determined by conservation of mass and entering any two of: the total volume flared, the average flow rate, or flaring duration. Using conservation of mass, the missing variable is readily calculated. Specifying all three can lead to errors if not entered correctly.

$$[\text{Volume}] = [\text{Flowrate}] \times [\text{Duration}]$$

Volume

The volume is the total volume to be flared during the flaring of this zone.

Flow Rate

The flow rate is the average flow rate during flaring of this zone. An estimate of the average flow rate is $Q_{\max}/2$.

Duration

The duration of actual flaring of this zone needs to be entered. Don't enter the time elapsed since the start of operations. For instance, if flaring occurs during daylight hours only (12-hours) and flaring occurred on two days of operations, then the duration is 24-hours.

Transient Source

See Chapter 6: Transient Blowdown Sources

Fuel Gas

The fuel gas input group is greyed out if no fuel gas is added. When fuel gas is added, enter the fuel gas to raw gas ratio for each of the Q_{\max} , Q_{ave} and Q_{\min} scenarios.

| Fuel Gas | UNITS | ENTRY | WARNINGS |
|---|--|---|--|
| Is Fuel Gas Added? | Last resort, see D060 7.4(4a) | <input type="radio"/> No <input checked="" type="radio"/> Yes | Adjust Fuel Gas to Raw Gas Ratio manually in Cell C42-E42, then check dispersion results |
| | Maximum (QMAX) | Average (QAVE) | Minimum (QMIN) |
| Fuel Gas to Raw Gas Volume Rate Ratio (default is zero) | 0 | 0.1 | 0.2 |
| Warnings | Acceptable NHV: 30.3 MJ/m ³ | Acceptable NHV: 35.4 MJ/m ³ | Acceptable NHV: 39.7 MJ/m ³ |

Below the input locations for each fuel gas ratio, an information or warning message appears. The message may contain important information such as the required fuel gas ratio to meet D060 minimum heating values. The messages may be influenced by other **iFLARING** entries such as gas composition, flow rates, lift gas and/or flare assist.

Lift Gas

The Lift Gas input group is greyed out if no lift gas is used to supplement the flow to the surface for the well. It is assumed that lift gas is homogeneously mixed with the raw gas brought to the surface.

| Lift Gas | UNITS | ENTRY |
|---|---|---|
| Is CO ₂ or N ₂ used to Initiate Lift in Well? | | <input type="radio"/> No <input checked="" type="radio"/> Yes |
| Lift Gas Flow Rate (See Lift Gas composition below) | 10 ³ m ³ /d (15°C, 101.325 kPa) | 10 |

In addition to the amount of lift gas entered in this group, the lift gas gas-composition must be entered on the lower part of the **iFLARING** page in the Gas Composition input group. Lift gas may be inert or hydrocarbon. If the lift gas is inert, then additional fuel gas may be required. The warning messages below the fuel gas ratio inputs can provide important information regarding extra fuel gas requirements.

Flare Assist

Flare assist is not commonly used for non-routine flaring but may be an important aspect of routine flaring at a facility. *AERflare* incorporates the effects of either or both steam assist and air assist. Although commonly used to influence the visual impacts of flaring (i.e., reduce particulates) through the addition of momentum at the source and some latent heat, flare assist has been found to reduce flare efficiency by reducing of the net heating value of the flared gas. Flare assist may reduce particulate formation, however, the formation of

particulates is not an accurate measure of flaring efficiency. Because both air and steam introduce composition components beyond theoretical stoichiometric conditions, flare assist efficiency studies indicate a reduction of flare combustion efficiency. While small rates of flare assist don't significantly impact combustion efficiency, and the added momentum may assist the flare, steam to raw gas rates above 2 can reduce combustion efficiency below ideal levels. *AERflare* combines the flare assist streams into a single flared gas stream while conserving momentum and energy. *AERflare* uses a combustion efficiency model based upon the net heating value of the flared gas stream in relation to ambient wind speed. Since flare assist increases momentum but reduces heating value, a competing effect results especially at high assist rates.

| Flare Assist | UNITS | ENTRY |
|-----------------------|-------|---|
| Is Flare Assist Used? | -- | <input type="radio"/> No <input checked="" type="radio"/> Yes |
| Steam or Air Assist? | -- | <input type="radio"/> Steam <input type="radio"/> Air <input checked="" type="radio"/> Both |

Steam Assist

Flare Assist: Number of Ports

Steam flare assist may consist of many injector ports. It is assumed that all of the ports will increase upward momentum. Ports located around the flare exit diameter as well as ports in the centre of co-flowing injectors are included.

Flare Assist: Port Diameter of a Single Injector

All of the injection ports are assumed to be the same diameter. If injectors vary in diameter then an equivalent diameter can be entered based upon the total area of all ports.

$$D = \sqrt{\frac{Total_Area}{N_{ports}} \times \frac{4}{\pi}}$$

Entry Mass rate or Volume Rate?

Typically steam assist is specified as a mass flow rate. *AERflare* allows for either mass or volume flow.

Steam Assist Pressure

The quality of the steam is required. *AERflare* assumes saturated steam and will calculate the critical pressure. If the pressure is known, it should be entered.

Steam Assist Temperature

The quality of the steam is required. Typical low pressure steam is about 150 °C. *AERflare* assumes saturated steam and will calculate the saturated temperature.

Steam Assist

AERflare allows steam assist flow rates to vary with flaring scenario rates (**Qmax**, **Qave** and **Qmin**). Because of the significant impact flare assist rates have on the flame combustion and flame instability (i.e., blowout or flammability limits) flare assist rates must be tuned to the raw gas flow rates.

Air Assist

Air Assist: Number of Ports

Air flare assist may consist of many injector ports. It is assumed that all of the ports will increase upward momentum. Ports located around the flare exit diameter as well as ports in the centre of co-flowing injectors are included.

Air Assist: Port Diameter of a Single Injector

All of the injection ports are assumed to be the same diameter. If injectors vary in diameter then an equivalent diameter can be entered based upon the total area of all ports.

$$D = \sqrt{\frac{Total_Area}{N_{ports}} \times \frac{4}{\pi}}$$

Air Assist Rate

The air assist flow rates are entered as a volume flow rate at reference conditions ($\times 10^3 \text{m}^3/\text{d}$, 15°C and 101.325 kPa). *AERflare* allows air assist flow rates to vary with flaring scenario rates (**Qmax**, **Qave** and **Qmin**). Because of the significant impact flare assist rates have on the flame combustion and flame instability (i.e., blowout or flammability limits) flare assist rates must be tuned to the raw gas flow rates.

Flare Assist Flammability Check

Below the Air Assist flow rate entries a warning message may appear for each of the flaring scenario rates (**Qmax**, **Qave** and **Qmin**) indicating whether the flare is considered over-assisted. The flare is considered over-assisted when the flaring efficiency is predicted to drop below 98%.

Gas Compositions

The gas composition input group provides entries for the raw gas, lift gas and fuel gas streams. The flare assist streams of steam and air have known gas composition and don't require specific entry. The user should provide a referenced raw gas stream composition that may or may not have the same H₂S concentration as the flare modelled amount. The reason for this is to allow for regulatory H₂S limit or fluctuating range of H₂S. The *AERflare* model will re-normalize the raw gas composition using requested H₂S in place of the H₂S content specified in the Raw Gas composition.

The fuel gas composition is similarly entered. Typically, fuel gas will be 100% propane if the flaring is performed at remote locations. Otherwise, fuel gas may be supplied by pipeline spec natural gas which contains typically >90% methane. Representative pipeline quality natural gas composition is listed in Hubbard (2009) and TransCanada (2012) are listed in Table 4.

Table 4: Representative Pipeline Quality Natural Gas (Hubbard 2009)

| Major & Minor Components (Mole%) | Minimum | Maximum | Alberta Maximums |
|----------------------------------|---------|--------------------|-----------------------|
| Methane | 75 | -- | Not specified |
| Ethane | -- | 10 | Not specified |
| Propane | -- | 5 | Not specified |
| Butanes | -- | 2 | Not specified |
| Pentanes plus | -- | 0.5 | Not specified |
| Nitrogen & other inerts | -- | 3-4 | Not specified |
| Carbon dioxide | -- | 3-4 | 2% by Volume |
| Trace Components | | | |
| Hydrogen Sulphide | -- | 0.25-1.0 gr/100scf | 23 mg/m ³ |
| Mercaptan Sulphur | -- | 0.25-1.0 gr/100scf | |
| Total Sulphur | -- | 5-20 gr/100scf | 115 mg/m ³ |
| Water Vapour | -- | 7.0 lb/mmscf | 65 mg/m ³ |
| Oxygen | -- | 0.2-1.0 ppmv | 0.4% by volume |

Lift gas composition may be inert (e.g., CO₂, N₂) or may be a hydrocarbon. The lift gas composition can be entered similarly to raw and fuel gas. The lift gas composition should be referenced.

The gas composition should sum to 1.0000. If the entries do not sum to 1.0000, a warning is displayed as shown below. This feature assists in preventing typographical errors.

Gas Composition Total

The gas composition total is calculated below each stream composition provides a check that the gas composition was entered correctly. It is assumed that the inputs are normalized to 1.0000 and therefore, the Gas Composition Total should display 1.0000 when the entries are completed. Blank cells are assumed to be zero.

Gas Analysis Reference

The Gas Analysis Reference should be entered in the field at the bottom of gas stream. The reference should include the following:

- location of where the gas was sampled
- date of the sample
- well name or id

iTERRAIN

The **iTERRAIN** page is used to input mapping and terrain elevations. The inputs are split into two inputs group. The first input group is used to enter mapping details and the maximum terrain elevation in the study area (within 10 km of the flare location). The second input group is used to enter the terrain elevations from the flare location to the maximum elevation point.

The **iTERRAIN** page is designed to force the user to read a map rather than just entry of digital terrain data. Careful consideration for the map details assists in the understanding of the location of sensitive receptors and validation of receptor terrain heights. At the same time, it is recognized that users may be using digital versions of 1:50,000 map sheets and digital terrain elevations are also available. If digital elevations are used, digital contours must be demonstrated to be representative of 1:50,000 scale map sheet contours and maps must show the location of closest distance to contour elevation selections.

Topographical Map Details and Maximum Terrain

The map details input group is used to document the 1:50,000 topographical map-set used to for determining map elevations, contour intervals and maximum elevation.

| Topographical Map Details and Maximum Terrain | UNITS | ENTRY | COMMENTS |
|--|----------------|--|----------|
| 1:50,000 topographical map(s) for terrain within 15 km of flare | (e.g., 82 O/1) | 82 O/1 | |
| Contour interval units of map with maximum elevation within 10 km | | <input checked="" type="radio"/> metres <input type="radio"/> feet | |
| Contour interval of map with maximum elevation | metres | 10 | |
| Is maximum elevation a surveyed peak? | | <input checked="" type="radio"/> Yes <input type="radio"/> No | |
| Maximum contour elevation or surveyed peak elevation within 10 km (200 mm radius on map) | metres | 753 | |
| Map distance from flare to centre of maximum contour or maximum surveyed peak elevation | mm | 139 | |

1:50,000 Topographical Map(s)

The list of 1:50,000 scale topographical map sheets used in the review of the elevation contours.

Contour Interval Units of Map

Specify whether the map has units of feet or metres.

Contour Interval of Map with Maximum Elevation

Specify the contour interval on the map sheet. The goal is to determine the maximum contour elevation within 10 km (see **iSTART** [rmaxdist](#)) of the flare location. 10km is considered the maximum reasonable applicability of a plume model in elevated terrain for flaring assessment.

Is Maximum Elevation A Surveyed Peak?

1:50,000 topographic maps mark surveyed peaks on hills but not necessarily on minor hills or sub-peaks on hill complexes. The maximum location is a surveyed peak then that elevation is used as the last point in the terrain list. If digital elevation data is used to determine the maximum elevation, that elevation is considered a surveyed peak. Otherwise, if a map sheet is used, it is not possible

to determine the peak between contour intervals, and the surveyed peak is set to “no” and the distance to centre of the maximum contour is entered.

Maximum Contour Elevation or Surveyed Peak Elevation

Specify determined maximum elevation as a surveyed peak (or digital elevation model maximum) or the maximum contour level within 10 km (see **iSTART rmaxdist**). 10 km is 200 mm on 1:50,000 scale topographical map. The units of the maximum elevation or contour level should correspond to the entry above (*Contour Interval Units*.)

Map Distance from Flare to Centre of Maximum Contour or Maximum Surveyed Peak Elevation

Enter the distance (in user measurement, mm) from the flare location to the centre of the maximum contour or to the maximum surveyed peak elevation. If the peak is not a surveyed peak then the maximum terrain elevation is determined as:

$$\text{Maximum Elevation} = \text{Maximum Contour Level} + \frac{\text{Contour Interval}}{2}$$

Worst Case Terrain and Complex Terrain Criteria Parameters

The non-routine flaring air dispersion modelling uses an hour-by-hour source characterization with the effective height of the source change for each hour of the meteorology. Therefore, the impacts of terrain height on the air dispersion modelling are also varying. Additionally, because terrain heights regularly exceed stack height, most air dispersion modelling assessments invoke the model’s complex terrain processing algorithms. *AERflare* requires worst case terrain heights to be input for screening by the air dispersion model. *AERflare* evaluates both parallel and elevated terrain air dispersion modelling predictions.

Based upon the user inputs in the *Topographical Map Details* input group, the *Worst Case Terrain* input group has created a skeleton table to be completed by the user. Listed in the table are the contour levels and input prompts for the map distance (in mm for a 1:50,000 scale topographical map) to the nearest contour line. The table displays common complex terrain criteria at each location/contour level pair.

| Worst Case Terrain and Complex Terrain Criteria Parameters | | | |
|--|-------|-------------------|---|
| Using 1:50,000 scale NTS topographical map(s), measure the shortest distance (in mm), from flare to the indicated contour elevations | | | |
| CONTOUR ELEVATION | ENTRY | CONTOUR ELEVATION | ELEVATED TERRAIN CRITERIA PARAMETERS |
| metres | mm | feet | |
| 674 | 0 | 2211 | Above Flare Base |
| 680 | 22 | 2231 | 0.5 % (slope) |
| 690 | 59 | 2264 | 16 m (plume) |
| 700 | 74 | 2297 | 26 m (plume) |
| 710 | 88 | 2329 | 36 m (plume) |
| 720 | 106 | 2362 | 46 m (plume) |
| 730 | 121 | 2395 | 56 m (plume) |
| 740 | 126 | 2428 | 66 m (plume) |
| 750 | 134 | 2461 | 76 m (plume) |

Below the Worst Case Terrain input group is a graphic showing the entries of terrain height and distance compared to a schematic of the stack height and complex terrain criterion for the stable atmosphere. Gaussian plume air dispersion models are most likely to predict maximum concentrations near the point where the complex terrain criterion crosses the terrain elevations.

The graphic also shows the effective flame height for the average meteorological wind speed and temperature.

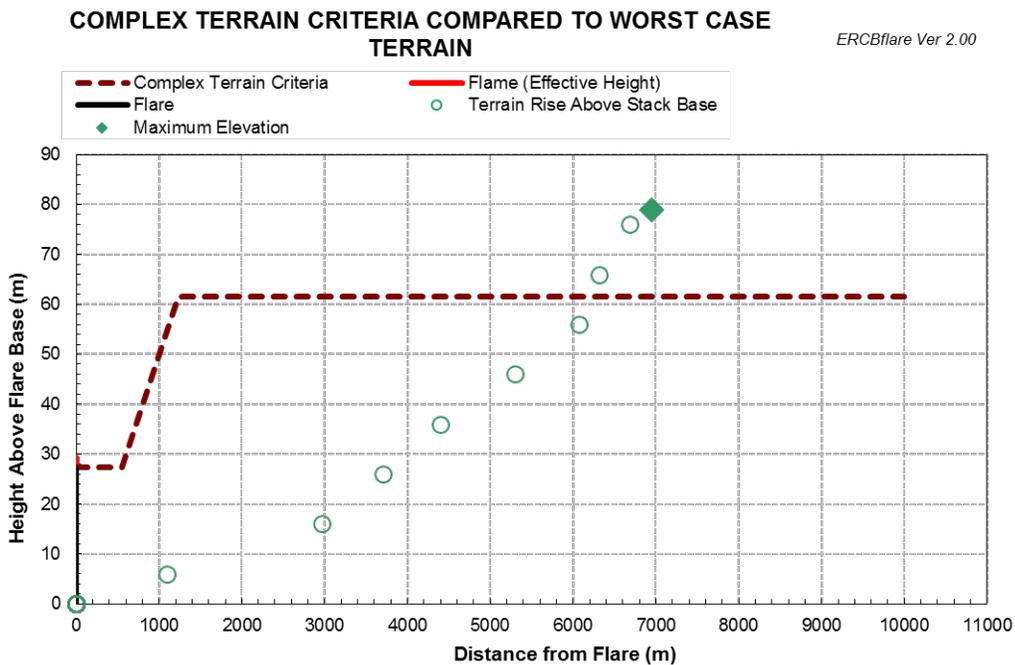


Figure 6: Worst Case Complex Terrain Graphic Showing Terrain Elevations as a Function of Distance

Complex Terrain Summary

The *Complex Terrain Summary* Group lists summary information about the terrain elevations relative to the stack height and stable plume rise predictions.

| Complex Terrain Criteria Summary | feet | metres |
|---|--------------|-------------------|
| Maximum Terrain Elevation | 2470 | 753 |
| Stable Plume Criterion Elevation | 2638 | 804 |
| Stack Height Criterion Elevation | 2301 | 701 |
| Well Centre Elevation | 2211 | 674 |
| Maximum Terrain Height Above Flare Base | 259 | 79 |
| Stable Plume Criterion Height Above Flare Base | 427 | 130 |
| Stack Height Criterion Above Flare Base | 90 | 27 |
| | miles | kilometres |
| Stack Height Criterion Extends from Flare to | 0.34 | 0.55 |
| Slope Criterion Extends from Stack Height Criterion (above) to Stable Plume Height Criterion at | 0.98 | 1.58 |
| Distance from Flare to maximum elevation | 4.3 | 7.0 |
| Slope to maximum elevation | 1.1% | 1.1% |



The **iTERRAIN** graphic is a good way to confirm the user entries for terrain elevations are representative.

Get DEM Data – BUTTON

The **Get DEM Data** button is used for automatic terrain processing. When the button is pressed, *AERflare* uses the UTM coordinates or Latitude/Longitude coordinates entered on the **iFACILITY** page to determine the NTS mapsheets required for modelling domain around the flare location. *AERflare* first looks in the *DEMLIB* area (see **iBIN** page) for the mapsheet. If the file is not available it will be downloaded automatically and placed into the *DEMLIB* library location. *AERflare* will then process all of the required mapsheets and fill in the **iTERRAIN** page based upon the mapsheet data. The raw data is displayed to the right of the **iTERRAIN** main entry area. The DEM mapsheet data is 25 m resolution.

The elevation of the flare location is determined from the DEM data using triangulation. The elevation at the flare location is displayed to the right of the **iTERRAIN** main entry area. The user should verify that the DEM data elevation is similar to the site survey elevation entered on the **iFACILITY** page. Differences between the **iFACILITY** page elevation and the DEM map data

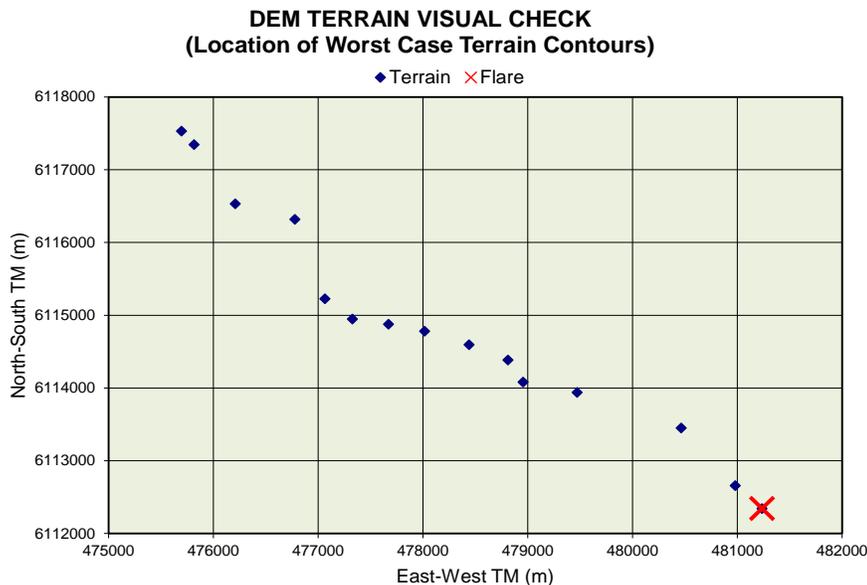
elevation can result in an artificial increase effective stack height or an artificial lowering of the stack height. The `melev=1` setting on the **iSTART** page is used, the elevation of the flare on the **iFACILITY** is reset to the elevation determined by the DEM.

Load XYZ DEM Data – BUTTON

User-defined DEM data can be used in place of the **DEMLIB** library. A text file with comma or space delimited x,y,z data. Where x,y are coordinates in the same projection used to specify the source location on the **iFACILITY** page; and, z is the elevation in metres. The same processing is used as the DEM mapsheet data. The user-defined DEM data should be of similar resolution (25 m) and data quality as the DEM mapsheet data.

DEM Terrain Visual Check

At the bottom of the **iTERRAIN** page is a graphic that can be used as a visual check against a contour map for the region. The graphic, shown below for Site A (see Example 2). The graphic shows the location of the flare source in UTM coordinates and the location of the terrain elevations representing the closest distance to the worst case terrain contour. Each location represents a contour level as listed in the Worst Case Terrain and Complex Terrain Criteria Parameters section of **iTERRAIN** page.



iNOTES

The **iNOTES** page has two purposes. First, the AER reviewers specifically request a descriptive response for the first four questions to assist in their understanding of non-routine flaring. Secondly, the page allows the user keep track of assumptions or information regarding the assessment

Information is to be provided for the following prompts on the **iNOTES** page. These prompts are the minimum information AER requires to gain an understanding of the non-routine operations:

- 1) For permanent facilities describe the flaring event modelled including the type of facility, pipeline segments or vessels to depressurize (if applicable), PSV size, etc.
- 2) Estimate the frequency of the flaring event
 - a) number of events per year;
 - b) duration of each event;
 - c) total number of hours per year
- 3) Describe attempts to reduce or eliminate the flaring event(s) if applicable
- 4) State any engineering assumptions you've made in completing the entries for *AERflare*

The remainder of the **iNOTES** page can be used to summarize references, assumptions or other notes pertinent to the flaring scenario. The **iNOTES** area can be used in *Batch* mode to store sensitivity and scenario notes.



For non-routine flares, AER requests a descriptive response for the first four questions to assist in their understanding of the necessity for flaring. You may provide additional information as attachments, but the information entered in those responses should provide a sufficient executive summary for the reviewer. Failure to provide sufficient information may cause delays in processing the application for the flaring permit.

4. AIR DISPERSION MODELLING AND OUTPUT

Non-routine flaring events are typically of short duration, less than an hour, but may extend over a day. The flow rate may be steady (constant) in time if there is a supply of gas but may decrease in time if a vessel or pipeline is being blown down. Regulatory air dispersion models such as *AERMOD* and *CALPUFF* simulate steady releases with a continuous plume. *CALPUFF* is the only model that can directly model short duration and transient releases.

A modelling approach is needed to apply the existing air dispersion models to non-routine flaring emission sources in order to verify compliance with ambient air quality objectives. The continuous plume models can be used with appropriate inputs and adjustments to the output. When the release is not continuous, the hour by hour predictions can be used as this is equivalent to modelling the release occurring in any hour of the year. The daily and annual average predictions cannot be used as they are based on a continuous release.

For a steady release the inputs are based on the release rate. For example, inlet gas or acid gas diverted to flare can be modelled as steady releases. The gas released to the flare is being replaced by gas coming into the plant or process area and the pressures within the piping remains relatively constant. For a steady release of d -minutes duration, the predicted 1 hour average concentration outputs from a continuous plume model are adjusted. If the release duration is less than 60 minutes, the hourly predictions are multiplied by $d/60$. If the release duration d is greater than or equal to 60 minutes, the hourly predictions are not adjusted.

The **MODELLING** page presents a summary of the flared gas streams flow rates. Below the flow rates, are listed the heat released to the plume, calculated excess air, estimated flame temperature, flared mixture net heating value and the conversion efficiency based up on the average meteorological conditions. The combustion efficiency of the combusted portion is slightly higher to allow for the unconverted portion which is stripped and not unconverted. These are determined using:

$$\eta_{conv} = 1 - \frac{A}{NHV^3} \exp\left(\frac{B U_a}{(g U_s D_s)^{1/3}}\right)$$

Where $A=133.3$ [(MJ/kg)³]; $B=0.317$; Net Heating Value (NHV) [MJ/kg]; U_a is ambient wind speed [m/s]; g is gravity [m/s²]; U_s is source exit velocity [m/s]; D_s is source diameter [m].

| Flare: 27.432 m exit height with 0.102 m exit diameter | | | | |
|---|--|-------------------|-------------------|-------------------|
| | UNITS | Maximum (QMAX) | Average (QAVE) | Minimum (QMIN) |
| Raw Gas Rate | 10 ³ m ³ /d (15°C, 101.325 kPa) | 15.000 | 7.500 | 1.875 |
| Fuel Gas to Raw Gas Volume Rate Ratio | -- | 0.000 | 0.000 | 0.000 |
| Fuel Gas Rate | 10 ³ m ³ /d (15°C, 101.325 kPa) | 0.000 | 0.000 | 0.000 |
| Steam Assist Rate | 10 ³ m ³ /d (15°C, 101.325 kPa) | 0.000 | 0.000 | 0.000 |
| Air Assist Rate | 10 ³ m ³ /d (15°C, 101.325 kPa) | 0.000 | 0.000 | 0.000 |
| Lift Gas Rate | 10 ³ m ³ /d (15°C, 101.325 kPa) | 0.000 | 0.000 | 0.000 |
| Routine Flaring Parameters at Average Ambient Conditions of 93.7 kPa, 5.0°C and Wind Speed of 3.5 m/s | | | | |
| Sensible Heat Release to Plume | kW | 4111 | 2054 | 513 |
| Excess Air | % | 112% | 112% | 112% |
| Estimated Flame Temperature | °C | 857 | 857 | 857 |
| Flared Mixture Net Heating Value | MJ/m ³ | 32.02 | 32.02 | 32.02 |
| Conversion Efficiency | % | 99.67% | 99.63% | 99.48% |

Pseudo-Source Parameters

The *AERflare* calculations produce a set of pseudo-source parameters based upon conservation of energy and conservation of momentum. Using an estimate of the flame temperature and momentum *AERflare* determines the buoyancy flux and the momentum flux parameters. These flux parameters are used by air dispersion models to determine the final rise of the emissions plume. These flux parameters can then be used to reverse engineer (back calculate) source parameters that will result in the calculation of the flux parameters. These source parameters are called pseudo-source parameters (see Figure 7) since they mimic a source that will lead to the correct plume rise. In the figure, D_s , H_s , U_s and T_s represent the actual source diameter, height, exit velocity and temperature. *AERflare* calculations pseudo-source parameters for D_s^* , H_s^* and U_s^* to conserve the source energy and momentum. T_s is the estimate real source temperature. U_s^* includes the momentum provided by steam or air assist. H_s^* is the estimated flame height including the stack height, H_s , and stack tip down wash. D_s^* is back-calculated from buoyancy and momentum flux formulations used for plume rise calculations. The X_s^* and Y_s^* are determined using the Brzustowski flare model based upon the wind speed, wind direction and flare parameters.

AERflare provides a summary of the pseudo-source parameters on the **oMODELLING** page. The pseudo-source parameters can be used for refined air dispersion modelling of the flare source in air dispersion models or *AERflare*. Pseudo-source parameters are based upon the actual source parameters for the flare scenario but do not necessarily have real physical relevance. That is, the pseudo-source diameter is not a real diameter of the stack or flame width, but only a calculated diameter to mimic a source so that the calculated plume rise is

correct. Caution should be used in using the pseudo-source parameters for anything except their intended purpose.

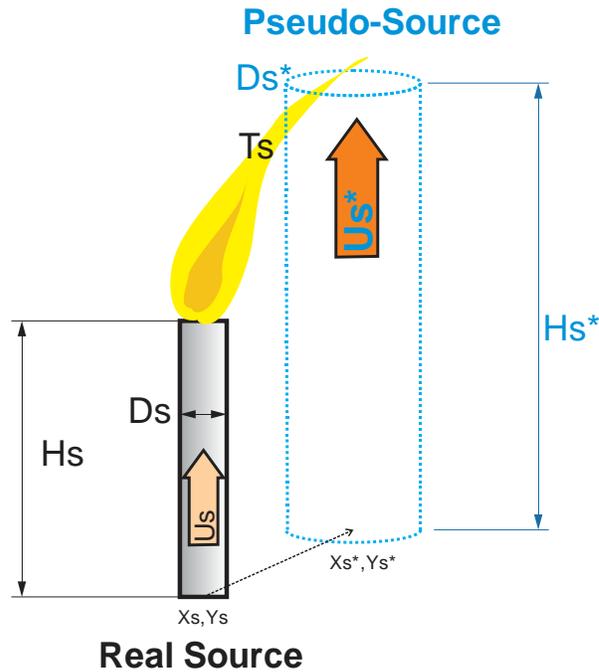


Figure 7: SO₂ Flare Model for Source Parameters

The pseudo-source parameters for the SO₂ emissions for a sour gas flare are based on the estimated flame temperature using the estimated combustion efficiency. The combustion efficiency is a function of the net heating value of the flared gas and of the ambient wind speed. There the pseudo-source parameters can change as quickly as the meteorology changes. The summary table shows the parameters for each of the **Q_{max}**, **Q_{ave}** and **Q_{low}** flow rate scenarios. Note that the SO₂ source model assumes that 100% of the raw gas sulphur is converted to SO₂. The effective height of the SO₂ source is estimated flame height based upon the Brzustowski Flare Model.

| SO ₂ Dispersion Model Stack Exit Input Parameters | UNITS | Maximum (QMAX) | Average (Volume/Duration) | Minimum (QMIN) |
|---|-------|-------------------|------------------------------|-------------------|
| SO ₂ Emission Rate | g/s | 75.263 | 37.631 | 9.408 |
| Effective Height | m | 29.226 | 28.551 | 27.688 |
| Pseudo Diameter | m | 4.719 | 4.717 | 4.713 |
| Pseudo Velocity | m/s | 0.966 | 0.483 | 0.121 |
| Estimated Temperature | K | 1130.64 | 1130.63 | 1130.49 |
| Assumed Ambient Air Temperature | K | 278.15 | 278.15 | 278.15 |



Note that the SO₂ source model assumes that 100% of the raw gas sulphur is converted to SO₂.

For SO₂ dispersion modelling, users must not apply combustion efficiency factors to reduce the SO₂ emissions to gain regulatory acceptance.

The pseudo-source parameters for the H₂S emissions for a sour gas flare are based on flare studies (Kostiuk, Johnson and Thomas 2004) that show that flare inefficiency in high winds is a result of fuel stripping from the combustion zone of the flame. This is illustrated in Figure 8. The fuel stripping is un-combusted fuel and therefore contains non-oxidized raw gas components or partially oxidized raw gas components depending upon the kinetics of the component and the residence time at higher temperatures. Some of the raw gases exit from the flame tip (path A) and some raw gases exit through path B. Both paths have approximate equal magnitude of emissions. *AERflare* assumes the gases exiting path B remain as H₂S, whereas the fraction that exists through path A will likely have been heated sufficiently to oxidize the H₂S.

The source model for H₂S is based upon a simplifying assumption that the temperature of the gases (path B) is constant and is the average of the raw gas temperature and lower flammability limit of the mixed raw gases (because the gases are not combusted they must be less than the combustion temperature). Therefore the energy available for plume rise of the path B gases is proportional to the mass emission rate which is a function of wind speed. Pseudo-source parameters are back calculated based upon the heat transfer to buoyancy and an effective height equal to half of the flame height based upon the Brzustowski Flare Model.

The SO₂ source model energy is corrected for the small loss in energy lost by the stripping model used in the H₂S model for completeness. The inefficiency fraction the raw gas carries accounts for a small amount of momentum which is used to estimate the source exit velocity. The exit velocity is limited by the *AERflare* source model minimum exit velocity to prevent number errors in dispersion models determined through experience.

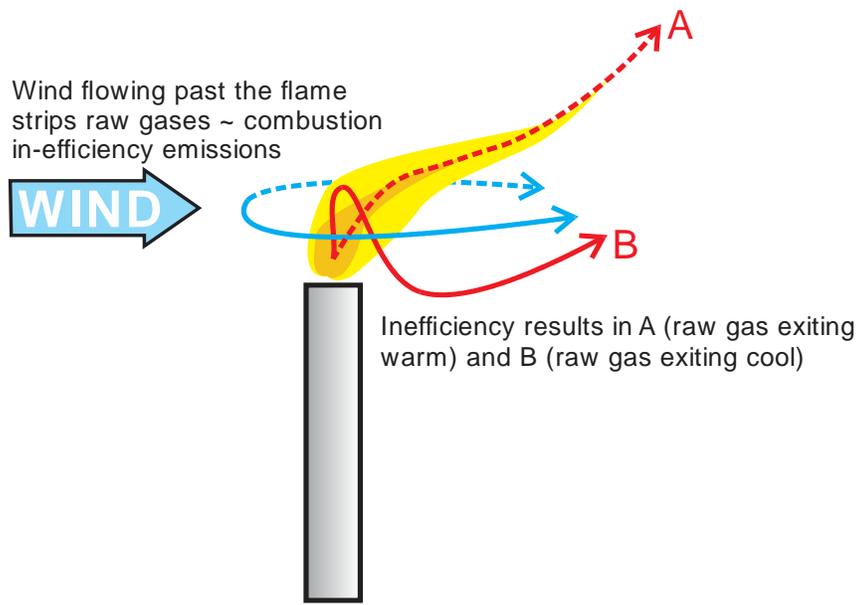


Figure 8: H₂S Stripping Model for Source Parameters

The table of the H₂S pseudo-source parameters can be used for refined air dispersion modelling of the H₂S source. The temperature for the H₂S source model is a result of the energy and momentum back calculation.

| H ₂ S Dispersion Model Stack Exit Input Parameters | UNITS | Maximum (QMAX) | Average (Volume/Duration) | Minimum (QMIN) |
|---|-------|----------------|---------------------------|----------------|
| H ₂ S Emission Rate | g/s | 0.032 | 0.027 | 0.016 |
| Effective Height | m | 28.329 | 27.991 | 27.476 |
| Pseudo Diameter | m | 0.085 | 0.110 | 0.169 |
| Pseudo Velocity | m/s | 1.031 | 0.515 | 0.129 |
| Estimated Temperature | K | 521.99 | 521.99 | 521.99 |
| Assumed Ambient Air Temperature | K | 278.15 | 278.15 | 278.15 |

Calculation Buttons

Calculation buttons (see **oMODELLING** page) are used to perform air dispersion modelling using *AERMOD* and to create *AERMOD* ready input files. The generalized flowchart that represents the calculation process once a calculation button is pressed is shown in Figure 9. User inputs are gathered from the three principal *AERflare* input pages (**iFACILITY**, **iFLARING** and **iTERRAIN**). For a flaring emissions scenario (**Qmax**, **Qave** or **Qmin**) a terrain assessment is selected, either (parallel or elevated terrain). For the parallel scenario the terrain is forced to be the same elevation as the flare base elevation. For the elevated

terrain scenario, the terrain entered on the **iTERRAIN** page is interpolated for a receptor grid from 100m to 10km. Once the maximum terrain elevation is reached, all points on the receptor grid remain at the maximum elevation. *AERMOD* uses a slope based algorithm for determining hill height influences at each receptor location which are calculated by *AERflare*.

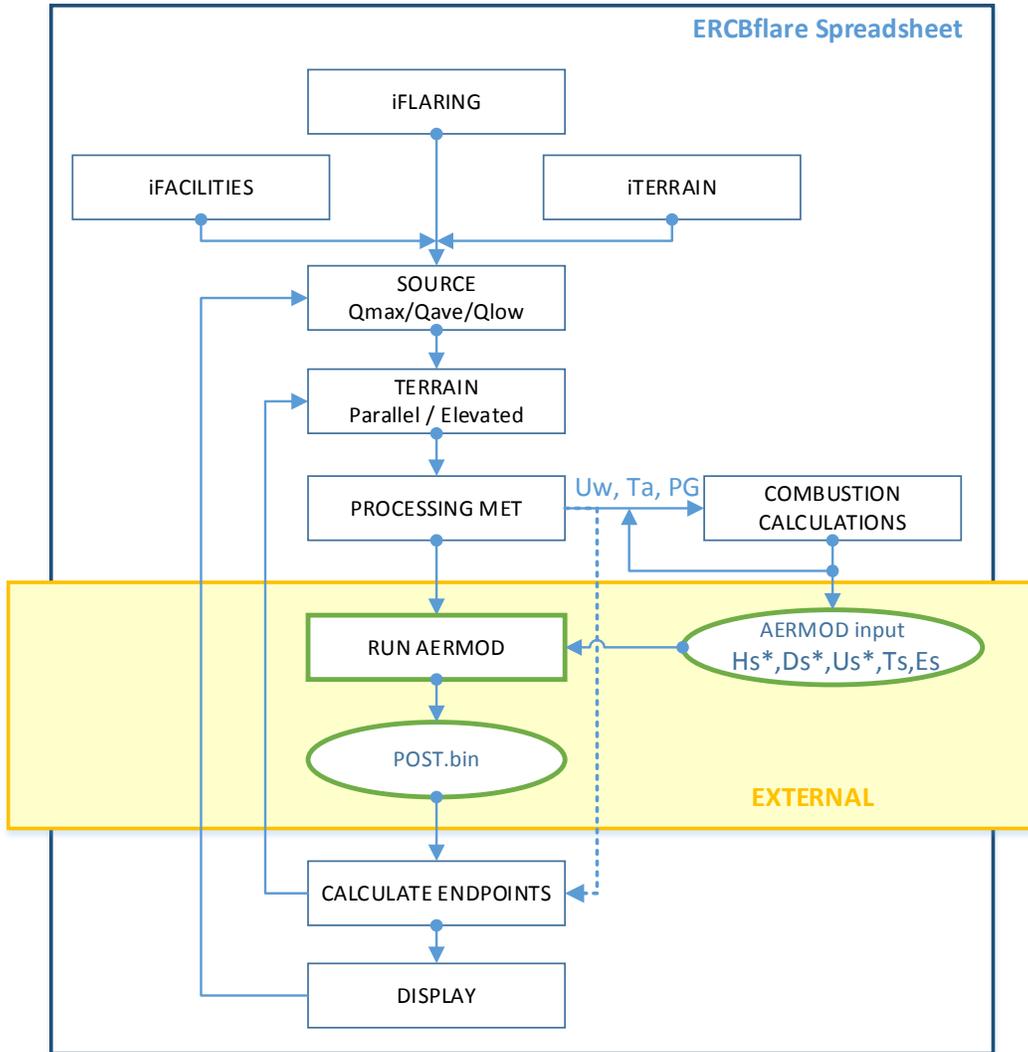


Figure 9: Calculation Flowchart

Either a screening or a user specified site specific *AERMOD* style meteorological surface file is sequentially processed. For each hour of meteorology, the ambient wind speed, temperature and atmospheric stability class (U_w , T_a and PG) are determined and then inserted into the *AERflare* combustion calculation engine. The output from the combustion and related calculations are a set of source pseudo-parameters that conserve source energy and momentum. Source Height, diameter, velocity, temperature, and emissions (H_s^* , D_s^* , U_s^* , T_s and E_s) are saved to an *AERMOD* ready variable emissions source file.

Once all of the meteorology has been processed in this way, the AERMOD program is executed to perform the air dispersion modelling calculations. The hourly *AERMOD* output for each receptor is saved into a binary output file (POST.BIN). This file is then processed by *AERflare* and the Risk Based Criteria (RBC) are used to compare and against the respective statistics calculated. The *AERMOD* program, AERMOD.inp file and POST.bin file are external to the *AERflare*, in a DOS COMMAND PROMPT window.

The process is repeated to determine the concentrations for both parallel and elevated terrain. Both parallel and elevated terrain are assessed since this represent the range of terrain elevations possible, thus bounding the range of expected concentrations with distance. Parallel terrain results may be applicable along or through a valley and the elevated terrain may be applicable when winds blow over hills in the study area.

The process is repeated to determine the concentrations for **Qmax**, **Qave** and **Qmin**. Because there is a non-linear relationship between the energy released, plume rise, combustion efficiency, downwash and air dispersion modelling predictions, it is important to assess the range of likely flaring rates to ensure compliance with ambient air quality objectives.

For Routine Mode flare air dispersion modelling, the process outlined in Figure 9 is simplified since only the Alberta average meteorological conditions are used.

There are eight calculation buttons available when the user selects the **Recalculate** button and is redirected to the **MODELLING** page (listed below) and discussed in the following sections.

| Button | Flaring Assessment Mode | Purpose |
|--|-------------------------|---|
| 1.AERSCREEN-MAX | Routine | Screening Evaluation |
| 2.AERSCREEN-(RBC) (User Met) | Routine | Bridge to Refined Modelling |
| 3.AERMOD-(RBC Refined Modelling using User Terrain and User Met) | Routine | Refined Modelling |
| 4.Create AERMOD files (Modelled Wind Speed)- (User Terrain and User Met) | Routine | Create AERMOD ready files for further assessment by the user. |
| 5.AERSCREEN-MAX (HbH) | Non-Routine | Screening for Permit |
| 6.AERSCREEN-RBC (User Met) | Non-Routine | Bridge to Refined Modelling for Permit |
| 7.AERMOD-RBC Refined Modelling using User Terrain and User Met | Non-Routine | Refined Modelling for Permit |
| 8.Create AERMOD files (HbH with User Terrain and User Met) | Non-Routine | Create AERMOD ready files for further assessment by the user. |



It is recommended that you DO NOT use your computer for other concurrent Windows applications when running the dispersion models, because this can cause interference and instability within the calculations.

1. AERSCREEN-MAX

This calculation runs *AERMOD* using *AERSCREEN* methodology. Wind is from a single wind direction blowing towards all receptors, always. Two assessments are performed, one for parallel terrain (terrain heights equal to the flare base elevation) and complex terrain (terrain heights as input on the **iTERRAIN** page) allowing the *AERMOD* processing to determine the how terrain impacts the ambient air quality predictions. The screening meteorological data sets are used to account for land cover and provide a seasonal variation in meteorology. Approximately 2500 variations in meteorology are assessed. Because the number of variations is less than 7884 ([mndata](#)), only the maximum concentration is used in the interpretation of the air dispersion modelling results (although the seasonal predictions are available for interpretation).



The *AERSCREEN* modelling runs include both the parallel and complex terrain assessments. The parallel terrain predictions are a typical worst case for wind directions not towards terrain, and the complex terrain predictions are a typical worst case for wind directions towards terrain. All assessment must include terrain

AERflare iterates to determine the maximum concentration when a XY receptor grid is not used. The receptor grid used for AERSCREEN-MAX uses a logarithmic distribution of points between 100 m and 10000 m using 100 receptors. The terrain elevations are interpolated from the **iTERRAIN** page. The receptor point of the maximum concentration is determined and the distances of the receptor points before and after are extracted from the receptor array. This minimum and maximum distance is then used re-determine the maximum concentration using a logarithmic distribution of 100 receptor points. This process continues until the distance between receptor points at the maximum is less than DXMIN from the **iSTART** page.

2. AERSCREEN-RBC (User Met)

This calculation runs *AERMOD* using *AERSCREEN* methodology. Wind is from a single wind direction blowing towards all receptors always. Two assessments are

performed, one for parallel terrain (terrain heights equal to the flare base elevation) and complex terrain (terrain heights as input on the **iTERRAIN** page) allowing the *AERMOD* processing to determine the how terrain impacts the ambient air quality predictions. A site specific 5-year meteorological data set created by the user is used to account for site-specific land cover and to provide site-specific variations in meteorology. A minimum of 8760 hours (see **iSTART mndata**) of variations in meteorology should (according to ESRD Air Quality Model Guideline, for on-site data) be used but 5-years are required when using AESRD MM5 meteorological screening data. The Risk Based Criteria (RBC) can be used to determine whether the air quality dispersion modelling results meets ambient air quality objectives. 5-years of meteorology are required for a monthly assessment using Risk Based Criteria.

AERflare iterates to determine the maximum concentration when a XY receptor grid is not used. The receptor grid used for *AERSCREEN-MAX* uses a logarithmic distribution of points between 100 m and 10000 m using 100 receptors. The terrain elevations are interpolated from the **iTERRAIN** page. The receptor point of the maximum concentration is determined and the distances of the receptor points before and after are extracted from the receptor array. This minimum and maximum distance is then used re-determine the maximum concentration using a logarithmic distribution of 100 receptor points. This process continues until the distance between receptor points at the maximum is less than **dxmin** from the **iSTART** page.

3. *AERMOD-RBC (User Terrain & User Met)*

This calculation runs *AERMOD* using its full 2D capabilities and elevated terrain processing. Two assessments are performed, one for parallel terrain (terrain heights equal to the flare base elevation) and complex terrain. The terrain elevations are determined according to the user receptor grid and will height factors (see **iUSERTER** page) allowing the *AERMOD* processing to determine the how terrain impacts the ambient air quality predictions. A site specific 5-year meteorological data set created by the user is used to account for site-specific land cover and to provide site-specific variations in meteorology. A minimum of 8760 hours (see **iSTART mndata**) of variations in meteorology should (according to ESRD Air Quality Model Guidelines, for on-site data) be used but 5-years are required when using AESRD MM5 meteorological screening data. The Risk Based Criteria (RBC) can be used to determine whether the air quality dispersion modelling results meets ambient air quality objectives. 5-years of meteorology are required for a monthly assessment using Risk Based Criteria.

AERflare does not iterate to determine the maximum concentration when an XY user terrain grid used. A minimum distance along the fence (nearest grid distance specified in the Receptor Grid Spacing group on **iUSERTER** page) of **dxmin** (see

iSTART page) is used. The user should evaluate the location of the determined maximum concentrations and compare the location to the receptor grid spacing.

4. Create AERMOD files (Average Wind Speed)

This calculation is similar to #3 AERSCREEN-RBC(User Met) except that only the *AERMOD* input files are created. *AERMOD* is not run and no ambient air quality predictions are created. This option is useful for advanced users to perform refined air dispersion modelling external to the *AERflare* spreadsheet calculations but using the *AERflare* model to create the source parameters. The advanced user can add site specific receptor grid and terrain into the *AERMOD* files created and run *AERMOD* independent of *AERflare*.

Post-processing of an external *AERMOD* output file can be performed using the **oPOSTPROCESS** page.

5. AERSCREEN-MAX (HbH)

This calculation runs *AERMOD* in using *AERSCREEN* methodology. Wind is from a single wind direction blowing towards all receptors always. Two assessments are performed, one for parallel terrain (terrain heights equal to the flare base elevation) and complex terrain (terrain heights as input on the **iTERRAIN** page) allowing the *AERMOD* processing to determine the how terrain impacts the ambient air quality predictions. The screening meteorological data sets are used to account for land cover and provide a seasonal variation in meteorology. Approximately 2500 variations in meteorology are assessed. The source parameters for the flare are determined on an hour-by-hour (HbH) basis. Therefore, flare efficiency and plume rise are affected by the hour by hour variation in wind speed, temperature and stability. Because the number of variations is less than 8760 (see **iSTART** [mndata](#)), only the maximum concentration is used in the interpretation of the air dispersion modelling results (although the seasonal predictions are available for interpretation).

6. AERSCREEN-RBC (HbH User Met)

This calculation runs *AERMOD* in using *AERSCREEN* methodology. Wind is from a single wind direction blowing towards all receptors always. Two assessments are performed, one for parallel terrain (terrain heights equal to the

flare base elevation) and complex terrain (terrain heights as input on the **iTERRAIN** page) allowing the *AERMOD* processing to determine the how terrain impacts the ambient air quality predictions. A site specific 5-year meteorological data set created by the user is used to account for site-specific land cover and to provide site-specific variations in meteorology. A minimum of 8760 hours (see **iSTART mndata**) of variations in meteorology should (according to ESRD Air Quality Model Guideline for on-site data) be used but 5-years are required when using AESRD screening MM5 meteorology. The source parameters for the flare are determined on an hour-by-hour (HbH) basis. Therefore, flare efficiency and plume rise are affected by the hour by hour variation in wind speed, temperature and stability. The Risk Based Criteria (RBC) can be used to determine whether the ambient air quality modelling results meets ambient objectives. 5-years of meteorology are required for a monthly assessment using Risk Based Criteria.

7. AERMOD-RBC (HbH User Terrain & User Met)

This calculation runs *AERMOD* using its full 2D capabilities and elevated terrain processing. Two assessments are performed, one for parallel terrain (terrain heights equal to the flare base elevation) and complex terrain. The terrain elevations are determined according to the user receptor grid and will height factors (see **iUSERTER** page) allowing the *AERMOD* processing to determine the how terrain impacts the ambient air quality predictions. A site specific 5-year meteorological data set created by the user is used to account for site-specific land cover and to provide site-specific variations in meteorology. A minimum of 8760 hours (see **iSTART mndata**) of variations in meteorology should (according to ESRD Air Quality Model Guideline, for on-site data) be used but 5-years are required when using AESRD MM5 meteorological screening data. The source parameters for the flare are determined on an hour-by-hour (HbH) basis. Therefore, flare efficiency and plume rise are affected by the hour by hour variation in wind speed, temperature and stability. The Risk Based Criteria (RBC) can be used to determine whether the ambient air quality modelling results meets ambient objectives. 5-years of meteorology are required for a monthly assessment using Risk Based Criteria.

8. Create AERMOD files (HbH User Ter/User Met)

This calculation is similar to #7 AERSCREEN-RBC(HbH User Met) except that only the *AERMOD* input files are created. *AERMOD* is not run and no ambient air quality predictions are created. This option is useful for advanced users to

perform refined air dispersion modelling external to the *AERflare* spreadsheet calculations but using the *AERflare* model to create the source parameters. The advanced user can add site specific receptor grid and terrain into the *AERMOD* files created and run *AERMOD* independent of *AERflare*.

Post-processing of an external *AERMOD* output file can be performed using the **oPOSTPROCESS** page.

Example Run-Times

Example run times are listed in the table below. The test computer has the following specifications:

- Intel i7 CPU, 950 MHz bus @ 3.07 GHz; 18 GB Ram
- Windows 8, 64bit OS, x64 processor, Office 2013 (32 bit)
- 7.5 Windows Experience Index
- Example Site A

The following calculation times were recorded analyzing Example 2-Site A. The Evaluation calculations were performed for SO₂ maximum emissions and H₂S maximum emissions only.

| Calculation Button | Run Time |
|--------------------|----------------------|
| 1 | 0:01:43 (NS=4) *** |
| 2 | 0:02:46 (NS=4) *** |
| 3 | 0:45:35 (NS=6) ** |
| 4 | 0:00:42 (NS=6) ** |
| 5 | 00:09:06 (NS=12) *** |
| 6 | 1:23:49 (NS=12) *** |
| 7 | 1:18 (NS=6) ** |
| 8 | 00:20:00 (NS=6) ** |

NS= Number of scenarios [4=(1xSO₂ + 1xH₂S)x(parallel+complex)]; [12=(3xSO₂ + 3xH₂S)x(parallel+complex)]

** For Calculation buttons 3 and 7, AERflare uses the User Defined Terrain file. AERflare therefore does not run the screening parallel and elevated terrain, but only the user's terrain in elevated terrain mode.

*** Includes searching for worst case concentration at a resolution of [dxmin=20m](#)



It is recommended that only a single AERflare spreadsheet be open at one time and no other Excel spreadsheet be loaded. This is because Excel triggers recalculations when a spreadsheet cell is changed. Because the AERflare incorporates a very large number of calculations, even small calculation delays for refreshing extraneous spreadsheets can increase run-times.

Other calculations associated with terrain and land-use assessment are listed in the table below.

| Calculation Button | Page | Time |
|--------------------|----------|---------------|
| Get DEM Data | iTERRAIN | 47.93 seconds |
| Get LCC Data | iUSERMET | 93.08 seconds |
| Create UserMet | iUSERMET | 50.23 seconds |
| Create ScreenMet | iUSERMET | 3.23 seconds |
| Create Receptors | iUSERTER | 438.5 seconds |

Permit Flare Air Dispersion Modelling

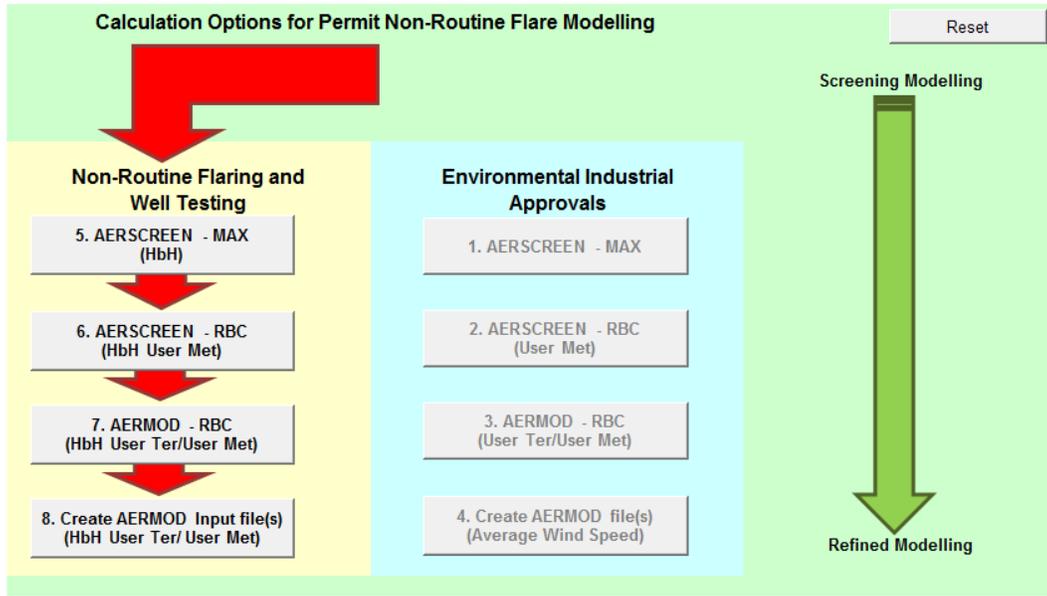
The Permit Flaring assessment begins with a selection of: PERMIT from the choice of **PERMIT** or **EVALUATION** on the **iSTART** page. Selection of **PERMIT** forces the flaring classification to be **Non-Routine—Planned Flaring**. The calculations options on the **oMODELLING** page are adjusted to use the HbH dispersion modelling techniques and the results are compared to Risk Based Criteria (RBC) suitable for this type of event.

| | | | | | | | |
|---|----------------------------------|---|--|--|--|---|---|
| Are these flaring calculations for an ambient air quality evaluation or for a temporary permit application? | | <input checked="" type="radio"/> Permit <input type="radio"/> Evaluation | Select PERMIT to display fields applicable to non-routine planned flaring for temporary permit application including air dispersion modelling. Select EVALUATION to display fields applicable to air dispersion modelling of flaring. | | | | |
| Flaring Classification | | The flaring classification defines what the Risk Based Criteria (RBC) will be used to assess acceptable modelling predictions. The classification also sets limits on the maximum acceptable concentration for modelling. | | | | | |
| | | RBC % (Limit 1) | Max % (Limit 2) | SO ₂ RBC (µg/m ³) | SO ₂ Max (µg/m ³) | H ₂ S RBC (µg/m ³) | H ₂ S Max (µg/m ³) |
| Routine -- Continuous or Intermittent Flaring for more than 720 hours per year | <input type="radio"/> Locked | 99.9 | -- | 450 | -- | 14 | -- |
| Non-Routine -- Planned Flaring | <input checked="" type="radio"/> | 99 | 99.9 | 450 | 900 | 14 | 7652 |
| Non-Routine -- Unplanned Flaring | <input type="radio"/> Locked | 90 | 99.9 | 450 | 9923 | 14 | 7652 |

When **Permit** mode is used for *AERflare*, the air dispersion modelling options (**oMODELLING** page) are highlighted by the red arrows on the left-hand side. For a permit for non-routine flaring, the assessment must be performed using the buttons:

- #5. AERSCREEN-MAX(HbH),
- #6. AERSCREEN-RBC (User met),
- #7. AERMOD-RBC (HbH-User Ter/User Met) or
- #8. Create AERMOD Input File(s) (HbH User Ter/User Met).

These options represent an increasing level of air dispersion modelling sophistication from screening level to refined dispersion modelling.



The **oMODELLING** summary page displays a stamp of the model used for the predictions and the time period used for the meteorological data. Also displayed is the meteorological dataset, the terrain file (if used), and the *AERMOD* root file name selected (if used). The number of hours in the meteorological data set used is displayed. The number of hours in the dataset is important since it determines whether the RBC can be used or whether a monthly assessment can be used. A monthly assessment can only be used when there are five years of data (providing 2160 hours for analysis)

| Continuous or Steady | Planned Non-Routine Flaring | |
|--|------------------------------------|---|
| Dispersion Model Used | 6 | AERSCREEN-(HBH + User Met) RBC Concentration(s) |
| AERMOD Version Used | 12345 | |
| Meteorological File Used | flare\Examples\SiteA\AERMOD.SFC | |
| Terrain Insert File Used | | |
| AERMOD Output File Base | | |
| # Hours in Meteorological File | 43823 | |
| Dispersion Model Predictions These results account for the duration of the flaring and 1h hour averaging time. | Annual | |

Evaluation Flare Air Dispersion Modelling

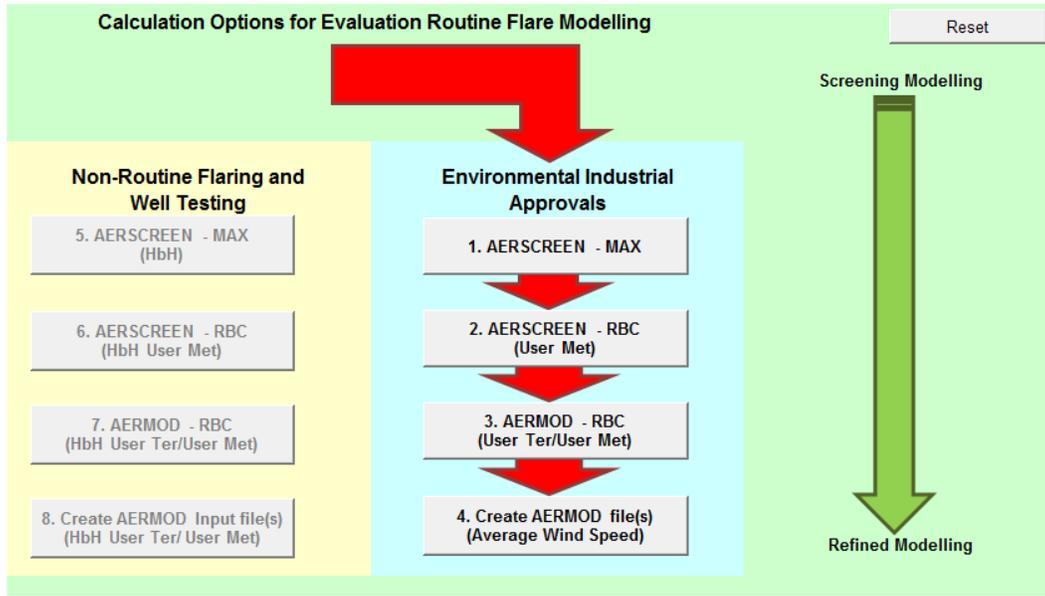
Based upon the selecting of the flaring assessment mode on the **iSTART** page, the Evaluation Flaring assessment begins with a selection of: Evaluation.

| | | | | | | | | |
|---|---|--|-----------------|--|--|---|---|------|
| Are these flaring calculations for an ambient air quality evaluation or for a temporary permit application? | <input type="radio"/> Permit <input checked="" type="radio"/> Evaluation | Select PERMIT to display fields applicable to non-routine planned flaring for temporary permit application including air dispersion modelling. Select EVALUATION to display fields applicable to air dispersion modelling of flaring. | | | | | | |
| Flaring Classification | The flaring classification defines what the Risk Based Criteria (RBC) will be used to assess acceptable modelling predictions. The classification also sets limits on the maximum acceptable concentration for modelling. | | | | | | | |
| | | RBC % (Limit 1) | Max % (Limit 2) | SO ₂ RBC (µg/m ³) | SO ₂ Max (µg/m ³) | H ₂ S RBC (µg/m ³) | H ₂ S Max (µg/m ³) | |
| | Routine -- Continuous or Intermittent Flaring for more than 720 hours per year | <input checked="" type="radio"/> | 99.9 | -- | 450 | -- | 14 | -- |
| | Non-Routine -- Planned Flaring | <input type="radio"/> | 99 | 99.9 | 450 | 900 | 14 | 7652 |
| Non-Routine -- Unplanned Flaring | <input type="radio"/> | 90 | 99.9 | 450 | 9923 | 14 | 7652 | |

When **Evaluation Mode** is used for *AERflare*, the air dispersion modelling options are highlighted by the red arrows as shown on the right-hand side of **oMODELLING**. Assessments may begin with a low-level screening calculations(s) using the **#1. AERSCREEN-MAX** using maximum predicted concentrations produced using the *AERSCREEN* screening meteorological datasets. For evaluation flaring, the default assessment is routine **Continuous** flaring and can be performed using the buttons:

- **#1. AERSCREEN-MAX**,
- **#2. AERSCREEN-RBC (UserMet)**,
- **#3. AERMOD-RBC (User Ter/User Met)** or
- **#4. Create AERMOD file(s) (Average Wind Speed)**

The calculations start with rapid and conservative modelling assumptions and proceed to more sophisticated refined air dispersion modelling.



Evaluation calculations can also be performed for the non-routine **Planned Flaring** or non-routine **Unplanned Flaring**. When **Planned** or **Unplanned** flaring is selected (see **iSTART**) then the non-routine flaring calculations (hour-by-hour assessment) on the left of **oMODELLING** are used.

AERSCREEN Inputs

The source model inputs are calculated on the **oCALCULATIONS** combustion modelling page and summarized on the **oMODELLING** page. The **oAERSCREEN** page collects all of the inputs used for the *AERMOD* air dispersion modelling runs and is presented in the *AERMOD Source Parameters* group. The table lists the same pseudo-source parameters presented on the **oMODELLING** page (Q_s , H_s , D_s , U_s , T_s) as well as the Brzustowski Flare Model effective source location (Z_L , X_L). Also listed are the efficiency and emissions for the average meteorological conditions. A table is presented for the SO_2 source and the H_2S source.

For **Evaluation** flaring, the average meteorological conditions are used and the pseudo-source parameters listed in the table are the source parameters used in the air dispersion modelling. The average meteorological conditions are defined in the Non-Defaults section of the **iSTART** page.

| Run flags (1=run; 0=not run) | | | 1 | 1 | 1 |
|---|----------|-------------------|----------------|---------------------------|------------------|
| Modelling Case # | | | 1 | 2 | 3 |
| Species | | | SO2 | SO2 | SO2 |
| AERMOD Source Parameters | Variable | Units | Maximum (QMAX) | Average (Volume/Duration) | Minimum (QMAX/8) |
| Emission Rate | Qs | g/s | 75.263 | 37.631 | 9.408 |
| Effective Height | Hs | m | 29.228 | 28.552 | 27.689 |
| Pseudo Diameter | Ds | m | 4.720 | 4.720 | 4.717 |
| Pseudo Velocity | Us | m/s | 0.968 | 0.484 | 0.121 |
| Estimated Temperature | Ts | K | 1133.63 | 1133.74 | 1134.13 |
| Assumed Ambient Air Temperature | Ta | K | 278.15 | 278.15 | 278.15 |
| zL - vertical coordinate upward from flare tip (used) | ZL | m | 1.80 | 1.12 | 0.42 |
| xL - horizontal coordinate downwind from flare tip | XL | m | 4.83 | 5.32 | 5.84 |
| NHV | | MJ/m ³ | 32.02 | 32.02 | 32.02 |
| Conversion Efficiency | | % | 99.67% | 99.63% | 99.48% |
| Sulphur | | t/d | 3.3 | 1.6 | 0.4 |
| Sulphur | | t | 4.88 | 4.88 | 4.88 |

Hour-by-Hour

The pseudo-source parameters for the Permit flaring air dispersion modelling vary hour-by-hour. In this case, height, diameter, temperature, velocity, emissions and location are functions of the hourly meteorology. The *AERMOD* Gaussian plume air dispersion model does not have the inherent ability vary all these parameters hourly. The variable emissions source file allows only the temperature, velocity and emission rate to vary hourly. It assumes that the sources parameters such as height and diameter are physical (real) dimensions that normally would not vary.

AERflare uses a co-located source(s) configuration to bypass this limitation of the *AERMOD* model. Ideally, *AERflare* would configure a unique source for each hour of meteorology where any given source only has an emission when that hour of meteorology occurs.

| | | | SO2 | SO2 | SO2 |
|---------------------------------------|----------|---|----------------|---------------------------|------------------|
| | | | Maximum (QMAX) | Average (Volume/Duration) | Minimum (QMAX/8) |
| Hour-By-Hour Source Parameters | | | | | |
| Rise Min | Rise Min | m | 44.0 | 37.0 | 30.0 |
| Rise 33% | Rise 33% | m | 101.4 | 75.5 | 50.1 |
| Rise 66% | Rise 66% | m | 192.4 | 125.6 | 70.2 |
| Rise Max | Rise Max | m | 374.6 | 234.2 | 101.0 |
| Virtual Source 1 | ds1 | m | 4.776 | 4.767 | 4.735 |
| Virtual Source 2 | ds2 | m | 4.742 | 4.748 | 4.784 |
| Virtual Source 3 | ds3 | m | 4.787 | 4.786 | 4.750 |
| Virtual Source 1 | hs1 | m | 28.9 | 28.2 | 27.5 |
| Virtual Source 2 | hs2 | m | 30.0 | 29.2 | 28.0 |
| Virtual Source 3 | hs3 | m | 31.6 | 30.2 | 28.6 |

That configuration would require enormous numerical resources. Instead, a fewer number of sources are defined. *AERflare* estimates the final plume rise height based upon the U.S. EPA *ISCST* model plume rise which uses simplistic PG and wind speed as inputs. For the complete meteorological data set, *AERflare* determines the distribution of final plume rise heights and divides the range in N parts. It then summarizes the pseudo-source heights and diameters that lead those plume rise predictions. The pseudo-source parameters for each of the *nsources* is determined based upon the average of the pseudo-source parameters for that plume rise group. *AERflare* uses by default *nsources*=9. Sensitivity testing has proven shown that the predictions are not strongly influenced by the selection of *nsources*>3, and *nsources*=9 was chosen for numerical efficiency and sufficient for screening purposes.

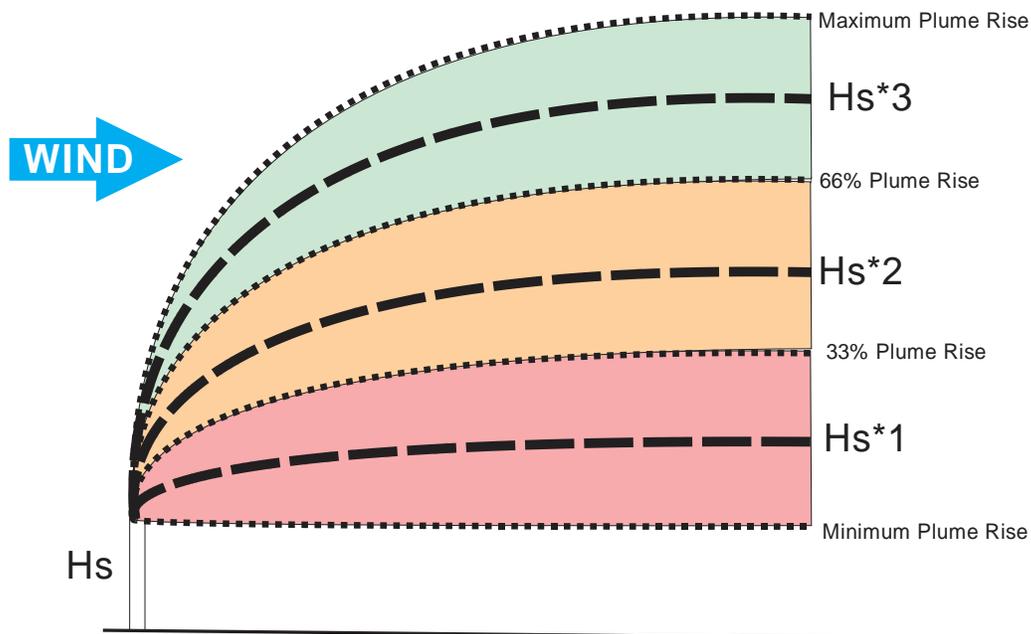


Figure 10: Illustration of the Range of Plume Rise (centrelines) for An Hour By Hour Source Model

The **oAERSCREEN** page displays a summary of the *nsources* virtual source plume rise groups and average pseudo-source heights and diameters. The hour-by-hour processing creates a variable emissions source file and *AERMOD* input file containing *nsources* virtual sources based upon the input meteorological data set.

The hour-by-hour air dispersion modelling using *AERflare* is numerically more intensive (slower) since it requires the spreadsheet to recalculate for each hour of meteorology. Although the spreadsheet recalculation for a given wind speed, temperature, and atmospheric stability is less than $\Delta t=0.005$ sec, when a 5-year meteorological data set is processed, this results in $(5 \times 8760 \text{ hours} \times \Delta t \approx 3 \text{ min})$ run

time. The source processing must be completed for each of the **Qmax**, **Qave** and **Qmin** emission rates and for each of SO₂ and H₂S sources (i.e., 6 times). For faster run times, the stand-alone *ABflare* refined model can be used.

Air Dispersion Modelling Predictions

oAERSCREEN Output Summary

After the *AERMOD* air dispersion modelling is completed, *AERflare* loads the output file and meteorological file, and post-processes the predictions. The **oAERSCREEN** page is updated with the raw air dispersion modelling predictions. The *AERMOD* predictions for hourly emissions durations are listed in the table for parallel terrain and elevate terrain. The table is updated for both SO₂ and H₂S source model predictions for **Qmax**, **Qave** and **Qmin** emissions scenarios.

| AERSCREEN OUTPUT | | Units | Maximum (QMAX) | Average (Qave) | Minimum (QMIN) |
|--|----------------|-------------------|--------------------------|----------------|----------------|
| | | | Parallel Airflow Terrain | | |
| Maximum Concentration | cmax | µg/m ³ | 570 | 449 | 238 |
| Distance to Maximum Concentration | xmax | m | 933 | 706 | 443 |
| Wind Speed | ws | m/s | 0.5 | 0.5 | 0.5 |
| PG Stability Class | PG | PG | F | F | F |
| Distance Concentration drops below Obj#1 | xobj1 | m | 2460 | -1 | -1 |
| Distance Concentration drops below Obj#2 | xobj2 | m | -1 | -1 | -1 |
| Distance Concentration drops below Obj#3 | xobj3 | m | 10000 | 10000 | 8459 |
| Concentration CMAX (99.9th) | winter or yr 1 | µg/m ³ | 367 | 289 | 196 |
| | spring or yr 2 | µg/m ³ | 244 | 161 | 128 |
| | summer or yr 3 | µg/m ³ | 489 | 403 | 215 |
| | fall or yr 4 | µg/m ³ | 458 | 377 | 208 |
| | month or yr 5 | µg/m ³ | | | |
| Concentration RBC (99.0th) | winter or yr 1 | µg/m ³ | 264 | 199 | 134 |
| | spring or yr 2 | µg/m ³ | 201 | 147 | 89 |
| | summer or yr 3 | µg/m ³ | 313 | 309 | 154 |
| | fall or yr 4 | µg/m ³ | 321 | 275 | 133 |
| | month or yr 5 | µg/m ³ | | | |

Note that this table is also used for sub-hourly blowdown air dispersion raw predictions, which are also hour. The post-processed hourly average

concentrations for blowdowns or sub-hourly emissions are provided on the **oMODELLING** page in the modelling summary section.



The **oAERSCREEN** page 'AERSCREEN OUTPUT' group is not corrected for flare duration (sub-hourly flaring or blowdown flaring).

c_{max}

The maximum concentration (c_{max}) representing the 100% (peak) concentration assuming a 1h emission duration.

x_{max}

The distance (x_{max}) from the flare to the location of the maximum concentration (c_{max}). The distance is the planar distance and not the distance as measured along the surface. Typically, the difference is small.

WS

The wind speed (ws) that resulted in the maximum concentration (c_{max}).

PG

The atmospheric stability class (**PG**: Pasquill-Gifford stability class) that resulted in the maximum concentration (c_{max}).

x_{obj1}

The distance (x_{obj1}) where the predicted maximum concentrations drop below the Objective 1 listed in the **oAERSCREEN** page *Objectives and Limits* group. Objective 1 is ambient air quality objective. If the maximum concentration (c_{max}) prediction does not exceed Objective 1, then x_{obj1} is set to -1.

x_{obj2}

The distance (x_{obj2}) where the predicted maximum concentrations drop below the Objective 2 listed in the **oAERSCREEN** page *Objectives and Limits* group.

Objective 2 is emergency evacuation criteria. If the maximum concentration (**cmax**) prediction does not exceed Objective 2, then xobj2 is set to -1.

xobj3

The distance (**xobj3**) where the predicted maximum concentrations drop below the Objective 3 listed in the **oAERSCREEN** page *Objectives and Limits* group. Objective 3 is 1/10th of the ambient air quality objective and is representative of the maximum extent where plume overlap with other sources is considered. Thus xobj3 is representative of the required domain size for refined air dispersion modelling for the flare. If the maximum concentration (**cmax**) prediction does not exceed Objective 3, then **xobj3** is set to -1 or blank.

Concentration CLIMIT

Concentration **CLIMIT** or **CMAx** are the concentrations predicted for the Flaring Mode upper concentration limit (**CLIMIT**) as specified on the **iSTART** page. When an *AERflare* screening meteorological data set is used, the results are displayed for each season in the meteorological file. When a site specific meteorological data set is used, the table shows results for each year of the meteorological data. The column on the right of the table displays the total number of hours of predictions represented in the statistic. When $N < \text{mndata}$, the statistic is considered to be not valid for regulatory air dispersion modelling approvals and applications.

Concentrations assume a 1h emission duration.

Concentration RBC

Concentration **RBC** (Risk Based Criteria) are the concentrations predicted for the Flaring Mode **RBC** criteria as specified on the **iSTART** page. When an *AERflare* screening meteorological data set is used, the results are displayed for each season in the meteorological file. When a site specific meteorological data set is used, the table shows results for each year of the meteorological data. The column on the right of the table displays the total number of hours of predictions represented in the statistic. When $N < \text{mndata}$, the statistic is considered to be not valid for regulatory modelling approvals and applications.

Concentrations assume a 1h emission duration.

*o*MODELLING Output Summary

After the *AERMOD* air dispersion modelling is completed, *AERflare* loads the output file and meteorological file, and post-processes the predictions. The **oAERSCREEN** page is updated with the raw air dispersion modelling predictions and the **oMODELLING** page presents the conclusions of the air dispersion modelling corrected for flare emission duration and the maximum of the parallel terrain and elevated terrain predictions. The table is updated for both SO₂ and H₂S source model predictions for **Q_{max}**, **Q_{ave}** and **Q_{min}** emissions scenarios. The table shows the maximum **CLIMIT** and maximum RBC for multi-season or multi-year assessments.

The variables are defined and discussed in the *oAERSCREEN Output Summary* section.

| SO ₂ Predictions | Units | Maximum 1h (QMAX) | Average 1h (Volume/Duration) | Minimum 1h (QMAX/8) | Transient Blowdown 1h Maximum | Variable |
|---|-------------------|--|------------------------------|---------------------|-------------------------------|----------|
| Averaging time is (minutes): 60 and Total Flare duration is (minutes): 4320.0 | | Worst Case of Parallel or Elevated Terrain Results | | | | |
| Maximum Concentration | µg/m ³ | 1489 | 946 | 368 | NA | cmax |
| Distance to Maximum Concentration | m | 6579 | 6280 | 5462 | | xmax |
| Wind Speed | m/s | 1.0 | 1.0 | 1.0 | | ws |
| PG Stability Class | PG | F | F | F | | PG |
| Distance Concentration drops below Obj#1 | m | 10000 | 10000 | -1 | | xobj1 |
| Distance Concentration drops below Obj#2 | m | -1 | -1 | -1 | | xobj2 |
| Distance Concentration drops below Obj#3 | m | 10000 | 10000 | 10000 | | xobj3 |
| Climit Maximum Concentration (99.9th) | µg/m ³ | 1366 | 881 | 342 | NA | climit |
| RBC Maximum Concentration (99.0th) | µg/m ³ | 910 | 590 | 230 | NA | RBC |

One-Hour Averages from Sub-Hourly Emissions

The *AERMOD* predictions are based upon hourly meteorology and therefore the predicted concentrations represent one-hour time averages. Flare durations may be less than one-hour, so the *AERMOD* predictions are adjusted based upon the fraction of non-zero emissions during the hour. This methodology does not account for along wind diffusion which a puff-style air dispersion model can account for.

When flare durations are less than one-hour duration, then the hourly-average concentration (**C_{1h}**) is determined from the modelled concentration (**C_{modelled}**) based upon continuous emissions by:

$$C_{1h} = \frac{\text{Duration}}{1h} \times C_{\text{modelled}}$$

For a transient blowdown release, modelled as a sequence of N steps of an exponential curve, the hourly concentration is determined using the equation above cumulatively for the first step and remain steps until 1h is reached or the end of the duration is reached. It is assumed that a 1h hour period starts at the beginning of a step, therefore the calculation is performed recursively for N steps beginning with the Nth step. Because large amounts of energy are associated with the first step (i.e., high energy results in efficiency and high plume rise so ground level predictions are small), the maximum 1h average concentration can occur for sequences starting with the second or higher steps.

AER D060 Permit Conditions

The **oSUMMARY** page provides a summary of the source and scenario inputs compared to AER D060 permitting conditions. The AER D060 reference number is provided for reference along with the D060 allowable limit. The scenario value for each condition is listed under *This Application* and it is compared to the allowable value. The *Test* column states whether the *This Application* meets or does not meet the D060 permitting condition and the *Requirements* column provides suggestions.

| AER D060 Permit Conditions | D060 Ref. | Test | This Application | Allowed | Requirements |
|---|-----------|------------------|------------------|----------|---|
| Volume Allowance Threshold Tier for Gas Wells | 3.3.1[2] | | 3 | | Based upon the Lahee classification See D060-3.3.1[2a] for tier limits |
| H ₂ S gas concentration (%) | 3.3.1[1] | See Requirements | 16 | 5 | Permit is required |
| Volume per Zone (10 ³ m ³) | 3.3.1[2a] | PASS | 22.50 | 200 | Volume allowance is based upon well before re-classification |
| Total Volume (10 ³ m ³) | 3.3.1[2d] | PASS | 22.5 | 200 | Volume allowance is based upon well before re-classification |
| Event Sulphur Emissions (t) | 7.12.1 | See Requirements | 4.882 | 1 | Modelling is required |
| Event Duration (min) | 7.12.5[1] | See Requirements | 4320 | 15 | Modelling is required |
| H ₂ S more than 1% (or 10 mol/kmol) | 7.12.1 | See Requirements | 16 | 1 | Modelling is required |
| Small Volume: low sulphur rate (t/d) | 3.3.2[2a] | See Requirements | 3.255 | 1 | Modelling is required |
| Small Volume: low gas volume over duration (10 ³ m ³) | 3.3.2[2b] | PASS | 22.5 | 50 | NO permit is required |
| Conditions to Apply for a Blanket Permit: total volume per site (10 ³ m ³) | 3.5.3[5a] | PASS | 22.5 | 100 | Blanket Permit could be considered |
| Conditions to Apply for a Blanket Permit: sulphur emissions per site (t) | 3.5.3[5b] | PASS | 4.9 | 10 | Blanket Permit could be considered |
| Conditions to Apply for a Blanket Permit: risk-based criteria met | 3.5.3[5c] | NA | NA | NA | Requires refined modelling |
| Conditions to Apply for a Blanket Permit: complex terrain issues | 3.5.3[5d] | See Requirements | COMPLEX | PARALLEL | Blanket Permit would be considered only with modelling backup |

The **oSUMMARY** page also provides a similar check list compared to the AER D060 Figure 4 flow chart for air dispersion modelling and approval requirements for Flaring Approvals. The *Test* column shows the result of the comparison of the *This Application* compared to the AER D060 Figure 4 allowed. The *Requirements* column provides suggestions on further actions required.

| Temporary Flaring Permit Process: D060 Flowchart (Figure 4) | D060 Ref. | Test | This Application | Allowed | Requirements |
|--|-----------------|--|---|---------|---|
| Is Well Classified as Critical ? | 3.3.1[1] | <input type="radio"/> Critical <input checked="" type="radio"/> Non-Critical | | | |
| H2S > 5% | 3.3.1[1] | <input checked="" type="radio"/> Yes <input type="radio"/> No | 16.00% | 5% | Permit is required |
| H2S > 1 % | 3.3.2[1a] | <input checked="" type="radio"/> Yes <input type="radio"/> No | 16.00% | 1% | Air quality evaluation is required (7.12) |
| Flared Volume > Volume Allowance (10 ³ m ³) | 3.3.1[2] | <input type="radio"/> Yes <input checked="" type="radio"/> No | 22.5 | 200 | NO volume exceedance permit is required |
| Small Volume Exemption limits exceeded? | 3.3.1[2a,2b,2c] | <input checked="" type="radio"/> Yes <input type="radio"/> No | | | |
| Is Temporary Flaring Permit Required? | 3.3.1 | <input checked="" type="radio"/> Yes <input type="radio"/> No | Permit is required Submit spreadsheet electronically along with printouts and maps | | |

The **oSUMMARY** page provides a summary table of the Approval Limits group. This list is the essence of the flare test approval application and the values should be carefully reviewed since the approval will limit the flare test program to the values listed in the table.

| Permit Limits | UNITS | |
|--|--|--|
| Oil or Gas Well ? | | <input type="radio"/> Oil <input checked="" type="radio"/> Gas |
| Flare Stack Tip Exit Height | m | 27.4 |
| Flare Tip Exit Diameter | mm | 102 |
| Maximum Raw Gas Flaring Rate | 10 ³ m ³ /d (15°C, 101.325 kPa) | 15.0 |
| Maximum H ₂ S Concentration in Raw Gas | (rounded up to nearest 0.5%) | 16.00% |
| Total Volume for Testing and Cleanup of Subject Zone | 10 ³ m ³ (15°C, 101.325 kPa) | 22.5 |
| Total Volume for Testing and Cleanup of All Zones | 10 ³ m ³ (15°C, 101.325 kPa) | 22.5 |
| Total Estimated Duration for ALL Zones | days | 8 |
| Start Date | | November 1, 2012 |
| Finish Date | | December 15, 2012 |
| Duration | days | 45 |

Output Summary of Source

The **oSUMMARY** page provides a summary of the flare source assessed for the flare test application.

Valuable information is listed in the table for both the approval review and the operator:

- For example, the table lists the fuel gas total volume required based upon the heating value requirements or fuel gas addition. The operator can use

this information to evaluate the feasibility of providing this fuel gas for the flaring event.

- For example, near the bottom of the table the minimum and maximum diameter of the flare nozzle are recommended on the basis of sonic velocities and flaring efficiency. In the example below, the table indicates that the diameter of the source is not within the recommended range and therefore it does not produce acceptable velocities. In this case, however, the actual source is 102 mm whereas the recommended diameter limit is 100 mm. A review of the average efficiency at the top of the summary group or on the **MODELLING** page indicates that the efficiency is adequate, therefore the actual size (i.e., nominal pipe diameter, 102 mm) is acceptable but since it is at the high end of the recommended range, it could possibly lead to a lazy plume (stack down wash) under certain meteorological conditions.

| Flaring Emissions | | |
|--|---|---|
| | UNITS | VALUE |
| Estimated Conversion Efficiency at Average Windspeed | % | 99.48% |
| Maximum Sulphur Emission Flowrate | t/d | 3.3 |
| Maximum Sulphur Event Emission | t | 4.9 |
| Maximum Equivalent CO ₂ Emission | t | 36.2 |
| Net Heating Value | | |
| | UNITS | VALUE |
| Heating Value of Raw Gas | MJ/m ³ | 32.0 |
| Heating Value of Fuel Gas | MJ/m ³ | na |
| Heating Value of Mixture | MJ/m ³ | 32.0 |
| Is Heating Value of Mixture Acceptable? | D060-7.1.1 | <input checked="" type="radio"/> Yes <input type="radio"/> No |
| Fuel Gas Addition | | |
| | UNITS | VALUE |
| Is Fuel Gas required to compensate for Lift Gas? | | <input type="radio"/> Yes <input checked="" type="radio"/> No |
| Fuel Gas Supply Rate to meet 20.0 MJ/m ³ while Lift Gas is Flowing Back | 10 ³ m ³ /d (15°C, 101.325 kPa) GJ/h | -- -- |
| Is Fuel Gas Added for Dispersion or to meet Heating Value Requirements? | | <input type="radio"/> Yes <input checked="" type="radio"/> No |
| Proposed Fuel Gas to Raw Gas Volume Rate Ratio | | 0.000 |
| Fuel Gas Supply Capacity for Dispersion or to meet Heating Value Requirements | 10 ³ m ³ /d (15°C, 101.325 kPa) GJ/h 10 ³ m ³ (15°C, 101.325 kPa) | -- -- -- |
| Thermal Radiation | | |
| | UNITS | VALUE |
| Maximum Total Thermal Radiation at Ground Level | kW/m ² | 1.2 |
| Is Thermal Radiation Acceptable? | D060-7.4.1 | <input checked="" type="radio"/> Yes <input type="radio"/> No |
| Flare Tip Exit Diameter | | |
| | UNITS | VALUE |
| Maximum Exit Velocity | m/s | 22 |
| Average Exit Velocity | m/s | 11 |
| Does Proposed Flare Stack Tip Exit Diameter Result in Acceptable Exit Velocities? | D060-7.1.1 | <input checked="" type="radio"/> Yes <input type="radio"/> No |
| Minimum Recommended Flare Stack Tip Diameter | mm | 37 |
| Maximum Recommended Flare Stack Tip Diameter | mm | 157 |

Output Summary of Air Dispersion Modelling

The **oSUMMARY** page provides a high level summary of the *AERflare* air dispersion modelling. The table is divided in to two sections: screening and refined air dispersion modelling. The screening air dispersion modelling is based upon the screening meteorological data sets and the maximum predicted concentrations. The refined air dispersion modelling section is based upon site specific meteorological predictions and RBC statistics. High concentrations are flagged and require more refined air dispersion modelling.

| Dispersion Modelling Summary | UNITS | VALUE | LIMIT | COMMENTS | |
|---|-------------------|--|---|---|----------|
| Does Dispersion Modelling have to be Considered? | | <input checked="" type="radio"/> Yes <input type="radio"/> No | | Modelling is required | |
| Modelling Method Used | | 5 | | AERSCREEN-Max Concentration Only (Average Wind Speed) | |
| AERMOD version used | | 12345 | | | |
| SCREENING MODELLING Maximum Predicted Ground Level SO ₂ Concentration using AERSCREEN and Screening Meteorology | | Planned Non-Routine Flaring Modelling Results | Concentration Criteria µg/m ³ | | |
| Maximum SO ₂ Concentration | µg/m ³ | 2108 | 450 | Adjust parameters/modelling approach | |
| Maximum H ₂ S Concentration | µg/m ³ | 15 | 14 | Adjust parameters/modelling approach | |
| Is Refined Dispersion Modelling Required? | | <input checked="" type="radio"/> Yes <input type="radio"/> No | | Refined modelling is required | |
| REFINED MODELLING Risk-based Predicted Ground Level SO ₂ Concentration using AERSCREEN and Site-Specific Meteorology | | Planned Non-Routine Flaring Modelling Results | Concentration Criteria µg/m ³ | Percentile | COMMENTS |
| Minimum Number of Meteorological Data Points in a Year | -- | NA | | | |
| SO ₂ Modelling Completed for all three flowrates | -- | <input checked="" type="checkbox"/> Qmax <input checked="" type="checkbox"/> Qave <input checked="" type="checkbox"/> Qmin | | | |
| SO ₂ Concentration Prediction 99.9th | µg/m ³ | 0 | 900 | 99.9 | |
| SO ₂ Concentration Prediction 99th | µg/m ³ | 0 | 450 | 99 | |
| H ₂ S Modelling Completed for all three flowrates | -- | <input checked="" type="checkbox"/> Qmax <input checked="" type="checkbox"/> Qave <input checked="" type="checkbox"/> Qmin | | | |
| H ₂ S Concentration Prediction 99.9th | µg/m ³ | 0 | 7652 | 99.9 | |
| H ₂ S Concentration Prediction 99th | µg/m ³ | 0 | 14 | 99 | |
| Is More Refined Dispersion Modelling Required? | -- | <input type="radio"/> Yes <input checked="" type="radio"/> No | | | |

Output Figure 1

The **oFIGURE 1** page presents the detailed output of the **oAERSCREEN** summary. **oFIGURE 1** can be used to select SO₂ or H₂S air dispersion modelling predictions for maximum concentration, wind speed producing the maximum concentration, PG stability producing the maximum concentration, or mixing

height producing the maximum concentration. These figures and combinations can be useful for designing flare management programs or illustrations in air dispersion modelling reporting.

In Figure 11, an air dispersion modelling output example is shown. Terrain elevation are shown in green using the right abscissa. The Q_{max} , Q_{ave} and Q_{min} are shown for the parallel assessment using thick line styles, while thin line styles are used for the elevated terrain assessment. The figure shows where maximum predictions occur relative to the terrain. Also shown on the figure are the RBC and CLIMIT concentration objectives.

Figure 12 shows the wind speed that leads to the maximum concentration predictions. Figure 12 corresponds to the concentration predictions in Figure 11. Worse case meteorological conditions are a function of terrain elevation and distance from the source.

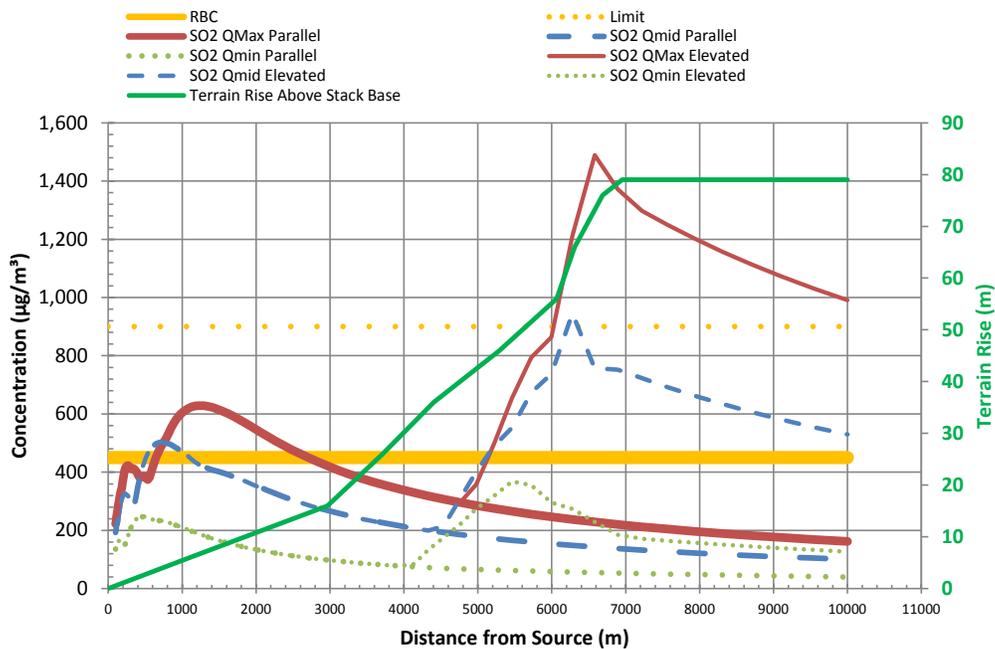


Figure 11: Example of FIGURE 1 showing the Maximum Concentration at the Receptor Location in Comparison to the Terrain Elevation

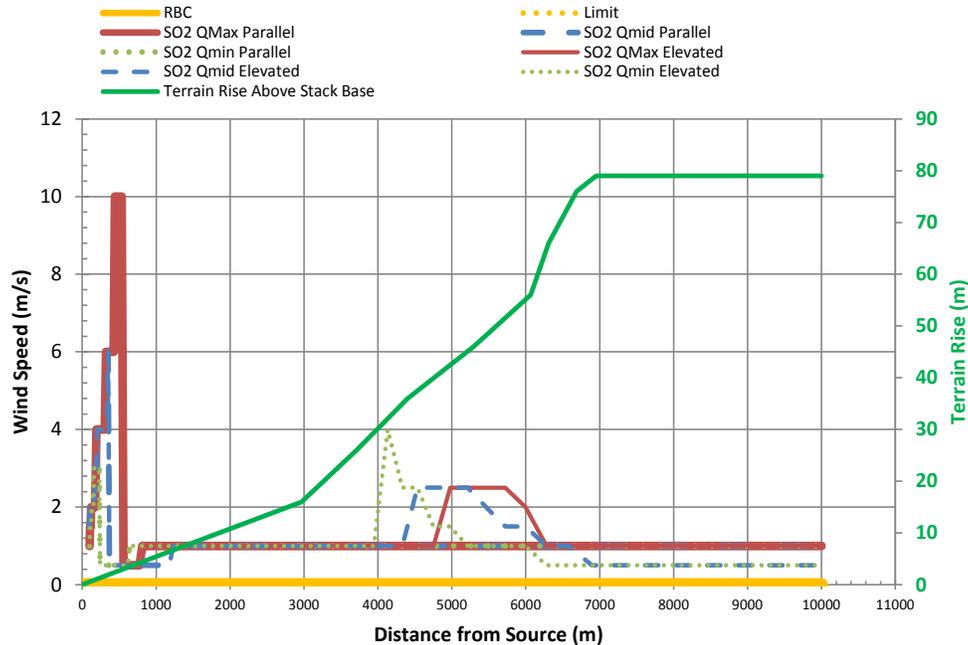


Figure 12: Example of FIGURE 1 showing the Wind Speed that Causes the Maximum Concentration at the Receptor Location

Output Figure 2

The graphic provide on the **oFIGURE 2** page provides a useful summary of the hour-by-hour predicted SO₂ emissions and H₂S emissions based upon the combustion efficiency and the hour-by-hour meteorology. Note that, the *AERflare* assessment for SO₂ requires the assessment based upon 100% conversion (i.e., constant emissions). The SO₂ emissions provided in **oFIGURE 2** are for reference only.

Figure 13 shows a probability plot for SO₂ emissions (left abscissa) and H₂S emissions (right abscissa). The actual SO₂ emissions reflect the predicted efficiency for 99% of the time as shown in Figure 14. The H₂S emissions are relatively low most of the time but are high for the 1% of the time, when the flare is inefficient.

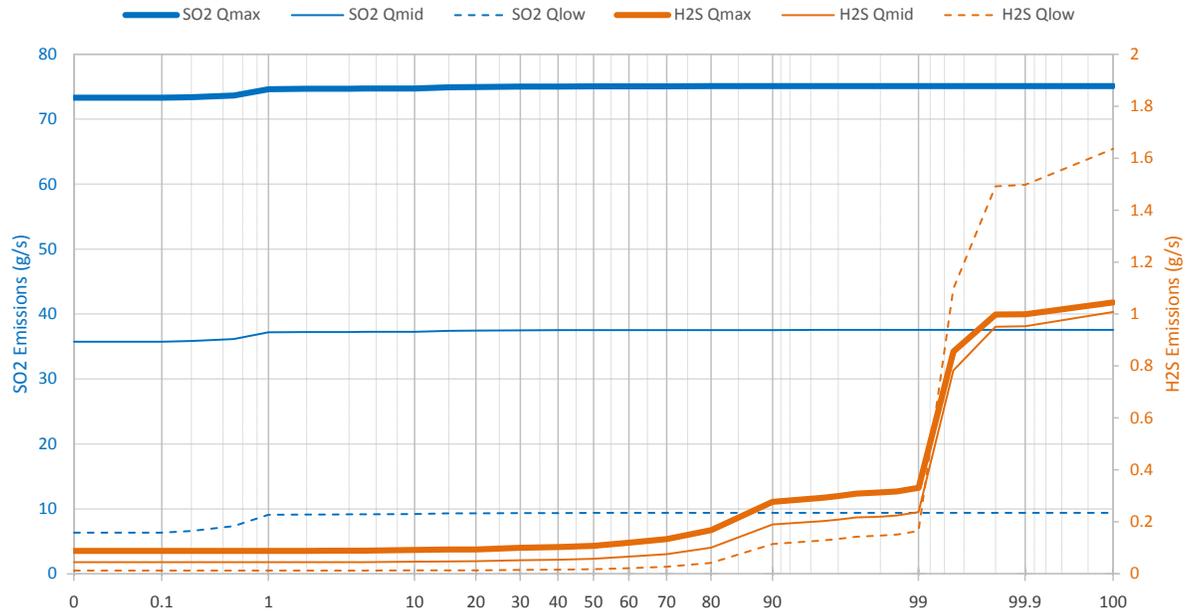


Figure 13: Example Emissions Chart from oFIGURE 2 for Hour-By-Hour Assessment

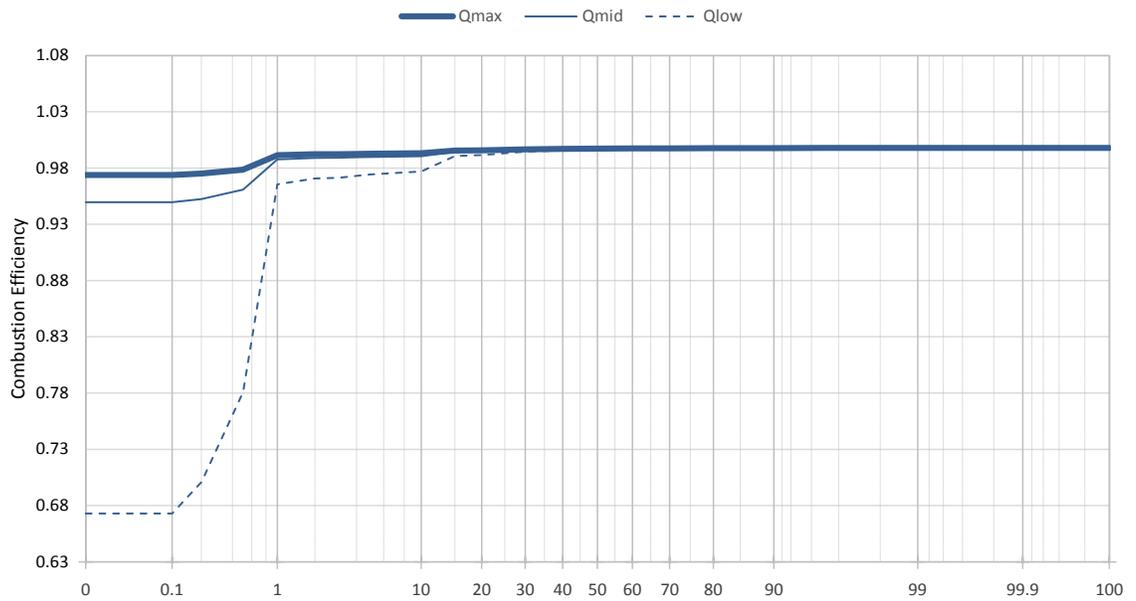


Figure 14: Example Efficiency Chart from oFIGURE 2 for Hour-By-Hour Assessment

5. TRANSIENT BLOWDOWN FLARING

Transient blowdown air dispersion flaring modelling represents unique challenges for source modelling and air dispersion modelling. Because of the combined non-linearity, a single emission rate does not provide a robust weight of evidence for the protection of human or environmental health. Also, air dispersion models are not designed to accommodate facility modelling of random, time varying, transient emissions sources. Therefore, simplifications are required so that a robust and conservative estimate of ambient air quality can be attained using existing air dispersion modelling and methods.

Transient Blowdown Inputs

Pipelines or process vessels blowing down are examples of transient releases. The gas released to the flare is not being replaced by gas coming into the plant or process vessels thus the pressure within the piping decreases. The release rate is proportional to the pressure and thus it decreases. The exponential function is a reasonable approximation of the blowdown of vessels through a constant area orifice. The release rate in time can be described by knowing the maximum flow rate and the total volume of gas released.

$$\dot{Q}(t) = \dot{Q}_{MAX} \exp\left(\frac{-t}{\tau}\right)$$

where

$$\tau = \frac{Q_{total}}{\dot{Q}_{MAX}}$$

The time constant (τ , tau) is the time it would take to release the total volume at the maximum flow rate. Theoretically, as the release rate approaches zero, it takes an infinite time to release the total volume of gas, so a limit applied to the duration.

Transient releases are more difficult to model as a steady release rate has to be assumed due to the model limitations. Dramatic differences in ambient air quality modelling predictions result if the maximum rate is used compared to the average rate over the duration.

Exponential releases decay slowly and would take an infinite time for the flow rate to reach zero and for all of the mass to be released. But we must stop modelling at some time. The exponential blowdown is for sonic conditions at the smallest area in the discharge piping. The pressure profile of the source would be the same as the mass release rate profile as the flow rate is directly proportional to the pressure. Below the critical pressure the exit velocity is no longer sonic and the flow rate decreases as the square root of pressure. The critical pressure is about twice atmospheric pressure. The pressure in the vessel cannot drop below atmospheric pressure or the flow would reverse. Some mass will remain in the piping.

The initial mass in the system is based on the initial absolute pressure. The fraction remaining at the atmospheric pressure can be determined and used to stop the flow rate. For typical initial pressures of 10,000 kPa and atmospheric pressure of 100 kPa, the fraction of the mass released is $f = 1 - 100/10000 = 99\%$. This assumes an isothermal blowdown and ideal gas. The exponential blowdown equation can be easily solved to yield the release duration, as follows:

$$t_{duration} = -\tau \ln(1 - f)$$

Transient Source Group

The Transient Source group on the **iFLARING** page is used to enter the required inputs to describe a transient source. The continuous exponential transient source blowdown curve is simplified into a three-step sequence of flaring scenarios that are evaluated independently and the results are combined to simulate a sequential event. The transient source inputs lead to parameters that create a flaring scenario for **Qmax**, **Qmid** and **Qlow** which are modelled in place of the previously discussed **Qmax**, **Qave** and **Qmin** scenarios.

| Transient Inputs | UNITS | ENTRY |
|---|---|---|
| Expected Maximum Initial Pressure, PRESS0 | kPa (gauge) | 4200 |
| Expected Minimum Initial Gas Temperature, TEMPO | °C | 30 |
| Expected Minimum Final Pressure, PRESS1 | kPa (gauge) | 0 |
| Pipeline/Vessel Inside Diameter, VESSELDIA | m | 0.4364 |
| Pipeline/Vessel Length, VESSELLEN | m | 25100 |
| Minimum Orifice Diameter, ORIFICE_DIA | mm | 43 |
| Discharge Coefficient, DCOEFF | -- | 0.6 |
| Select the way the blowdown curve is converted from a continuous curve to discrete steps MDIST | -- | <input type="radio"/> 1. Equal Duration <input checked="" type="radio"/> 2. Equal Mass |
| Raw Gas User Initial maximum flow rate, QMAX | 10 ² m ³ /d (15°C and 101.325 kPa) | |
| Raw Gas User Total volume within vessels/pipes, QTOTAL | 10 ² m ³ (15°C and 101.325 kPa) | |
| User selected # of puffs, NPUFFS | -- | 3 |
| User selected puff duration, PUF DUR | min | |

Expected Maximum Initial Pressure, PRESS0

The initial pressure of the vessel or pipeline (gauge pressure) is required. The final pressure cannot go below site ambient pressure. The initial pressure may be the maximum operating pressure of the vessel or typical operating pressure of the vessel.

Expected Minimum Initial Gas Temperature, TEMPO

The initial temperature of the vessel is required to determine the physiochemical properties of the gas. For pipelines, the initial temperature may be correlated to seasonal changes in ambient temperature. *AERflare* does not provide a linkage between meteorological temperature and source temperature, and therefore separate analysis may be required using high, average and low initial vessel temperatures in order to determine the net impact of the source conditions on the predictions.

Expected Minimum Final Pressure, PRESS1

The final pressure of the blowdown may be a function of secondary systems or the vessel may be allowed to blowdown to near atmospheric pressure. In real systems, this may require a very long time, therefore, a non-zero gauge pressure of approximately 1 atmosphere (101 kPa) is a realistic endpoint.

Pipeline/Vessel Inside Diameter, VESSELDIA

The inside diameter and length of the vessel and pipeline are required to determine the total volume of gas flared. If the vessel is relatively short compared to the diameter, then it likely has rounded ends. Additionally, if the vessel is a facility blowdown, then reverse engineering may be required to enter pseudo-diameter and lengths so that the total volume is correct.

Pipeline/Vessel Length, VESSELLEN

The inside diameter and length of the vessel and pipeline are required to determine the total volume of gas flared. If the vessel is relatively short compared to the diameter, then it likely has rounded ends. Additionally, if the vessel is a facility blowdown, then reverse engineering may be required to enter pseudo-diameter and lengths so that the total volume is correct.

Minimum Orifice Diameter, ORIFICE_DIA

The transient blowdown of a vessel may go through various piping fittings before reaching the flaring nozzle. The high rate of gas flow through the system will result in compressibility limits (choked flow) and the flow through the system is limited by the minimum diameter in the system. The minimum diameter may be the flare nozzle or a metering orifice.

Discharge Coefficient, DCOEFF

The minimum orifice diameter will control the rate of gas through and out of the system because of choked flow. The discharge coefficient is not readily determined, since it may be impacted by back pressure through piping to the flare. A limiting case for flow through an orifice (Figure 15, Mannan 2005) provides a default value of 0.6 which allows for pipe friction from the orifice to the flare.

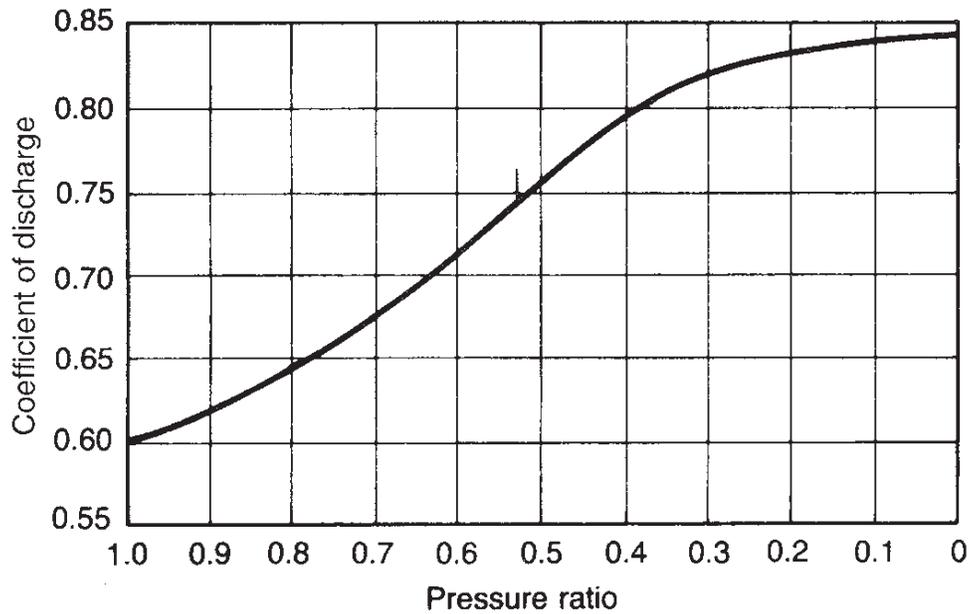


Figure 15: Coefficient of Discharge for Gas Flow Through an Orifice (Mannan 2005)

Select the way the blowdown curve is converted from a continuous curve to discrete steps, MDIST

MDIST directs *AERflare* to divide the blowdown into segments of equal volume or of equal mass. The recommended setting is to calculate segments of equal mass. The blowdown emission curve is well represented by an exponential decrease in emissions with time. The mass emissions are therefore exponentially distributed in time. The *AERflare* calculated source parameters to represent the plume rise are therefore naturally changing as a function of mass emissions. Equal volume steps may be more convenient when trying to match results from other air dispersion models or for simplifying the calculation of time averages. If the equal volume steps method is used for an exponential blowdown, the source parameters calculated by *AERflare* are based upon the step volume, and therefore at small release times, more mass is released at lower effective plume heights (see Figure 16.)

Raw Gas User Initial maximum flow rate, QMAX

The vessel initial and final conditions are used by *AERflare* to calculate the maximum flow rate (**QMAX**, initial flowrate of the continuous exponential blowdown curve) and the total volume (**QTOTAL**). An advanced user may calculate these variables usual in-house methods. *AERflare* accommodates non-default analysis for this input branch point by the direct entry of **QMAX** and

QTOTAL into the calculation sequence. The air dispersion modelling predictions are flagged as non-default.

Raw Gas User Total volume within vessels/pipes,
QTOTAL

See **QMAX**.

User selected # of puffs, **NPUFFS**

The continuous exponential curve must be assessed as a sequence of a discrete number of steps in emission rates. *AERflare* uses 3 steps to simulate the continuous curve.

User selected puff duration, **PUFDUR**

When the **MDIST** option is *Equal Duration*, the continuous exponential curve is divided in three steps over the calculated maximum duration or three steps of **PUFDUR** (puff duration) as entered by the user. If the **PUFDUR** results in a sequence shorter than total blowdown duration, then the final step is adjusted to contain the remaining mass in the blowdown curve.

Transient Blowdown Output

The source model is calculated on the **oBLOWDOWN** page. The **oBLOWDOWN** is a technical page that displays the results of the source calculations, and summarizes the **oAERSCREEN** detailed output similar to the **oFIGURE 1**. The output graphic on the **oBLOWDOWN** page shows maximum concentrations corrected for flaring duration and are there true 1h time averages.

The **oBLOWDOWN** page starts with a Modelling Flags and Warnings group. This table lists AER specific AER source requirements that may impact the requirement for a permit or the modelling.

The **oMODELLING** page displays the flaring rate (Figure 16) as a function of time. Shown in the figure is the continuous exponential curve that models the actual release (black line). The green curve is a three step discrete estimate of the black curve that will be used by *AERMOD* to model the flare, created by segments of equal pollutant mass. The blue curve is a three step discrete estimate

of the black curve that will be used by *AERMOD* to model the flare, created by segments of equal duration.

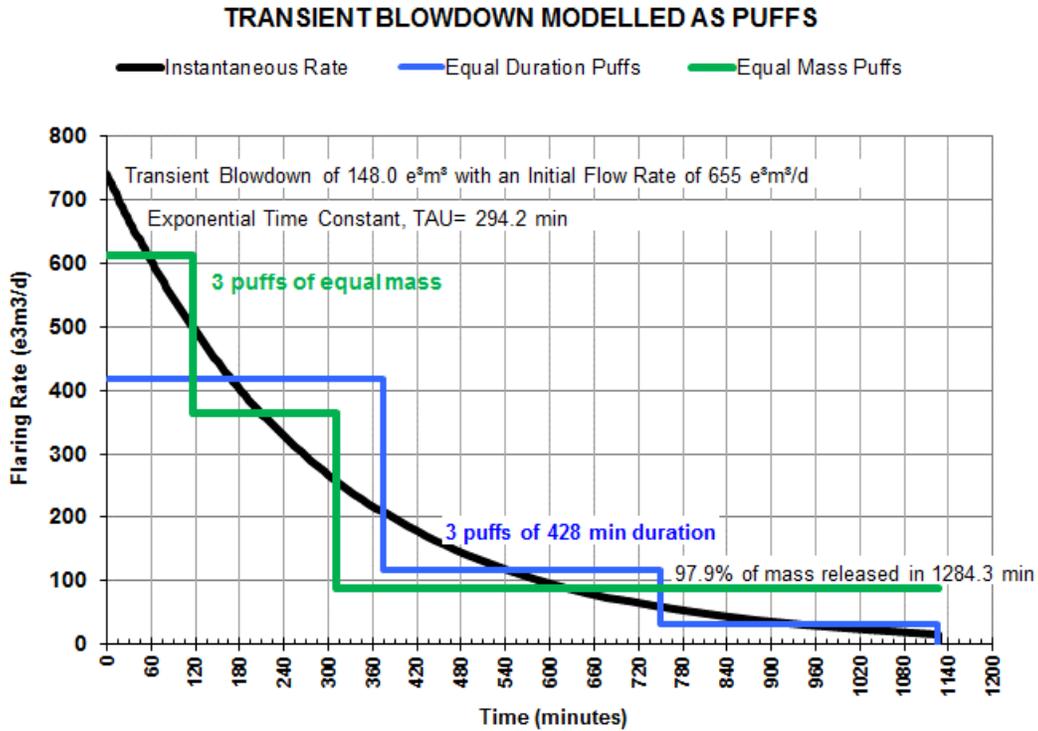


Figure 16: Example Continuous Exponential Blowdown Curve shown *AERflare* modelled Discrete Stepped Sequence using Equal Mass Steps or Equal Duration Steps

An important calculation group on the **oBLOWDOWN** page is illustrated below. It summarizes the source flowrates and durations for the equal mass and equal duration source models. The durations are used to predict 1h maximum time averages from the output concentrations. In this case, each of the blowdown steps is longer than one hour, and therefore maximum 1h average concentration from each step is a representative possible maximum concentration.

| Flowrates Modelled | | | | |
|--------------------------------|---|--------|--------|--------|
| Description | Units | Qhi | Qmed | Qlo |
| Equal Duration | 10 ³ m ³ /d (15°C and 101.325 kPa) | 418.23 | 116.79 | 32.61 |
| Duration | min | 375.25 | 375.25 | 375.25 |
| Equal Mass | 10 ³ m ³ /d (15°C and 101.325 kPa) | 611.62 | 364.97 | 87.10 |
| Duration | min | 116.09 | 194.54 | 815.13 |
| Volume Flowrate to Be Modelled | 10 ³ m ³ /d (15°C and 101.325 kPa) | 611.62 | 364.97 | 87.10 |
| Duration | min | 116.09 | 194.54 | 815.13 |

The graphic on the **oBLOWDOWN** page shows the summarized worst case screening blowdown results. The results are summarized by taking the worst case 1st stage, worst case 2nd stage and worst case 3rd stage from *oAERSCREEN* page.

AERflare screening assumes each blowdown stage occurs during the same hourly sequence. This may not be the case but represents a conservative estimate for screening purposes. For more detailed analysis, the **oPOSTPROCESSING** page can be used to combine 1st, 2nd and 3rd stage results on an hourly basis.

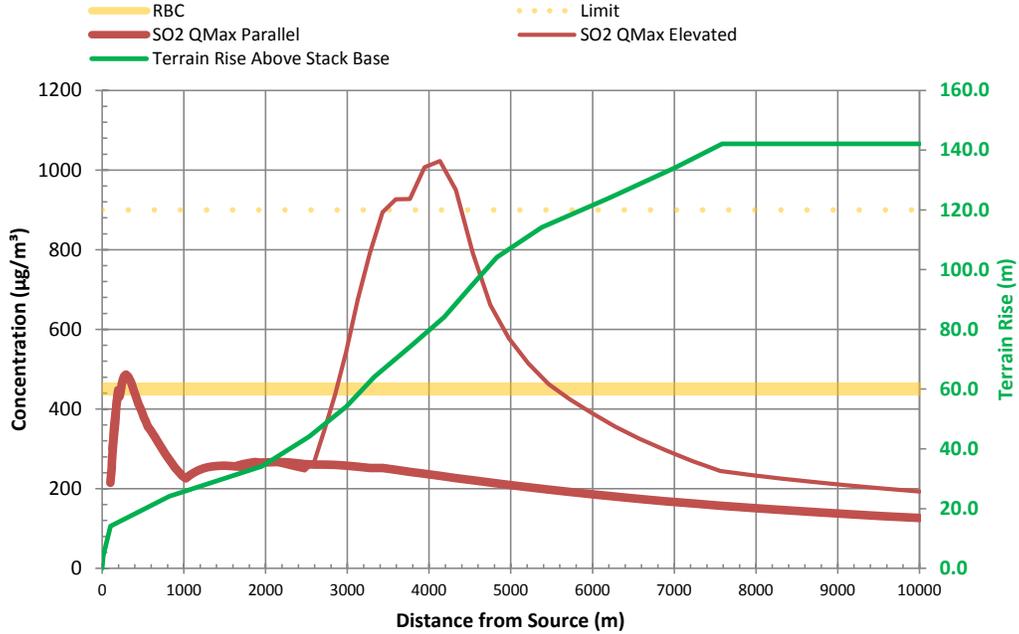


Figure 17: Blowdown Modelling Output from oAERSCREEN

6. ADVANCED TECHNIQUES

The *AERflare* screening air dispersion modelling results may indicate that the air quality may exceed the ambient air quality objectives. The *AERflare* tool can be used to determine the sensitivity of the source parameters (e.g., stack height, nozzle diameter, etc...) to the ambient air quality predictions. It may be further determined that refined air dispersion modelling is required to design and test the flaring scenarios. *AERflare* provides several options for further analysis including:

- creation of a site specific meteorological data set for refined air quality dispersion modelling,
- creation of a site specific receptor grid incorporating terrain,
- running *AERflare* in refined dispersion mode consistent with screening inputs and post-processing consistent with screening analysis
- a bridge to refined air dispersion modelling by producing *AERMOD* ready input files and *AERMOD* variable source emission files that can be run external to *AERflare*; and,
- post-processing of external *AERMOD* results using advanced statistics and Risk Based Criteria methodology.

These advanced modelling techniques are discussed in the following sections.

Site Specific Meteorology

The **iUSERMET** page is displayed when the *Show Technical Pages* option is selected on the **iSTART** page. The step-by-step process is displayed on the **iUSERMET** page. The page provides detailed instructions on how to create a site-specific meteorological data file for use with refined dispersion modelling. A site specific meteorological data set is the first step in refining the screening air quality dispersion assessment

Step 1-Get MMEU Data

The first step in creating a site specific meteorological data set is to acquire a surface and upper air data file. *AERflare* uses the AQMG recommended meteorological data set and meteorology extraction utility *MMEU* available from the ESRD web-site:

<http://www.albertamm5data.com/>

The *MMEU* program creates a SAMSON.dat and RAOBS.dat (surface and upper air raw data meteorological data files). These files are processed using the AERMET program to create *AERMOD* ready meteorological surface and upper air files.

The procedure for STEP 1 is provided on the **iUSERMET** page as shown below. The *MMEU* requires the location of the flare source in UTM coordinates only. Although *AERflare* can use other coordinates for its assessment, the **REFRESH** button can be used to convert the flare input coordinates to UTM coordinates acceptable by the *MMEU* program.

| Step 1 Get MMEU Data | | REFRESH |
|----------------------|---|---------|
| 1.1 | Press 'REFRESH' button on this page (see right) | |
| 1.2 | Start the MMEU Multi-Model Extraction Utility | |
| 1.3 | Select the 'AERMOD' output file type | |
| 1.4 | Enter the UTM coordinates of your site and UTM zone, as listed below | |
| 1.5 | Selection 'Interpolate from 4 Closest Cells' Extraction Option | |
| 1.6 | Ensure start date is January 1, 2002 and end date is December 31, 2006 | |
| 1.7 | Press 'Check Inputs' button to ensure inputs are valid | |
| 1.8 | Press 'Extract' button to start extraction process using MMEU | |
| 1.9 | A dialog window will appear. Enter the location for SAMSON.dat and RAOBS.dat files. Record your entries for Step 3. Press OK to proceed with the extraction. The extraction process can take several hours depending upon the computer and network speed. It is therefore best to plan ahead to ensure that this Step 1 is performed well in advance of the analysis. | |



The extraction process can take several hours depending upon the computer and network speed. It is therefore best to plan ahead to ensure that this Step 1 is performed well in advance of the analysis.

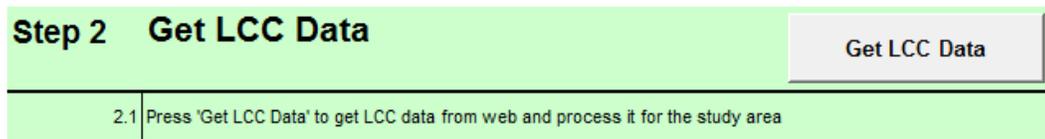
The *MMEU* extraction process is time consuming due to the large number of files and large size of files required to be processed. Therefore, depending on the computing resources available, this step can take a significant amount of time.



The *AERflare* site specific meteorological processing allows for users to make use of SAMSON.dat and RAOBS.dat files created using alternative methods. Therefore, STEP 1 can be by-passed if a user these two files from alternative sources

Step 2-Get LCC Data

Step two in the process of creating a site specific meteorological data file is determine the land-use surrounding the flare location. This step uses the flare coordinates entered in STEP 1 to download land-use classification codes (LCC) for Canada and process the data into an *AERMET* ready format. The steps in this process are simplified to, press the **Get LCC Data** button. However, behind the button are complex calculations.



When the button is pressed, *AERflare* determines the NTS map sheets required for the LCC assessment. The map sheets are output to the Map Sheets field on the page. *AERflare* then checks the LCCLIB local library if the LCC map sheet data has already been down loaded (see also the **iSTART** page [mlccget](#) flag). If the data does not exist locally, then it is automatically downloaded from the internet.

Once download, the LCC data map sheets are processed according to the *AERSURFACE* rules and algorithms. Surface roughness is determined based upon the LCC within 1 km of the flare location and Bowen ratio and albedo are determined based upon LCC data within 5 km of the flare location. The assessment uses a resolution of 100 m to subsample the LCC codes with in the area.



The 'Get LCC Data' uses the user entries on the **iUSERMET** page for the location of the flare. A user can enter any valid UTM coordinates on the **iUSERMET** page to analyze LCC codes for that site entered. This allows for what-if analysis or further evaluation for sensitivity.

The results of the LCC assessment are displayed in the table on the **iUSERMET** page. The table shows a listing of the LCC codes, the count of LCC codes within 5 km radius and the fractional percentage of the LCC for the study area. Also listed below the detailed LCC statistics, is a re-assessment of the screening LCC codes. This latter table can be used to compare to the land use file selected by the screening assessment. The screening assessment uses a coarse nearest-neighbour approach for the rapid assessment, and therefore there is expected to be differences compared to a site specific assessment provided on this page.

Step 3-Create User Meteorological File

The third step in creating a site specific meteorological data file to combine the surface and upper air data with the local land use statistics. The user is prompted for the SAMSON.dat and RAOBS.dat file created in STEP 1 with the addition of the time zone entry. The **Create UserMet** button is then used to create AERMOD ready surface and upper air files (AERMOD.sfc and AERMOD.pfl) which are created in the same folder as the SAMSON.dat file. The AERMET.exe program (see **iBIN** page) is used to create the output files.

| Step 3 Create User Met | | Create UserMet | |
|------------------------|---|----------------|--|
| 3.1 | Enter the time zone for the well location | | |
| 3.2 | Enter the full path for input files SAMSON.dat and RAOBS.dat. These are the output files from MMEU. | | |
| 3.3 | Press 'Create UserMet' to create a site specific REFINED meteorological file | | |
| 3.4 | AERMOD.sfc and AERMOD.pfl will be created in the same folder as the SAMSON.dat/RAOBS.dat files | | |

| | | | |
|-----------|---|--|--|
| Time Zone | 7 | UTC time zone. Entered as negative of UTC zone number. | |
|-----------|---|--|--|

| BIN | FULL PATH | BROWSE | COMMENTS |
|------------|--|--------|----------|
| SAMSON.dat | P:\ERCBtools\AERflare\Examples\SiteA\samson_sitesa.dat | ... | |
| RAOBS.dat | P:\ERCBtools\AERflare\Examples\SiteA\raobs_sitesa.dat | ... | |

The result of this step is a 5-year meteorological data set that is suitable for refined dispersion modelling.



The folder containing the SAMSON.dat will contain any error messages produced while running AERMET.exe. Output messages may be found in .lst, .msg, .rep or .err files.

Step 4 (Optional)-Create Site Specific Screening Meteorological File

An optional step is to create a site specific screening meteorological file. This file can be used similar to the AERflare provided screening meteorological data sets for rapid user what-if analysis or further evaluations. The user is prompted for an output folder. The **Create ScreenMet** button is pressed to create the screening meteorological data files using the MAKEMET.exe program (see **iBIN** page).

Step 4 (OPTIONAL) Create a Site Specific Screening Met

4.1 Enter the full path for the folder for processing screening meteorology

4.2 Press 'Create ScreenMet' to create a site specific SCREENING meteorological file

4.3 ScreenMet.sfc and ScreenMet.pfl will be created in the Screen Met Folder

| BIN | FULL PATH | BROWSE | COMMENTS |
|-------------------|--|------------------------------------|----------|
| Screen Met Folder | P:\2011\1100500-FlareModel\metfiles\testb\ | <input type="button" value="..."/> | |

Site Specific Terrain

The **iUSERTER** page is displayed when the *Show Technical Pages* option is selected on the **iSTART** page. The step-by-step process displayed on the **iUSERTER** page provides detailed instructions on how to create a site-specific receptor file for use with refined dispersion modelling.

Step 1- Define Receptor Grid

The procedure for STEP 1 is provided on the **iUSERTER** page as shown below. The process requires the location of the flare source in UTM or 10TM coordinates only. The **REFRESH** button can be used to convert the flare input coordinates to UTM coordinates.

Step 1 Define Receptor Grid

1.1 Press 'REFRESH' button on this page (see right)

1.2 Adjust the Receptor Grid Spacing. The Default entries represent the Air Quality Modelling Guideline recommended resolution

| | |
|-----------|---|
| | Centre of Domain |
| X UTM | 481234 |
| Y UTM | 6112345 |
| UTM Zone | 11 |
| | Conversion to Geographic Coordinates |
| Longitude | -117.2945 |
| Latitude | 55.1574 |



The **REFRESH** button can be by-passed and the user can enter valid UTM coordinates in the table. The **Create Receptor** button in the STEP 2 then processes the entered location.

The receptor grid spacing table is provided to create a default ESRD AQMG receptor grid. The default values can be changed to create user-specific grids.

| ID | Resolution (m) | Default (m) | Distance | Default | Receptors |
|-------|----------------|-------------|----------|---------|-----------|
| 1 | 20 | 20 | 100 | 100 | 40 |
| 2 | 50 | 50 | 500 | 500 | 416 |
| 3 | 100 | 100 | 500 | 500 | 0 |
| 4 | 250 | 250 | 2000 | 2000 | 264 |
| 5 | 500 | 500 | 5000 | 5000 | 360 |
| 6 | 1000 | 1000 | 10000 | 10000 | 320 |
| 7 | 5000 | 5000 | 10000 | 10000 | 0 |
| Total | | | | | 1400 |

Note: receptor spacing for ID=3 and ID=7 are non-default and allow for special considerations

Step 2-Create Receptors

In Step 2, the name for the output receptor file is prompted for then the **Create Receptors** button is pressed to create the receptors. When the button is pressed, *AERflare* determines the map sheets required for digital terrain information (digital elevation model, DEM). The map sheets used in the assessment are listed in the Map Sheets field. The assessment requires map sheets for the domain area (10 km square radius) plus an additional 5 km radius to determine hill scale factors for each receptor location. The hill scale factors are determined following the algorithm used in AERMAP which determines the worst case slope positive slope (greater than 10 degrees) from any hill in the study area at each receptor location.

AERflare first looks in the DEMLIB local library (see **iBIN** page) according to the **mgetdem** flag (see **iSTART** page). If the map sheet is not found within the library, it is automatically downloaded from the internet and stored within the DEMLIB location. The receptor grid defined in the table in STEP 1 is analyzed and is output for reference at the bottom of the **iUSERTER** page. It is also stored in the file location specified on **iUSERTER**. The file created is an *AERMOD* ready receptor insert file that can be used to insert receptor locations into an *AERMOD* ready input file using automation.

| Step 2 Create Receptors for AERMOD | | Create Receptors | |
|------------------------------------|--|------------------|--|
| 2.1 | Enter the path name for the output receptor list | | |
| 2.2 | Press 'Create Receptors' to create a receptor grid as specified in Step 1, and output to the path name. Or, select the check box to read receptors from a CSV file. Map sheets for DEM are automatically download as required or loaded from DEMLIB. | | |
| | <input type="checkbox"/> Read User Receptor Grid | | |
| 2.3 | The DEM map sheets used in the creation of the receptor files are listed below. The receptor locations (X,Y), elevation and hill scale heights are listed at the bottom | | |

| BIN | FULL PATH FOR OUTPUT | BROWSE | COMMENTS |
|-------------|--|--------|----------|
| terrain.dat | P:\ERCBtools\AERflare\Examples\SiteA\userter.ter | ... | |

| | |
|------------|-----------------------------|
| Map Sheets | 083n04;083n05;083n06;083n03 |
|------------|-----------------------------|

AERflare allows a user to input a text file in CSV format containing X,Y receptor grid points created external from *AERflare*. To load the file, check [Read User Receptor Grid](#) before pressing the **Create Receptors** button. *AERflare* will read the receptor file, then process the terrain elevation and receptor hill heights. This feature can be useful to examine regions of interest in a domain or a non-regular grid..

Step 3-Find the Maximum

AESRD Air Quality Model Guideline require the modeller to confidently determine the maximum concentration within the modelling domain. This can be a challenging interpretation of the predictions when elevated terrain is involved. The **iUSERTER** page can be used with *AERflare* to re-evaluate the air quality predictions by creating a receptor grid around the maximum predicted concentration from the first pass dispersion modelling.

Instead of using the **Refresh** button on the **iUSERTER** page, enter the X,Y UTM location of the maximum or point of interest. Then select the receptor spacing and distances to refine the search for the maximum concentration. For instance, the receptor configuration below could be used to continue to search for the maximum concentration near the location X=482,000, Y=6,113,000 where these X and Y values are manually entered into table, and the resolution and distances are manually changed to define a grid with a 20m spacing within 100m of the X,Y location, 50m between 100 and 500m from the location, and 100m less than 1000m from the location. The user can then repeat Step 2, and create a second user receptor file for analysis. The **Reset to Default** button can be used to return the Receptor Grid Spacing table to its default values. The orange backgrounds indicate values different than default values.

| | |
|-----------|---|
| | Centre of Domain |
| X UTM | 482000 |
| Y UTM | 6113000 |
| UTM Zone | 11 |
| | Conversion to Geographic Coordinates |
| Longitude | -117.2945 |
| Latitude | 55.1574 |

Reset to Default

Receptor Grid Spacing

| ID | Resolution (m) | Default (m) | Distance | Default | Receptors |
|--------------|----------------|-------------|----------|---------|------------|
| 1 | 20 | 20 | 20 | 100 | 8 |
| 2 | 20 | 50 | 100 | 500 | 112 |
| 3 | 50 | 100 | 500 | 500 | 416 |
| 4 | 100 | 250 | 1000 | 2000 | 320 |
| 5 | 500 | 500 | 1000 | 5000 | 0 |
| 6 | 1000 | 1000 | 1000 | 10000 | 0 |
| 7 | 5000 | 5000 | 1000 | 10000 | 0 |
| Total | | | | | 856 |

Note: receptor spacing for ID=3 and ID=7 are non-default and allow for special considerations

Refined Modelling

Refined dispersion modelling is available through *AERflare* using the **oMODELLING** calculation buttons or using the create *AERMOD* ready input files options.

Permit Flare Air Dispersion Modelling

On the **oMODELLING** page:

- Click on button **7. AERMOD (HbH User Terr/User Met)** or **8. Create AERMOD Input File(s) (HbH User Ter/User Met)**
- You will be prompted for a file name and folder in which to place the files. Locate the folder where you want the files to be created and enter a name: *AERMOD.inp*. Click OK to continue
- You will then be prompted for the filename of the site specific meteorological file (see **iUSERMET** page) to be used to create the hour by hour emissions source file. Locate the file and select it. Click **OK** to continue.

- You will then be prompted for a receptor insert file to be used (see **iUSERTER** page). If the user presses cancel at this step, then a screening receptor configuration is used.



If the user presses cancel at this step, then a screening receptor configuration is used.

- AERflare* will then look through the sources and meteorology to create *AERMOD.inp* for each of the scenarios.
- If the **#7** was pressed the analysis continues by running *AERMOD* and post processing the results. If **#8** was pressed, the *AERMOD* ready files are created but not processed.

Once complete, the folder will contain two files for each scenario to be assessed, where: n is the case number corresponding to the number on **oAERSCREEN**; and *<AERMOD>* is the filename entered on step 1 of this sequence of instructions.

| | |
|---------------------------------------|--|
| <i><AERMOD>_n.inp</i> | an AERMOD ready input file |
| <i><AERMOD>_n_emissions.dat</i> | an AERMOD ready variable source file linked to <i>AERMOD_n.inp</i> |

Evaluation Flare Air Dispersion Modelling

On the **oMODELLING** page:

- Click on button **3.AERMOD-RBC (User Ter/User Met)** or **4.Create AERMOD files (Average Wind Speed)**
- You will be prompted for a file name and folder in which to place the files. Locate the folder where you want the files to be created and enter a name: *AERMOD.inp*. Click OK to continue
- You will then be prompted for the filename of the site specific meteorological file (see **iUSERMET** page) to be used to create the hour by hour emissions source file. Locate the file and select it. Click **OK** to continue.

4. You will then be prompted for a receptor insert file to be used (see **iUSERTER** page). If the user presses cancel at this step, then a screening receptor configuration is used.



If the user presses cancel at this step, then a screening receptor configuration is used.

5. *AERflare* will then look through the sources to create *AERMOD.inp* for each of the scenarios.
6. If the **#3** was pressed the analysis continues by running *AERMOD* and post processing the results. If **#4** was pressed, the *AERMOD* ready files are created but not processed.

Once complete, the folder will contain two files for each scenario to be assessed, where: n is the case number corresponding to the number on **oAERSCREEN**; and *<AERMOD>* is the filename entered on STEP 1 of this sequence of instructions.

| | |
|------------------------------|----------------------------|
| <i><AERMOD></i> _n.inp | an AERMOD ready input file |
|------------------------------|----------------------------|

Post-Processing External Refined Modelling Output

A step-by-step process for the assessment of externally generated *AERMOD* results is provided on the **oPOSTPROCESS** page. The **oPOSTPROCESS** page allows the user to calculate more detailed statistics from the *AERMOD* output. If the user selects the option to keep output files (**mkeepout**) on the **iSTART** page, the output from *AERflare* can be re-post-processed with more detail using the **oPOSTPROCESS** page.

The **oPOSTPROCESS** page requires that the following *AERMOD* output control options were used:

```
OU PLOTFILE 1 ALL FIRST myplot.dat
OU POSTFILE 1 ALL UNIFORM mypost.bin
```

The myplot.dat file is required to provide a listing of the receptor data points used included in the assessment. The mypost.bin file contains the hour by hour predictions of *AERMOD* for each receptor. These control options are used by *AERflare* and when the ‘Keep Output’ (*mkeepout*) advanced *AERflare* setting is the [myplot].dat and [mypost].bin files are available for post-processing.

| | | | | |
|--|---|--|-----|-----------------------------------|
| input: PLOTFILE AERMOD output Plot File | P:\ABflare\ERCBflare\Ex4\maxratenofgr_1_elev.dat | | ... | |
| input: METFILE Meteorological File Used | P:\ABflare\ERCBflare\Ex3\AERMOD.SFC | | ... | |
| | Enter a single file or Enter three post files to analysis a BlowDown | | | Duration (minutes) |
| input: SINGLE POSTFILE or QMAX POSTFILE AERMOD output Post File | P:\ABflare\ERCBflare\Ex4\maxratenofgr_1_elev.bin | | ... | 60.0 |
| input: QAVE POSTFILE AERMOD output Post File | | | ... | <input type="checkbox"/> Blowdown |
| input: QMIN POSTFILE AERMOD output Post File | | | ... | |

| | | | |
|---------------------------------|-------|---------|---|
| Source Location, UTM x | m | 688183 | |
| Source Location, UTM y | m | 5513080 | |
| Time of Year to Model the Flare | -- | Annual | ▼ Modelling using user-meteorological files will use the selected month and the month before and after. |
| Chemical Pollutant Label | -- | SO2 | Label for Chart |
| Objective or Limit | µg/m³ | 450 | Limit for Chart |

The first required input is the **PLOTFILE**. This *AERMOD* output file contains a listing of the X,Y receptor points and hourly average maximum concentrations. *AERflare* requires this file for the listing of the X,Y receptors used in the analysis. The concentration data is not used by *AERflare*.

The second input is the **METFILE**. This *AERMOD* meteorological input file is the surface portion of the *AERMET* SFC and PFL pair. *AERflare* uses the SFC file to match the meteorological conditions to the same hour as a concentration statistic of interest. *AERflare* will output the wind direction, PG stability, wind speed and time of day that matches the concentration statistic.

AERflare will post-process a single *AERMOD* for a steady flare or three-file output sequence that composes a blowdown sequence. For the former case, the user will be required to post-process *AERflare* **Qmax**, **Qave** and **Qmin** output for SO₂ or H₂S steady flares individually, by sequentially entering the desired *AERMOD* output into the **QMAX POSTFILE** entry location, respectively. The user must also specify the flaring duration for the steady release in minutes. If the duration is greater than or equal to 60min, the user should enter 60min. The duration is used to adjust the *AERMOD* output from an hourly average concentration to a sub-hourly average. For blowdown flares, the blowdown

emission curve is divided into three equal mass duration flares. The **oPOSTPROCESS** uses the durations provided for each of the **QMAX**, **Q MID** and **QLOW** output files to determine the worst case hourly time average. The worst case hourly time average may be a combination of one, two or all three emission rates depending upon their respective duration. *AERflare* makes combinations of results based upon the same modelling output hour.

The flare location information allows *AERflare* to calculate the distance to maximum concentration. The time of year can be used to determine annual statistics or various monthly flaring alternatives. If ‘Annual’ is selected, the output file is analyzed in annual divisions to determine percentiles, then the maximum of all years is extracted. If a month is selected, then the month and each shouldering month is pooled to form a single dataset for which statistics are calculated. This methodology ensures there is a sufficient number of data points to apply the RBC criteria.

After the user presses the ‘Post-Process’ button, the standard *AERflare* statistics are calculated, as shown below:

| SUMMARY OUTPUT | | Units | Maximum (QMAX) | Number of Data Points in Sample |
|--|----------------|-------------------|----------------|---------------------------------|
| Maximum Concentration | cmax | µg/m ³ | 1755 | 43823 |
| Distance to Maximum Concentration | xmax | m | 1337 | |
| Wind Speed | ws | m/s | 1 | |
| PG Stability Class | PG | PG | E | |
| Distance Concentration drops below Obj#1 | xobj1 | m | 1716 | |
| Distance Concentration drops below Obj#2 | xobj2 | m | -1 | |
| Distance Concentration drops below Obj#3 | xobj3 | m | 1716 | |
| Concentration CMAX (99.9th) | winter or yr 1 | µg/m ³ | 1292 | 8760 |
| | spring or yr 2 | µg/m ³ | 1130 | 8760 |
| | summer or yr 3 | µg/m ³ | 1149 | 8784 |
| | fall or yr 4 | µg/m ³ | 1117 | 8760 |
| | month or yr 5 | µg/m ³ | 1112 | 8759 |
| Concentration RBC (99.0th) | winter or yr 1 | µg/m ³ | 236 | 8760 |
| | spring or yr 2 | µg/m ³ | 299 | 8760 |
| | summer or yr 3 | µg/m ³ | 311 | 8784 |
| | fall or yr 4 | µg/m ³ | 328 | 8760 |
| | month or yr 5 | µg/m ³ | 297 | 8759 |

This table is similar to what the user has already seen on the **oAERSCREEN** page and **oMODELLING** page. It lists the overall maximum concentration and the individual year or month **CLIMIT1** and RBC statistic concentration. Also provided for reference are the number of data points found for each sample.

The next data group allows the user to select statistics to meet specific end-points of interest or to plot a PDF curve, for example. On the left, the user can enter ‘Nth highest’ statistics. For example, the user can enter 9, to calculate the 9th highest concentration. On the right, the user can select percentile statistics. For

example, the user can enter the 99.9 to determine the 99.9 percentile concentration.

| User Selectable Statistics | | | | | |
|-----------------------------------|-------|--------------------------|---------------|---------|--------------------------|
| VARIABLE | INPUT | $\mu\text{g}/\text{m}^3$ | VARIABLE | INPUT % | $\mu\text{g}/\text{m}^3$ |
| Nth Highest 1 | 1 | 1754.99 | Percentile 1 | 50 | 52.75 |
| Nth Highest 2 | 2 | 1698.87 | Percentile 2 | 60 | 75.64 |
| Nth Highest 3 | 9 | 1319.58 | Percentile 3 | 70 | 95.17 |
| Nth Highest 4 | | | Percentile 4 | 80 | 120.76 |
| Nth Highest 5 | | | Percentile 5 | 90 | 166.81 |
| Nth Highest 6 | | | Percentile 6 | 95 | 210.18 |
| Nth Highest 7 | | | Percentile 7 | 96 | 226.36 |
| Nth Highest 8 | | | Percentile 8 | 97 | 246.41 |
| Nth Highest 9 | | | Percentile 9 | 98 | 283.93 |
| Nth Highest 10 | | | Percentile 10 | 98.5 | 297.20 |
| Nth Highest 11 | | | Percentile 11 | 99 | 327.97 |
| Nth Highest 12 | | | Percentile 12 | 99.5 | 460.46 |
| Nth Highest 13 | | | Percentile 13 | 99.6 | 528.00 |
| Nth Highest 14 | | | Percentile 14 | 99.9 | 1291.90 |
| Nth Highest 15 | | | Percentile 15 | 99.99 | 1698.87 |
| Nth Highest 16 | | | Percentile 16 | | |
| Nth Highest 17 | | | Percentile 17 | | |
| Nth Highest 18 | | | Percentile 18 | | |
| Nth Highest 19 | | | Percentile 19 | | |
| Nth Highest 20 | | | Percentile 20 | | |
| Nth Highest 21 | | | Percentile 21 | | |
| Nth Highest 22 | | | Percentile 22 | | |
| Nth Highest 23 | | | Percentile 23 | | |
| Nth Highest 24 | | | Percentile 24 | | |
| Nth Highest 25 | | | Percentile 25 | | |

The percentile data is plotted in the graphic below the table as shown below. The concentration limit is also shown on the plot and is entered by the user from the entry of **Chemical Pollutant Label** and **Objective or Limit** entries on the **oPOSTPROCESS** page. The results shown adjacent to the Nth highest or percentile entries are the maximum of annual statistics (for annual analysis) or the pooled monthly and shoulder month data for monthly analysis. The individual year data is listed at the bottom of the page for reference.

Also provided on the **oPOSTPROCESS** page are three summary matrices that list the Meteorology as a function of wind speed and PG stability; maximum concentration as a function wind speed and PG stability; and, receptor distance at maximum concentration as a function of wind speed and PG stability. The receptor distance matrix will be a function of the user's receptor grid density.

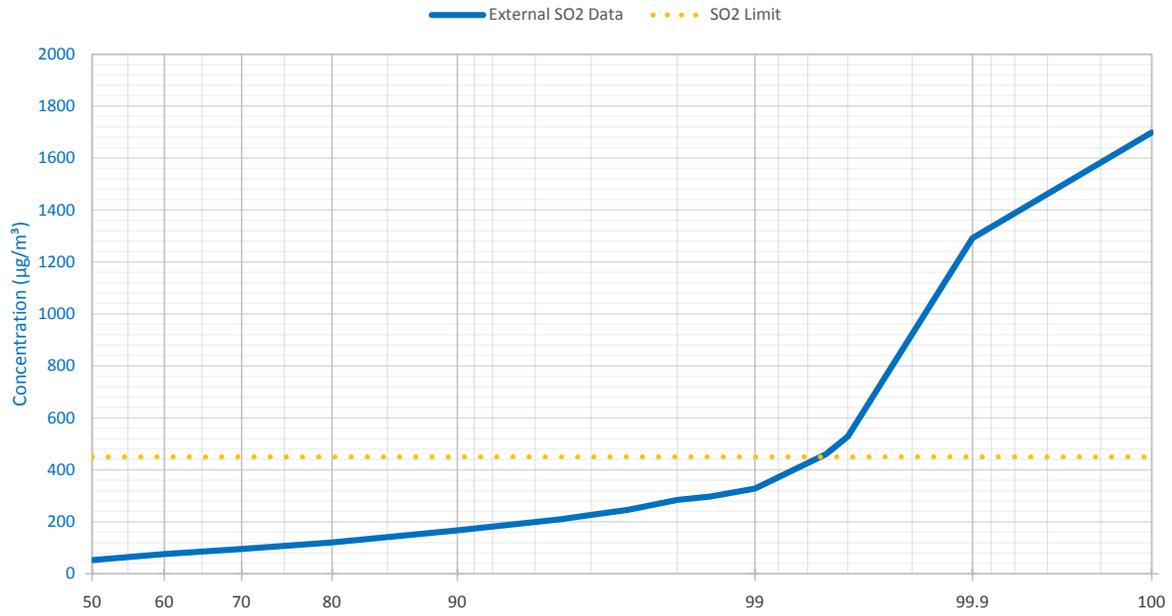


Figure 18: Probability Density Function Curve Determined from the Maximum of Annual Statistics

7. BATCH OPERATIONS

The *AERflare* spreadsheet tool provides a rapid screening tool assessment for many types of flaring assessments with a user-interface principally intended for individual scenario assessment. Also included with *AERflare* is ability to consecutively, process a list of scenarios for sensitivity analysis, what-if analysis or exist as a simple database. A sensitivity analysis is an assessment where the majority of the input variables are the same, but selected variables are modified using a range of input values (example, stack height) in order to determine a robust solution. For some operators with many flares, once all the base data has been collected and entered, the *AERflare* tool can be run for the entire list of flares and the process repeated if a common element (say gas composition or licenced SO₂ mole fraction) changes.

Operating *AERflare* on one or many scenarios makes use of the batch mode capabilities. In general, input data is stored on the **iBATCH** page and following an analysis, the output is saved on the **oBATCH** page.

Batch File Step-by-Step

The best way to start a batch mode configuration is to enter all of the input fields in *AERflare* on the **iFACILITY**, **iFLARING**, **iTERRAIN**, and **iNOTES** pages.

- Press Save to Batch Page to save all of the input fields on all of the *AERflare* pages to the next empty line on the **iBATCH** page
- Copy the scenario line on the **iBATCH** page to other blank lines to create the exact same input variables. Then change selected variables on the copied lines to create the sensitivity assessment
- Add a run flag in the first column of each **iBATCH** row where 1=run and 0=don't run.
 - All lines with a “1” in the run column will be loaded and processed during a batch mode operation.
 - All lines with a “0” in the run column will be skipped. Therefore, the run flag allows a user to keep a large list of flaring assessment

configurations on **iBATCH** page, but only process those configurations marked for assessment.

- Use “2” in the run column and the **Print Required** will be executed after job
- Press the **Run Batch** on the **iBATCH** page to run all of the scenarios on the with run flags set to 1. **WARNING** long run times may result if many lines are marked with a 1 in the run column.
- Summary output information is copied back to the **iBATCH** for each row entry and to the same row number on the **oBATCH** page.

In order for *AERflare* to accommodate early versions of *MS Excel* that are limited to 255 columns of data, the batch page is divided into inputs (**iBATCH**) and outputs **oBATCH**. Output on the **oBATCH** page corresponds to the identical row number on the **iBATCH** page.

AERflare does not perform house-keeping on either the **iBATCH** nor **oBATCH** page. If rows are inserted or deleted on the **iBATCH** page, the user should also do so on the **oBATCH** page to avoid confusion.

iBATCH Page as a Database

The **iBATCH** page can be used as a database (a collection of *AERflare* inputs) in a single location. This allow a single *AERflare* spreadsheet file to be used for many flaring scenarios configurations rather than having many *AERflare* spreadsheets with only a single flare configuration in each file.

Once an **iBATCH** page has been populated with entries, a user can scan the page and readily visualize differences and similarities between scenarios.

The best way to start a batch mode database is to enter all of the input fields in *AERflare* on the **iFACILITY**, **iFLARING**, **iTERRAIN**, and **iNOTES** pages.

- Press “Save to Batch Page” to save all of the input fields on all of the *AERflare* pages to the next empty line on the **iBATCH** page
- To start a new configuration, the data on the **iBATCH** page can be copied and edited or the entries on the **iFACILITY**, **iFLARING**, **iTERRAIN**, and **iNOTES** pages can be updated. In the latter case, press **Save to Batch Page** button once a scenario update has been completed. The scenario will be copied to the next empty line on the **iBATCH** page.

- Add a run flag in the first column of each **iBATCH** row where 1=run and 0=don't run. It is a safe practice, to enter "0" on all lines being stored on the **iBATCH**. This prevents accidentally processing the entire database when the **Run Batch** button is pressed.
- To reload a single scenario, select any cell on the row of the scenario to be reloaded, then press the **Load Current Row** button. All of the inputs from the **iBATCH** page will be copied to the respective cells on the **iFACILITY**, **iFLARING**, **iTERRAIN**, and **iNOTES** pages.

Example iBATCH Sensitivity Setup

The steps below will be a guide through a simple batch mode sensitivity configuration. In this tutorial example, we use the pre-loaded "Site A" configuration.

1. On the **iBATCH** page, select a cell on the row with the scenario name "Site A", then press the **Load Current Row** button at the top of the **iBATCH** page. This will copy all of the inputs and settings from the **iBATCH** page to the respective cells on the **iFACILITY**, **iFLARING**, **iTERRAIN**, and **iNOTES** pages.
2. On the **oMODELLING** page, press the non-routine modelling option **5. AERSCREEN-HBH** to run and *AERMOD* analysis using the screening meteorological data using the hour-by-hour flaring option.
3. Once the modelling has been completed, the **oMODELLING** page should display the results, as shown below. The results indicate that maximum concentration is 1311 $\mu\text{g}/\text{m}^3$. Since this concentration is greater than the SO_2 objective of 450 $\mu\text{g}/\text{m}^3$, it is desirable to determine the stack height required in order to meet the objective. This stack would represent an upper bound on the necessary stack height and only one possible design change option

| | | | | |
|--|----------------------------------|--|------------------------------|-------------------|
| Dispersion Model Used | 3 | AERSCREEN-(HBH) Max Concentration Only | | |
| Aermod Version Used | 12345 | | | |
| Meteorological File Used | Flare_v130114\metfiles\GRASS.sfc | | | |
| AERMOD Output File Base | | | | |
| # Hours in Meteorological File | 2635 | | | |
| Dispersion Model Predictions These results account for the duration of the flaring and 1h hour averaging time. | Annual | | | |
| SO₂ Predictions | Units | Maximum 1h (QMAX) | Average 1h (Volume/Duration) | Minimum 1h (QMIN) |
| Averaging time is (minutes): 60 and Total Flare duration is (minutes): 4320.0 | | Worst Case of Parallel or Elevated Terrain Results | | |
| Maximum Concentration | µg/m ³ | 1311 | 816 | 336 |
| Distance to Maximum Concentration | m | 6893 | 6280 | 5722 |
| Wind Speed | m/s | 1.0 | 1.0 | 1.0 |
| PG Stability Class | PG | F | F | F |
| Distance Concentration drops below Obj#1 | m | 10000 | 10000 | -1 |
| Distance Concentration drops below Obj#2 | m | -1 | -1 | -1 |
| Distance Concentration drops below Obj#3 | m | 10000 | 10000 | 10000 |
| Climit Maximum Concentration CMAX (99.9th) | µg/m ³ | NA | NA | NA |
| RBC Maximum Concentration RBC (99.0th) | µg/m ³ | NA | NA | NA |

4. Make 5-copies of the Site A scenario on the **iBATCH** page. This can be accomplished using two methods:
 - a. On the **iBATCH** page, select the entire row with the scenario name “Site A”, press “ctrl+C” to copy the data. Scroll down to an empty row, and select the cell in column A. Press “ctrl+V” to paste data. Repeat this step four more times. OR,
 - b. On the **iFLARING** page, press 5-times.
5. On the **iBATCH** page, scroll to the end row where the data was saved. Then scroll right to column “Flare Stack Tip Exit Height”. Change the entries from the provided height of 27 m to 30 m, 40 m, 50 m, 55 m and 60 m, respectively for each of the new lines.
6. Add a run flag in the first column of each **iBATCH** row where 1=run and 0=don’t run. Therefore, enter “0” for all other lines on the **iBATCH** page and enter “1” for the five lines that were just added. At the top left of the **iBATCH** page you should see “5 : Number of Scenarios Set to Run”
7. Double Check:
 - a. Column B: the selection of **Permit** vs **Evaluation** flaring option
 - b. Column C: the selection of **Continuous/Planned/Unplanned** flaring option
 - c. Column D: the selection of the calculation method to be used
 - d. Column E: the path to the meteorological data file has been entered correctly.

8. Press the **Run Batch** button to run *AERflare* for each of the 5 sensitivity runs just created. *AERflare* will consecutively: load the inputs from the **iBATCH** page; run *AERflare* using the inputs and the modelling options specified in columns B,C,D, and E; then save the results to the **oBATCH** page on the same row number as the inputs.
9. In this case, we are interested in the maximum predicted concentration values listed in Column BV. The results for a 55 m stack are 486 $\mu\text{g}/\text{m}^3$ and the results for a 60 m stack are 431 $\mu\text{g}/\text{m}^3$.

8. EXAMPLES

Four examples are included in this *AERflare* user guide

| | | |
|-----------|-----------------|--|
| Example 1 | N/A (Site A) | This is the example provided in the <i>ERCBflare</i> V1 user guide. The terrain was based upon a specific location, but the coordinates were arbitrarily selected. |
| Example 2 | Site A | This is an example of a well test flaring assessment, set at the arbitrary Site A coordinates. This example illustrates various levels of refinements in the modelling process. |
| Example 3 | Site B | This is an example of a pipeline blowdown flare assessment, set at an arbitrary location Site B. This example illustrates a non-routine flare for a pipeline blowdown. |
| Example 4 | Site C | This is an example of a well test flare assessment in highly complex terrain, with actual location and emission parameters. This example has been presented in the <i>ABflare</i> modelling. |

The locations of the sites used in the examples are shown on the left of Figure 19. Both Site A and Site B are in hilly areas that are above criterion complex terrain elevations. Site C is a very complex terrain location. On the right of Figure 19 are plotted the worst case terrain elevations as a function of distance from the flare location.

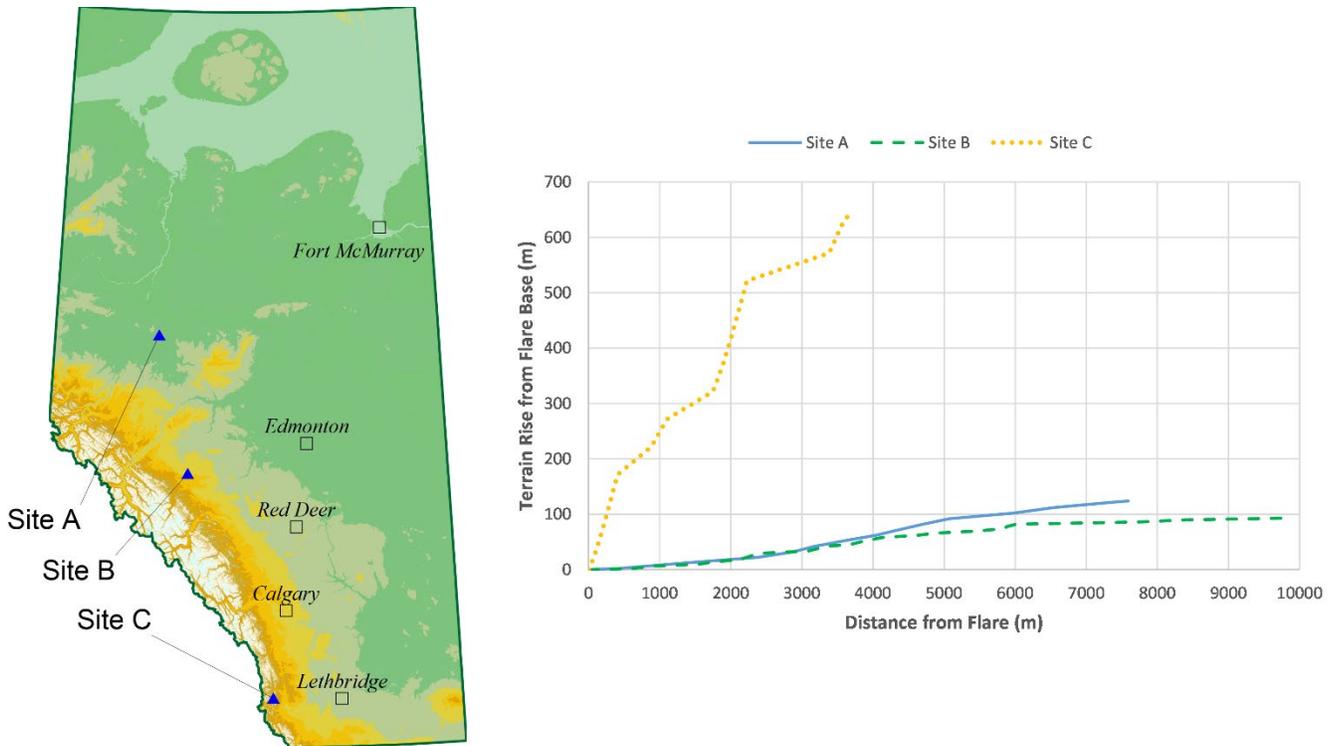


Figure 19: Locations and Worst Case Terrain Rise around Sites used in the AERflare examples.

Example 1 – Change from Previous Model to *AERflare*

This is the example provided in the *ERCBflare* v1.05 spreadsheet. The *ERCBflare* v1.05 did not provide a real location. The *AERMOD* dispersion model requires specific land use and meteorology, which is a function of a real location. An arbitrary location was selected and that location's terrain was similar to the *ERCBflare* v1.05 example.

The location and site elevation are listed below.

| | | | |
|------------------------------|----------------------------------|-------------|---|
| Mapping Projection | | UTM (NAD83) | ▼ |
| UTM Zone | | 11 | |
| Surface Coordinates of Flare | X Coord (m Easting) or Longitude | 481234 | |
| | Y Coord (m Northing) or Latitude | 6112345 | |
| Flare Base Elevation | m | 655.8701328 | |

On the **iFLARING** page, the following entries define the scenario with a gas composition set to 100% CH₄ (methane). Fuel gas is 100% C₃H₈ (propane).

| | | | |
|---|---|--------|---|
| Time of Year to Model the Flare | -- | Annual | ▼ |
| Flare Stack Tip Exit Height | m | 30.5 | |
| Flare Stack Tip Exit Diameter | mm | 305 | |
| Requested Maximum Raw Gas H ₂ S Concentration for Subject Zone or Source | % (for Permits round up to 0.5% increment) | 30.10% | |

A continuous flare scenario is described below with settings for **Q_{max}** and **Q_{ave}**.

| Flaring Type? | | <input checked="" type="radio"/> Continuous or Steady <input type="radio"/> Transient | |
|--|---|--|----------|
| Continuous or Steady | UNITS | ENTRY | WARNINGS |
| Maximum Raw Gas Flow Rate for Source of Sour Gas | 10 ³ m ³ /d (15°C and 101.325 kPa) | 250 | |
| MUST enter any 2 of the fields: i) VOLUME of Raw Gas to be Flared ii) AVERAGE FLOW RATE of Raw Gas iii) DURATION of Flaring | i) Volume 10 ³ m ³ (15°C and 101.325 kPa) | 400 | -- |
| | ii) Average Flow Rate 10 ³ m ³ /d (15°C and 101.325 kPa) | 125 | -- |
| | iii) Duration hours | | 76.8 |

Fuel gas is added as described below. Lift gas and flare assist was not used.

| Fuel Gas | UNITS | ENTRY | WARNINGS |
|---|--|---|--|
| Is Fuel Gas Added? | Last resort, see D060 7.4(4a) | <input type="radio"/> No <input checked="" type="radio"/> Yes | Adjust Fuel Gas to Raw Gas Ratio manually in Cell C41-E41, then check dispersion results |
| | Maximum (QMAX) | Average (QAVE) | Minimum (QMIN) |
| Fuel Gas to Raw Gas Volume Rate Ratio (default is zero) | 0 | 0.1 | 0.2 |
| Warnings | Acceptable NHV: 30.3 MJ/m ³ | Acceptable NHV: 35.4 MJ/m ³ | Acceptable NHV: 39.7 MJ/m ³ |

ERCBflare v1.05 used the US EPA *SCREEN3* model as its air dispersion model with the complex terrain calculations used in the US EPA *ISCST* model. The

results of the example are shown below. The 99th percentile values are based upon an interpolation of expected results based upon average meteorology for the province of Alberta. *SCREEN3* was run using RURAL land use classification. *SCREEN3* used 0.3m roughness height for RURAL and was formulated using the Pasquill-Gifford turbulence scheme. *SCREEN3* routinely predicted lower concentrations compared to newer dispersion models using the micro-meteorological turbulence scheme and incorporating other near-field effects.

| Parallel Airflow Terrain | Units | Maximum (QMAX) | Average (Volume/Duration) | Minimum (QMAX/8) |
|--|--|----------------|---------------------------|------------------|
| Maximum ERCBSCREEN3 Predicted SO ₂ Concentration | µg/m ³ | 1415 | 1058 | 618 |
| Distance to Maximum | m | 1250 | 1107 | 951 |
| Wind Speed of Maximum | m/s | 2 | 2 | 1.5 |
| Stability Class of Maximum | | A | A | A |
| ERCBSCREEN3 Predictions | 1. It is not necessary to provide additional dispersion modelling if Parallel Airflow Modelling is applicable and proposed flaring parameters meet AAAQO (see TEMPORARY APPROVAL SUMMARY sheet). | | | |
| 99 th Percentile ISCST3 Predicted SO ₂ Concentration | µg/m ³ | 515 | 395 | 312 |
| ISCST3 PREDICTIONS FROM NOMOGRAPHS | 1. It is not necessary to provide additional dispersion modelling if Parallel Airflow Modelling is applicable and proposed flaring parameters meet AAAQO (see TEMPORARY APPROVAL SUMMARY sheet), as nomographs based on curve-fit to ISCST3 modelling predictions. | | | |
| Worst Case Complex Terrain | | | | |
| Maximum ERCBSCREEN3 Predicted SO ₂ Concentration | µg/m ³ | 2959 | 2210 | 1258 |
| Distance to Maximum | m | 7000 | 7000 | 4900 |
| Wind Speed of Maximum | m/s | 1 | 1 | 1 |
| Stability Class of Maximum | | F | F | F |

The screening matrix of SO₂ predictions for the QMAX emission rate for *ERCBflare* v1.05 is shown below. High concentrations are predicted for the very unstable, very stable and high wind speed neutral extremes.

| Stability | Wind speed (m/s) | | | | | | | | | | | | |
|-----------|------------------|------|------|------|------|------|------|------|------|-----|------|------|------|
| | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | 4.5 | 5 | 8 | 10 | 15 | 20 |
| A | 1386 | 1370 | 1475 | 1393 | 1025 | | | | | | | | |
| B | 364 | 549 | 696 | 622 | 494 | 555 | 619 | 682 | 732 | | | | |
| C | 68 | 213 | 411 | 360 | 360 | 417 | 476 | 534 | 592 | 940 | 1105 | | |
| D | 15 | 26 | 43 | 35 | 55 | 83 | 119 | 161 | 207 | 485 | 674 | 1202 | 1598 |
| E | 2010 | 1889 | 1739 | 1631 | 1551 | 1471 | 1395 | 1325 | 1262 | | | | |
| F | 2959 | 2759 | 2509 | 2333 | 2204 | 2079 | 1957 | | | | | | |

Using the *AERflare* v2.01, and modelling using static source characterization of *AERflare* calculation #1 button, the results are shown below. *AERflare* using the *AERSCREEN* meteorological matrix for the grassland land use classification for the site is predicting higher concentrations for the same types of conditions (ie, Class A and Class F stability). The grassland land-use has a maximum roughness of 0.1m (see Table 3). The lower roughness contributes to the higher predictions.

| AERSCREEN OUTPUT | | | Units | Maximum (QMAX) | Average (Qave) | Minimum (QMIN) | Worst Case Complex Terrain | | |
|--|----------------|-------|--------------------------|----------------|----------------|----------------------------|----------------------------|-------|--|
| | | | Parallel Airflow Terrain | | | Worst Case Complex Terrain | | | |
| Maximum Concentration | cmax | µg/m³ | 3658 | 2525 | 1171 | 12846 | 8913 | 4820 | |
| Distance to Maximum Concentration | xmax | m | 2143 | 1724 | 1124 | 6838 | 5553 | 4775 | |
| Wind Speed | ws | m/s | 0.5 | 0.5 | 0.5 | 1.5 | 1.5 | 1 | |
| PG Stability Class | PG | PG | F | F | F | F | F | F | |
| Distance Concentration drops below Obj#1 | xobj1 | m | 10000 | 10000 | 8723 | 10000 | 10000 | 10000 | |
| Distance Concentration drops below Obj#2 | xobj2 | m | -1 | -1 | -1 | 9760 | -1 | -1 | |
| Distance Concentration drops below Obj#3 | xobj3 | m | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | |
| Concentration CMAX (100.0th) | winter or yr 1 | µg/m³ | 2487 | 1382 | 849 | 7431 | 5127 | 2796 | |
| | spring or yr 2 | µg/m³ | 2482 | 1765 | 716 | 6095 | 4163 | 2210 | |
| | summer or yr 3 | µg/m³ | 3142 | 2360 | 1043 | 9259 | 6372 | 3593 | |
| | fall or yr 4 | µg/m³ | 3658 | 2525 | 1171 | 12846 | 8913 | 4820 | |
| | month or yr 5 | µg/m³ | | | | | | | |
| Concentration RBC (99.9th) | winter or yr 1 | µg/m³ | 2052 | 1374 | 738 | 7135 | 4999 | 2470 | |
| | spring or yr 2 | µg/m³ | 1710 | 1229 | 660 | 5822 | 4076 | 2048 | |
| | summer or yr 3 | µg/m³ | 2552 | 1479 | 834 | 8907 | 6172 | 3135 | |
| | fall or yr 4 | µg/m³ | 3614 | 2487 | 1156 | 11480 | 8056 | 4439 | |
| | month or yr 5 | µg/m³ | | | | | | | |

For comparison purposes, if the land-use was [desert scrubland](#) the roughness would be similar to the *SCREEN3* formulation. The results below still show that the newer *AERMOD/AERSCREEN* predictions are greater than the *SCREEN3* predictions.

| AERSCREEN OUTPUT | | | Units | Maximum (QMAX) | Average (Qave) | Minimum (QMIN) | Worst Case Complex Terrain | | |
|--|----------------|-------|--------------------------|----------------|----------------|----------------------------|----------------------------|-------|--|
| | | | Parallel Airflow Terrain | | | Worst Case Complex Terrain | | | |
| Maximum Concentration | cmax | µg/m³ | 3433 | 2249 | 946 | 6078 | 4187 | 2289 | |
| Distance to Maximum Concentration | xmax | m | 509 | 443 | 443 | 7083 | 5704 | 5003 | |
| Wind Speed | ws | m/s | 10 | 10 | 1.5 | 1 | 1 | 0.5 | |
| PG Stability Class | PG | PG | C | C | A | A | A | A | |
| Distance Concentration drops below Obj#1 | xobj1 | m | 10000 | 10000 | 5015 | 10000 | 10000 | 10000 | |
| Distance Concentration drops below Obj#2 | xobj2 | m | -1 | -1 | -1 | -1 | -1 | -1 | |
| Distance Concentration drops below Obj#3 | xobj3 | m | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | |
| Concentration CMAX (100.0th) | winter or yr 1 | µg/m³ | 3132 | 2102 | 477 | 5299 | 3683 | 1912 | |
| | spring or yr 2 | µg/m³ | 3136 | 2104 | 711 | 4982 | 3453 | 1798 | |
| | summer or yr 3 | µg/m³ | 3132 | 2102 | 765 | 5296 | 3681 | 1911 | |
| | fall or yr 4 | µg/m³ | 2934 | 1988 | 910 | 6078 | 4187 | 2289 | |
| | month or yr 5 | µg/m³ | | | | | | | |
| Concentration RBC (99.9th) | winter or yr 1 | µg/m³ | 3132 | 2102 | 466 | 4787 | 3310 | 1721 | |
| | spring or yr 2 | µg/m³ | 3136 | 2104 | 474 | 4741 | 3276 | 1708 | |
| | summer or yr 3 | µg/m³ | 3132 | 2102 | 499 | 4788 | 3311 | 1720 | |
| | fall or yr 4 | µg/m³ | 2915 | 1978 | 761 | 5500 | 3792 | 2079 | |
| | month or yr 5 | µg/m³ | | | | | | | |

The screening matrix of SO₂ predictions for the [QMAX](#) emission rate for *AERflare* v2.01 is shown below. High concentrations are predicted for the very unstable and very stable extremes and has similar trends to the *ERCBflare* v1.05 predictions. Notice that while the matrix of conditions for *AERflare* appears

sparse compared to *ERCBflare*, the *AERMOD* complete micro-meteorological parameterization includes more and different variables than the *SCREEN3* version.

| Stability | Wind speed (m/s) | | | | | | | | | | | | |
|-----------|------------------|------|------|------|----|------|----|------|------|------|----|------|----|
| | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | 4.5 | 5 | 8 | 10 | 15 | 20 |
| A | 3433 | 885 | -- | 1220 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| B | 3427 | 824 | -- | 1270 | -- | 1593 | -- | -- | -- | -- | -- | -- | -- |
| C | -- | 149 | -- | 583 | -- | 1100 | -- | -- | 2076 | 1612 | -- | -- | -- |
| D | 1876 | 347 | 1047 | -- | -- | 1144 | -- | 1464 | 1378 | 1908 | -- | 3433 | -- |
| E | 1849 | 1148 | 1742 | -- | -- | 844 | -- | -- | -- | -- | -- | -- | -- |
| F | 6071 | 5842 | 4618 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

Using the new approach, the *AERflare* v.2.01 predictions using calculation #5 button are shown below. Calculation #5 button uses an hour-by-hour approach such that the change of meteorology and its effects on the flare source buoyancy and momentum are included. The impacts on the calculation conclusions will vary depending upon the flare’s design (exit velocity in comparison to ambient wind speed) and energy released. In this case, the maximum predictions are marginally lower than calculation #1 button results. AER believes the calculation #5 button is the better description of the flare source compared to average meteorological conditions.

| AERSCREEN OUTPUT | | | Units | Maximum (QMAX) | Average (Qave) | Minimum (QMIN) | Worst Case Complex Terrain | | |
|--|----------------|-------|-------|--------------------------|----------------|----------------|----------------------------|-------|-------|
| | | | | Parallel Airflow Terrain | | | Worst Case Complex Terrain | | |
| Maximum Concentration | omax | µg/m³ | | 3477 | 2478 | 1179 | 12914 | 9134 | 4809 |
| Distance to Maximum Concentration | xmax | m | | 1933 | 1731 | 1140 | 6838 | 5460 | 4789 |
| Wind Speed | ws | m/s | | 0.5 | 0.5 | 0.5 | 1.5 | 1.5 | 1 |
| PG Stability Class | PG | PG | | F | F | F | F | F | F |
| Distance Concentration drops below Obj#1 | xobj1 | m | | 10000 | 10000 | 8412 | 10000 | 10000 | 10000 |
| Distance Concentration drops below Obj#2 | xobj2 | m | | -1 | -1 | -1 | 9790 | -1 | -1 |
| Distance Concentration drops below Obj#3 | xobj3 | m | | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| Concentration CMAX (99.9th) | winter or yr 1 | µg/m³ | | 1982 | 1338 | 714 | 7146 | 5070 | 2499 |
| | spring or yr 2 | µg/m³ | | 1713 | 1190 | 646 | 5833 | 4118 | 2080 |
| | summer or yr 3 | µg/m³ | | 2114 | 1442 | 796 | 8919 | 6269 | 3156 |
| | fall or yr 4 | µg/m³ | | 3438 | 2322 | 1165 | 11513 | 8155 | 4425 |
| | month or yr 5 | µg/m³ | | | | | | | |
| Concentration RBC (99.0th) | winter or yr 1 | µg/m³ | | 1674 | 1105 | 541 | 5859 | 3942 | 2020 |
| | spring or yr 2 | µg/m³ | | 1354 | 901 | 573 | 4917 | 3436 | 1777 |
| | summer or yr 3 | µg/m³ | | 1787 | 1190 | 599 | 7389 | 5092 | 2491 |
| | fall or yr 4 | µg/m³ | | 3106 | 2098 | 986 | 9632 | 6669 | 3395 |
| | month or yr 5 | µg/m³ | | | | | | | |

A comparison of the buoyancy and momentum flux parameters that are used to calculate plume rise in the air dispersion models are summarized in Table 5. The table shows a dramatic difference between the older methods and the *ERCBflare* and *AERflare* methodology which conserves both buoyancy and momentum of the source.

Table 5: Comparison Buoyancy and Momentum Flux Parameters

| Model | FB-Buoyancy | FM-Momentum |
|---------------------------------|-------------|-------------|
| EUB-WellTest Ver 1 ^a | 565.2 | 667.3 |
| ERCBflare v1.05 | 625.1 | 29.5 |
| AERflare v2.01 ^b | 625.5 | 29.6 |

^a Used modified US EPA method similar to AENV spreadsheet mod_fircalcs.xls (v3.0)

^b AERflare FB/FM at average meteorological conditions

Example 2 – Refining the Modelling Assessment

The second example has been located at the same location (arbitrary Site A) and is an example of a lower flowrate well test flare. The second example can be loaded from the **iBATCH** page, from the second row.

| | | |
|---|---|--------|
| Flare Stack Tip Exit Height | m | 27.432 |
| Flare Stack Tip Exit Diameter | mm | 102 |
| Requested Maximum Raw Gas H ₂ S Concentration for Subject Zone or Source | % (for Permits round up to 0.5% increment) | 16.00% |

| Flaring Type? | | <input checked="" type="radio"/> Continuous or Steady <input type="radio"/> Transient | |
|--|---|--|----------|
| Continuous or Steady | UNITS | ENTRY | WARNINGS |
| Maximum Raw Gas Flow Rate for Source of Sour Gas | 10 ³ m ³ /d (15°C and 101.325 kPa) | 15 | |
| MUST enter any 2 of the fields: | i) Volume 10 ³ m ³ (15°C and 101.325 kPa) | | 22.500 |
| i) VOLUME of Raw Gas to be Flared | ii) Average Flow Rate 10 ³ m ³ /d (15°C and 101.325 kPa) | 7.5 | -- |
| ii) AVERAGE FLOW RATE of Raw Gas | iii) Duration hours | 72 | -- |
| iii) DURATION of Flaring | | | |

On the **oMODELLING** page the following table was created by using the calculation buttons for a flare permit in sequence. Each button represents an increasing level of sophistication in the modelling, moving from screening (most conservative) to refined (more realistic) predictions.

| Calculation | Meteorology | Terrain | Statistic | Concentration ($\mu\text{g}/\text{m}^3$) | Concentration Limits ($\mu\text{g}/\text{m}^3$) |
|-------------|------------------|---------------|-------------------------|--|---|
| Button 5 | Screening: Grass | Worst Case | Maximum | 2023 | 450 |
| Button 6 | Site Specific | Worst Case | Maximum | 1132 | NA |
| | | | CMAX=99.9 th | 1099 | 900 |
| | | | RBC=99 th | 912 | 450 |
| Button 7 | Site Specific | Site Specific | Maximum | 1010 | NA |
| | | | CMAX=99.9 th | 488 | 900 |
| | | | RBC=99 th | 366 | 450 |

Using **#5** button, the only modelling output available is the maximum concentration, since there are an insufficient number of data points in the screening meteorological data set, and it is not real meteorology. The maximum concentrations for both parallel air flow and complex terrain air flow are greater than the SO₂ objective. Therefore, two courses of action could be taken. First, a more refined modelling approach could be used or, second, the source could be changed (e.g., reduce gas rate, reduce sulphur emissions, increase stack height, smaller stack tip diameter, or addition of fuel gas).

If we proceed using more refined modelling, calculation **#6** can be used to add a site specific meteorology assessment to this flaring scenario. In this case, the screening worst case terrain is still used, therefore *AERflare* calculates both a parallel air flow and a complex terrain prediction. The concentration predictions for the more refined modelling are less than conservative **#5** results, but are still above the ambient guidelines. The same two courses of action are possible.

If we proceed using more refined modelling, **#7** button can be used to add both site specific meteorology and site specific terrain. In this case, the *AERflare* does not calculate parallel air flow predictions, since the site specific terrain includes all possible terrain and wind directions. The concentration predictions for the more refined modelling are about the same for the maximum concentration; however, the risk based concentration for the site specific terrain indicates that the plume impacts on the site specific terrain are less than the frequency predicted for worst case terrain. In this case, the RBC criterion is met, since 366 $\mu\text{g}/\text{m}^3$ at 99th percentile is less than 450 $\mu\text{g}/\text{m}^3$., and the CMAX criterion of 99.9th percentile is also less than the 900 $\mu\text{g}/\text{m}^3$.

The operator of the well test flare can either submit this flare design to AER, subject to the RBC permit application requirements or modify the source design to lower the predictions to meet the standard modelling requirement of 450 $\mu\text{g}/\text{m}^3$ at the 99.9th percentile.

To investigate options to reduce the concentration, the **iBATCH** page can be configured to increase fuel gas in steps. On the **iFLARING** page, select ‘YES’ for **Is Fuel Gas Added?** Enter 0 . 1 in each of the entry locations. At the top of the **iFLARING** page, press **Save to Batch** button to save the inputs to the **iBATCH** page. Repeat this process for fuel gas ratios 0 . 2 and 0 . 3. On the **iBATCH** page, enter run codes ‘1’ in the first column of each of the three added rows to the **iBATCH** and ensure that all other run codes are ‘0’ (or do not run). At the top of the **iBATCH** page press the **Run Batch** button. The table below presents the results for the **QMAX** flow rate for the fuel gas iteration along with the previous result for no fuel gas. These results indicate that should the well test operator decide not to be restricted by the **RBC** permit application requirements, the addition of fuel gas using a **FGR=0.1** will bring the ground level concentrations below the air quality modelling requirement of 99.9th percentile and 450 µg/m³.

| Fuel Gas Ratio | Maximum Concentration=100 th Percentile [µg/m ³] | Climit1=99.9 th Percentile [µg/m ³] | RBC=99 th Percentile [µg/m ³] |
|-----------------------------------|---|--|--|
| 0 | 1009 | 488 | 366 |
| 0.1 | 878 | 441 | 315 |
| 0.2 | 856 | 406 | 277 |
| 0.3 | 817 | 376 | 249 |
| Non-routine Flaring RBC end point | NA | 900 at 99.9th percentile | 450 at 99th percentile |
| Air Quality Modelling end point | NA | 450 at 99.9th percentile | NA |

An alternative solution, may be to increase stack height. In this case, on the **iFLARING** page reset the ‘**Is fuel gas Added?**’ back to ‘NO’, then create a series of batch jobs using increased stack heights of 35m, 40m and 45m. Running the batch mode on these stack heights produces the table below. These results indicate that the flare test operator should increase the stack height to 35 m in order to meet the AESRD ambient air quality guideline of 450 µg/m³ at a modelled 99.9th percentile.

| Stack Height (m) | Maximum Concentration=100 th Percentile [$\mu\text{g}/\text{m}^3$] | Climit1=99.9 th Percentile [$\mu\text{g}/\text{m}^3$] | RBC=99 th Percentile [$\mu\text{g}/\text{m}^3$] |
|-----------------------------------|---|--|--|
| 27 | 1009 | 488 | 366 |
| 35 | 947 | 312 | 265 |
| 40 | 887 | 312 | 220 |
| 45 | 861 | 288 | 190 |
| Non-routine Flaring RBC end point | NA | 900 at 99.9th percentile | 450 at 99th percentile |
| Air Quality Modelling end point | NA | 450 at 99.9th percentile | NA |

Up to now the modelling has been performed using the annual meteorology. Modelling requirements for AER D060 allow the operator to do the air quality modelling assessment for only the month of the non-routine flaring. We can repeat the Example 2 by re-loading the inputs from the **iBATCH** page. On the **iFLARING** page, change [Time of Year to Model the Flare](#) from ANNUAL to November. November is the start month indicated by the operator to conduct the non-routine flaring in the [Requested Permit Start Date](#) field on the **iFACILITY** page. Re-run the example using [#7](#) on the **oMODELLING** page. The results are compared below.

| Time of Year to Model | Maximum Concentration=100 th Percentile [$\mu\text{g}/\text{m}^3$] | Climit1=99.9 th Percentile [$\mu\text{g}/\text{m}^3$] | RBC=99 th Percentile [$\mu\text{g}/\text{m}^3$] |
|-----------------------------------|---|--|--|
| Annual | 1009 | 488 | 366 |
| November | 1010 | 486 | 393 |
| Non-routine Flaring RBC end point | NA | 900 at 99.9th percentile | 450 at 99th percentile |
| Air Quality Modelling end point | NA | 450 at 99.9th percentile | NA |

The air quality modelling for a [Time of Year to Model the Flare](#) that uses a month, restricts the post-processing of the results to the selected month plus the month before and after. In this case, the analysis includes October, November and December since November was selected.

The results in the table above show that the $\text{RBC}=392 \mu\text{g}/\text{m}^3$ prediction will meet the end point of $450 \mu\text{g}/\text{m}^3$. The RBC prediction is created from 10994 data points (see **oSUMMARY** in the [Minimum Number of Meteorological Data Points in a year](#) cell C83) out of the total (annual) meteorological data set of

43824 (# Hours in Meteorological File on **oMODELLING**, cell B75).

Typically, the annual assessment is a more conservative assessment because it includes poor dispersion modelling periods and it is possible that a selected month for a non-routine flare may not have those poor meteorological conditions. The 100% percentile value for the annual assessment will always be greater or equal to a monthly assessment. Because the sample sizes are different, the statistics for the RBC percentile for an annual assessment (N=43824) may be higher or lower than a monthly assessment (N=10994). AER will accept either prediction to meet the endpoint.

Example 3 – Pipeline Blowdown

This example has been located at an arbitrary location (Site B) and is an example of a pipeline blowdown. The third example can be loaded from the **iBATCH** page, from the third row.

The flare stack is described below.

| | | |
|---|---|--------|
| Flare Stack Tip Exit Height | m | 30.5 |
| Flare Stack Tip Exit Diameter | mm | 203 |
| Requested Maximum Raw Gas H ₂ S Concentration for Subject Zone or Source | % (for Permits round up to 0.5% increment) | 42.00% |

A blowdown is a transient source; a source with emissions that change in time following a predictable function of time. Transient sources are typically short duration (less than one hour) but may extend several hours. *AERflare* switches to transient source mode by selecting the **Flaring Type** on the **iFLARING** page.

| | |
|----------------------|--|
| Flaring Type? | <input type="radio"/> Continuous or Steady <input checked="" type="radio"/> Transient |
|----------------------|--|

When **Transient** is selected, the **Continuous or Steady** section of the **iFLARING** inputs is grayed out, and the **Transient Source** section of inputs is activated.

The pipeline in this example is 4.2 MPa maximum operating pressure (MOP) gauge and the section of pipeline that is involved in the blowdown to flare is 25.1 km long. The temperature of the pipeline is heated to 30 °C. The pipeline will be blown-down until it reaches 0 MPa. The stream path of the gas from the pipeline to flare tip may pass through several controls or restrictions. The

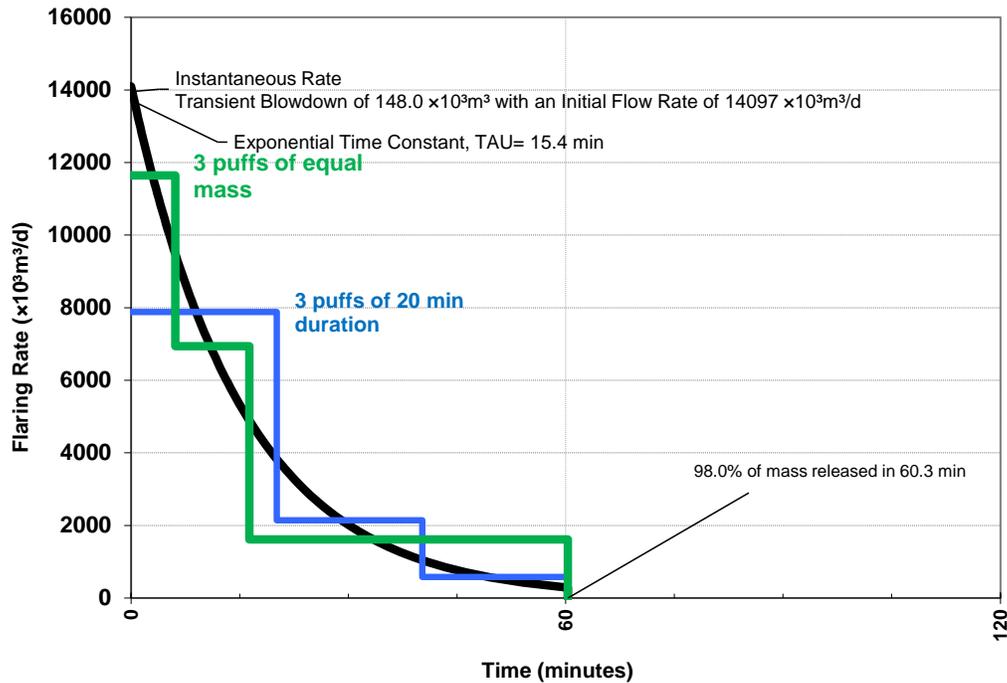
minimum orifice diameter (**ORIFICE_DIA**) introduces a choke point that will restrict the flow to the flare. In this case, the minimum restriction is an orifice of 204 mm. In addition to the minimum orifice diameter, the shape of the orifice will introduce drag furthering restricting the flow to the flare. With a perfectly smooth restriction, the Discharge Coefficient (**DCOEFF**)=1.0. For an orifice plate or gate valve, **DCOEFF**=0.6 is a good approximation. Because pipe length and pipe fittings between the vessel (a pipeline in this example) and the flare also affect the drag, **DCOEFF**=0.6 is a good overall approximation.

The remaining fields can be left at their default values as shown below, and are described in more detail in the Transient Blowdown chapter of this guide.

| Transient Source | UNITS | ENTRY |
|---|---|---|
| Expected Maximum Initial Pressure, PRESS0 | kPa (gauge) | 4200 |
| Expected Minimum Initial Gas Temperature, TEMP0 | °C | 30 |
| Expected Minimum Final Pressure, PRESS1 | kPa (gauge) | 0 |
| Pipeline/Vessel Inside Diameter, VESSELDIA | m | 0.4364 |
| Pipeline/Vessel Length, VESSELLEN | m | 25100 |
| Minimum Orifice Diameter, ORIFICE_DIA | mm | 43 |
| Discharge Coefficient, DCOEFF | -- | 0.6 |
| Select the way the blowdown curve is converted from a continuous curve to discrete steps MDIST | -- | <input type="radio"/> 1. Equal Duration <input checked="" type="radio"/> 2. Equal Mass |
| Raw Gas User Initial Maximum Flow Rate, QMAX | 10 ² m ³ /d (15°C and 101.325 kPa) | |
| Raw Gas User Total Volume within vessels/pipes, QTOTAL | 10 ² m ³ (15°C and 101.325 kPa) | |
| User selected # of puffs, NPUFFS | -- | 3 |
| User selected puff duration, PUF DUR | min | |

The inputs for the vessel provided (a pipeline in this example) are sufficient to describe a simplified depressurization curve using a mathematical exponential curve. The exponential curve is a good approximation to both a vessel(s) or pipeline depressurization. The transient emission rate calculations are shown on the **oBLOWDOWN** page. For this example, the blowdown curve is shown below. The depressurization duration is 60 min starting at a peak flow rate of **QMAX**=14097×10³m³/d with a total volume of **QTOTAL**=148×10³m³. The instantaneous flow is shown as the black line in the figure below. It is modelled in *AERflare* using discretized set-wise curve using **NPUFFS**=3 steps. The steps of equal mass is the AER recommended approach to modelling the curve since it better distributes the mass of the emission at the appropriate plume rise.

TRANSIENT BLOWDOWN MODELLED AS PUFFS



The table Flowrates Modelled summarizes the steps as Q_{hi} , Q_{med} and Q_{lo} . In this case, the Q_{hi} duration is 6.10 minutes, Q_{med} is 10.24 minutes and Q_{lo} is 43.96 minutes. The flowrate Q_{hi} , Q_{med} and Q_{lo} will be modelled in *AERflare* replacing the Q_{max} , Q_{ave} and Q_{min} flow rates for a steady flare, and then combined to account for the duration of each step.

| Flowrates Modelled | | | | |
|--------------------------------|--|----------|-----------|----------|
| Description | Units | Q_{hi} | Q_{med} | Q_{lo} |
| Equal Duration | $10^3 \text{m}^3/\text{d}$ (15°C and 101.325 kPa) | 7879.29 | 2140.98 | 581.75 |
| Duration | minutes | 20.10 | 20.10 | 20.10 |
| Equal Mass | $10^3 \text{m}^3/\text{d}$ (15°C and 101.325 kPa) | 11643.25 | 6937.03 | 1615.89 |
| Duration | minutes | 6.10 | 10.24 | 43.96 |
| Volume Flowrate to Be Modelled | $10^3 \text{m}^3/\text{d}$ (15°C and 101.325 kPa) | 11643.25 | 6937.03 | 1615.89 |
| Duration | minutes | 6.10 | 10.24 | 43.96 |

Using [#5](#), the output of the air dispersion modelling for the transient blowdown is shown in the table below. The individual outputs, Q_{max} , Q_{ave} and Q_{min} on the **oMODELLING** page are the 1 h time average based upon the respective durations, of 6.10 min., 10.24 min. and 43.96 min. as if they occurred as independent and separate events. The **oMODELLING** output **Transient Blowdown 1h Maximum** contains the worst case maximum 1 h average concentration from any sequence of the blowdown occurring in a one hour period. The initial phase of the blowdown (Q_{hi}) produces a very high ground level

concentration ($24\,521\ \mu\text{g}/\text{m}^3 = 2493 \times 60 / 6.1$ or see the **oAERSCREEN** page output for intermediate results) but since it occurs for only 6.1 min, it contributes much less to the hourly average. The last phase (**Qlo**) produces a ground level concentration of $14\,253\ \mu\text{g}/\text{m}^3$ averaged over 43.96 minutes. In this case, the maximum (100% percentile) concentration for the blowdown sequence of $17\,255\ \mu\text{g}/\text{m}^3$ exceeds the regulatory limit of $450\ \mu\text{g}/\text{m}^3$ and additional modelling refinements are required.

| Calculation | Meteorology | Terrain | Individual Output | Concentration 1h Time Average ($\mu\text{g}/\text{m}^3$) | Transient Blowdown 1h Time Average [$\mu\text{g}/\text{m}^3$] | Concentration Limits ($\mu\text{g}/\text{m}^3$) |
|-------------|------------------------------|------------|-------------------|--|---|---|
| Button 5 | Screening: Coniferous Forest | Worst Case | Qmax | 2468 | 17137 | 450 |
| | | | Qave | 4337 | | |
| | | | Qmin | 10402 | | |

AERflare screening calculates the worst case transient blowdown time average by determining the worst of each **Qmax**, **Qave** and **Qmin** predicted concentrations and determines the transient blowdown concentration as if they occurred in sequence, regardless of actual meteorological period that may have created them. A more refined approach is used using the calculations on **oPOSTPROCESS**, where the transient blowdown concentration is calculated each hour of the meteorology from **Qmax**, **Qave** and **Qmin** predictions, regardless of the duration of each step. In either the **oAERSCREEN** screening case or the more refined **oPOSTPROCESS**, both include approximations since *AERMOD* is not capable of the required complexity of dispersion modelling.

Using **#6** and **#7** produces more refined predictions for the transient blowdown. In both cases, the predictions do not meet the endpoints for RBC (99th) nor the allowable maximum (99.9th). The operator would need to consider alternatives such as: reduce volume flared, reduce duration flared, increase stack height or add fuel gas. In this case, a review of the individual source parameters for height and diameter, (**HS**, **DS**) at average meteorological conditions are nearly identical for each **Qhi**, **Qmid** and **Qlo** steps and suggests that the flow from choked flow from flare is a limiting condition. Increasing stack height is a logical starting point for a solution. Methods to investigate these options have already been discussed in Example 2.

| Calculation | Meteorology | Terrain | Statistic | Concentration ($\mu\text{g}/\text{m}^3$) | Concentration Limits ($\mu\text{g}/\text{m}^3$) |
|-------------|------------------------------|---------------|-------------------------|--|---|
| Button 5 | Screening: Coniferous Forest | Worst Case | Maximum | 17137 | 450 |
| Button 6 | Site Specific | Worst Case | Maximum | 7824 | NA |
| | | | CMAX=99.9 th | 4296 | 900 |
| | | | RBC=99 th | 2797 | 450 |
| Button 7 | Site Specific | Site Specific | Maximum | 7297 | NA |
| | | | CMAX=99.9 th | 3594 | 900 |
| | | | RBC=99 th | 1775 | 450 |

Example 4 – Well Test Flare in Complex Terrain

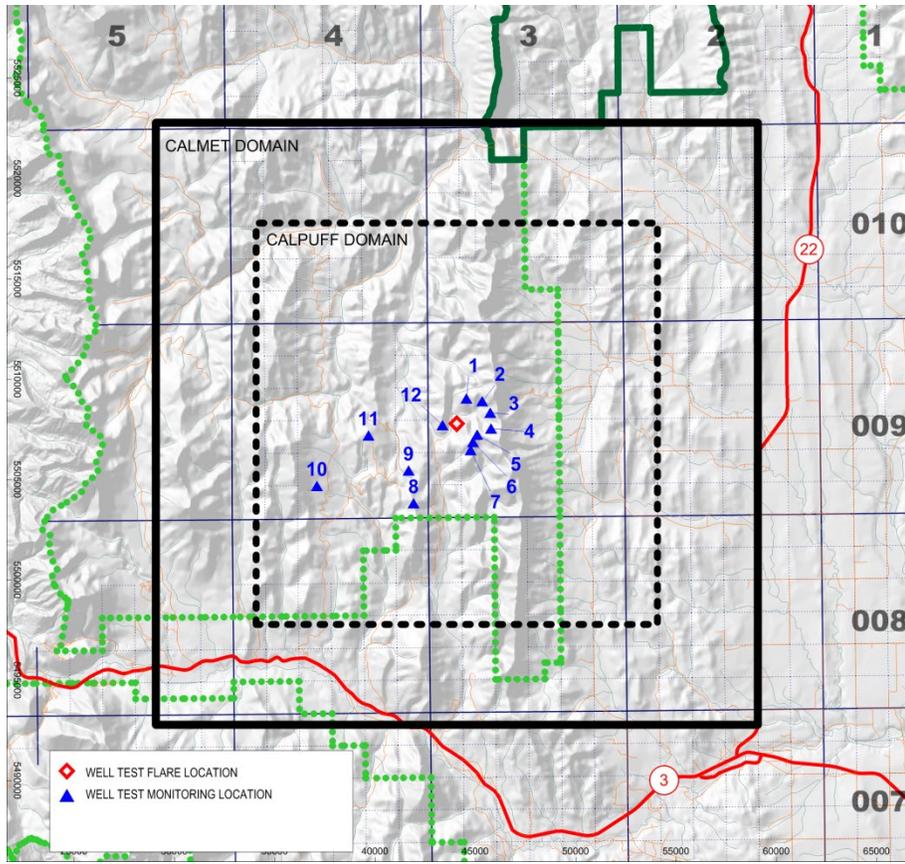
This example involves a real well test flare event at a real location. The source parameters were determined based upon a review of the gas analysis logs collected during the well testing. The site is located in complex terrain. The fourth example can be loaded from the **iBATCH** page, from the fourth row.

The well test flare is located in south west Alberta at the coordinates below:

| | |
|------------------------|---------|
| Northing (m) | 5513080 |
| Easting (m) | 688183 |
| Site Elevation (m ASL) | 1878 |

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The topography in the region surrounding the well site is shown in the figure below. Terrain rises from 1878 m at the well test flare location to 2245 m within 2.2 km. The well test was operated with 12 real-time air quality monitoring stations surrounding the flare location. The locations of the monitoring stations are listed in the table below the figure.



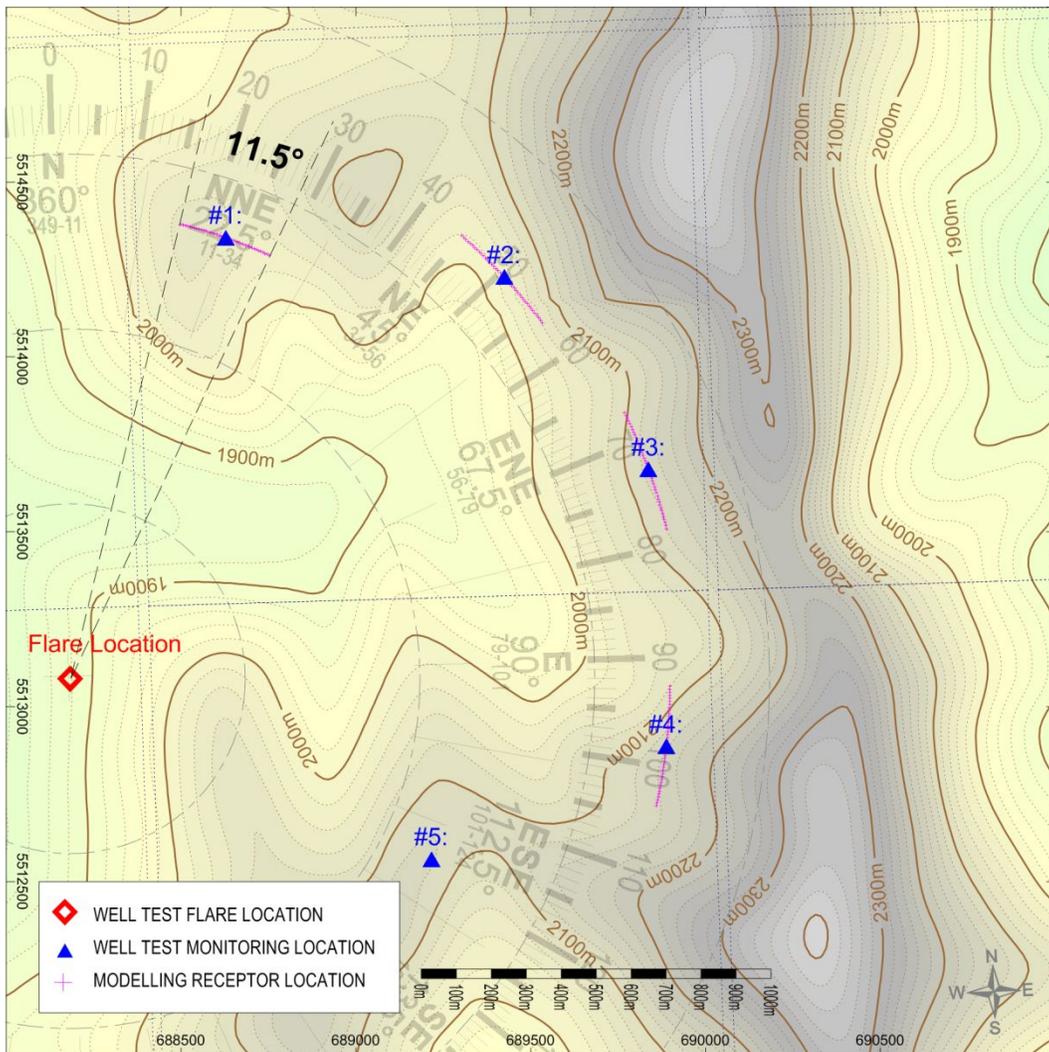
Topography in the Region of the Well Test Flare Showing Terrain Elevations and Locations of Monitoring stations

| Label | X | Y | Elev | Distance (m) | Direction To | Wind From |
|-------|--------|---------|------|--------------|--------------|-----------|
| #1: | 688628 | 5514341 | 2052 | 1337 | 19 | 199 |
| #2: | 689424 | 5514228 | 2027 | 1690 | 47 | 227 |
| #3: | 689837 | 5513678 | 2127 | 1758 | 70 | 250 |
| #4: | 689888 | 5512886 | 2140 | 1716 | 96 | 276 |
| #5: | 689216 | 5512564 | 2123 | 1154 | 117 | 297 |
| #6: | 689018 | 5512180 | 2120 | 1227 | 137 | 317 |
| #7: | 688899 | 5511785 | 2103 | 1480 | 151 | 331 |
| #8: | 686141 | 5509059 | 2028 | 4510 | 207 | 27 |
| #9: | 685848 | 5510684 | 1893 | 3346 | 224 | 44 |
| #10: | 681292 | 5509794 | 1861 | 7635 | 245 | 65 |
| #11: | 683804 | 5512380 | 2026 | 4435 | 261 | 81 |
| #12: | 687461 | 5513001 | 1935 | 727 | 264 | 84 |

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More detail of the elevations near the well test flare location is shown in the figure below. Receptor locations for air quality modelling were selected in two patterns: a grid over the entire domain similar to what would be used for regulatory approval air quality modelling; and, localized arch arrays over an 11.5° arch centred at the monitoring station. It is shown in the next section that the observed winds were predominantly from 200° (or blow to 20°, station #1). However, the modelled meteorology predicted winds at some times during the same interval towards 20°, 50° and 73°. Therefore, the modelling receptor grid used arch arrays to capture likely concentrations that would be comparable to the observed record.

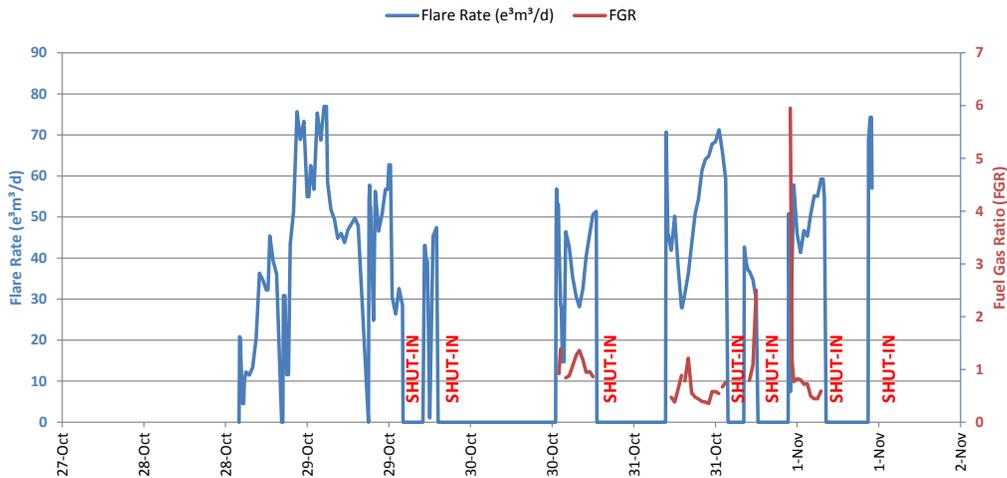
The receptor locations and elevations using the four arcs were determined external to *AERflare*. *AERflare* can import external receptor grids using the [Read User Receptor Grid](#) on the **iUSERTER** page.



Air Quality Modelling Receptor Locations near Monitoring Locations with Measurements

Meteorology for the site is determined following the procedure for site specific meteorology on **iUSERMET**.

The well clean up and associated gas rates being flared vary in time as shown in in the figure below. The flare rates were stopped, as marked, based upon real-time air quality dispersion modelling to prevent potential ground level exceedences. The gas rates observed during the well test are listed in the table below. The average gas rate was in this modelling example to best represent observed conditions. For regulatory modelling for approval of a well test flare, the maximum rate gas should be used. Propane fuel gas at an average rate of **FGR=0.95** was used during the flaring event.



Gas Rate and Fuel Gas Ratio During Well Test Flaring

| | | |
|---|---|--------|
| Flare Stack Tip Exit Height | m | 36.6 |
| Flare Stack Tip Exit Diameter | mm | 154 |
| Requested Maximum Raw Gas H ₂ S Concentration for Subject Zone or Source | % (for Permits round up to 0.5% increment) | 27.50% |

| Continuous or Steady | UNITS | ENTRY |
|--|---|-------|
| Maximum Raw Gas Flow Rate for Source of Sour Gas | 10 ³ m ³ /d (15°C and 101.325 kPa) | 90 |
| MUST enter any 2 of the fields: i) VOLUME of Raw Gas to be Flared ii) AVERAGE FLOW RATE of Raw Gas iii) DURATION of Flaring | i) Volume 10 ³ m ³ (15°C and 101.325 kPa) | 45 |
| | ii) Average Flow Rate 10 ³ m ³ /d (15°C and 101.325 kPa) | |
| | iii) Duration hours | 1 |

The gas analysis used for the well test flare was taken during clean-up operations. It represents the best estimate of the gas being flared.

| Gas Compositions (mole fraction) | Raw Gas |
|-------------------------------------|---------|
| H ₂ O | 0.0000 |
| H ₂ | 0.0002 |
| He | 0.0001 |
| N ₂ | 0.0197 |
| CO ₂ | 0.0700 |
| H ₂ S | 0.2750 |
| CH ₄ | 0.6328 |
| C ₂ H ₆ | 0.0014 |
| C ₃ H ₈ | 0.0002 |
| i-C ₄ H ₁₀ | 0.0001 |
| n-C ₄ H ₁₀ | 0.0001 |
| i-C ₅ H ₁₂ | 0.0001 |
| n-C ₅ H ₁₂ | 0.0001 |
| n-C ₆ H ₁₄ | 0.0001 |
| C ₇ ⁺ | 0.0001 |
| CO | 0 |
| NH ₃ | 0 |
| Total | 1.0000 |

Using the HBH emissions source using #7, the following is a listing to the AERMOD variable emission file. This sample shows the first three hours of modelling and there are 9 virtual sources. At any hour, only a single virtual source has a non-zero emission rate. In this sample, [Source 9](#) (representing the virtual source during meteorology that produces the highest plume rise) has an emission rate 776.15 g/s, temperature of 1294.68 K, and velocity of 3.281 m/s. At hour 2 and hour 3, [Source 8](#) has the non-zero emission.

```

SO HOUREMIS 2 1 1 1 SOURCE1 0.0 1140.95 3.116
SO HOUREMIS 2 1 1 1 SOURCE2 0.0 1140.95 3.116
SO HOUREMIS 2 1 1 1 SOURCE3 0.0 1140.95 3.116
SO HOUREMIS 2 1 1 1 SOURCE4 0.0 1140.95 3.116
SO HOUREMIS 2 1 1 1 SOURCE5 0.0 1140.95 3.116
SO HOUREMIS 2 1 1 1 SOURCE6 0.0 1140.95 3.116
SO HOUREMIS 2 1 1 1 SOURCE7 0.0 1140.95 3.116
SO HOUREMIS 2 1 1 1 SOURCE8 0.0 1140.95 3.116
SO HOUREMIS 2 1 1 1 SOURCE9 776.15 1294.68 3.281
SO HOUREMIS 2 1 1 2 SOURCE1 0.0 1140.89 3.116
SO HOUREMIS 2 1 1 2 SOURCE2 0.0 1140.89 3.116
SO HOUREMIS 2 1 1 2 SOURCE3 0.0 1140.89 3.116
SO HOUREMIS 2 1 1 2 SOURCE4 0.0 1140.89 3.116
SO HOUREMIS 2 1 1 2 SOURCE5 0.0 1140.89 3.116
SO HOUREMIS 2 1 1 2 SOURCE6 0.0 1140.89 3.116
SO HOUREMIS 2 1 1 2 SOURCE7 0.0 1140.89 3.116
SO HOUREMIS 2 1 1 2 SOURCE8 776.15 1290.25 3.267
SO HOUREMIS 2 1 1 2 SOURCE9 0.0 1140.89 3.116
SO HOUREMIS 2 1 1 3 SOURCE1 0.0 1140.89 3.116
SO HOUREMIS 2 1 1 3 SOURCE2 0.0 1140.89 3.116
SO HOUREMIS 2 1 1 3 SOURCE3 0.0 1140.89 3.116
SO HOUREMIS 2 1 1 3 SOURCE4 0.0 1140.89 3.116
SO HOUREMIS 2 1 1 3 SOURCE5 0.0 1140.89 3.116
SO HOUREMIS 2 1 1 3 SOURCE6 0.0 1140.89 3.116
SO HOUREMIS 2 1 1 3 SOURCE7 0.0 1140.89 3.116
SO HOUREMIS 2 1 1 3 SOURCE8 776.15 1290.25 3.267

```

The results of AERflare modelling are shown in the table below. These results indicate that at the flare test would meet the end points (at the receptor locations tested) when the #7 analysis is used.

| Calculation | Meteorology | Terrain | Statistic | Qmax Concentration (µg/m³) | Qave Concentration (µg/m³) | Qmin Concentration (µg/m³) | Concentration Limits (µg/m³) |
|-------------|------------------------------|---------------|-------------------------|----------------------------|----------------------------|----------------------------|------------------------------|
| Button 5 | Screening: Coniferous Forest | Worst Case | Maximum | 11676 | 10142 | 6378 | 450 |
| Button 6 | Site Specific | Worst Case | Maximum | 3310 | 2364 | 1091 | NA |
| | | | CMAX=99.9 th | 3293 | 2345 | 1051 | 900 |
| | | | RBC=99 th | 3212 | 2304 | 960 | 450 |
| Button 7 | Site Specific | Site Specific | Maximum | 1127 | 792 | 276 | NA |
| | | | CMAX=99.9 th | 736 | 478 | 214 | 900 |
| | | | RBC=99 th | 250 | 155 | 54 | 450 |

Using `mkeepout=1`, the raw AERMOD output results are saved to a file that can be analyzed using **oPOSTPROCESS**. If `mkeepout=1` was not used, then re-run Example 4 using this setting and #7. Once the modelling is complete select the **oPOSTPROCESS** tab. On **oPOSTPROCESS**, press **Refresh** to populate the page with the settings used in spreadsheet. Enter the path and file names of the output files entered during the #7 start-up, similar to below.

| | | | | |
|--|---|-----|-----------------------|-----------------------------------|
| input: PLOTFILE AERMOD output Plot File | P:\ERCBtools\AERflare\Examples\Ex4b\laermod_2_elev.dat | ... | | |
| input: METFILE Meteorological File Used | P:\ERCBtools\AERflare\Examples\Ex4b\AERMOD.SFC | ... | | |
| | Enter a single file or Enter three post piles to analysis a BlowDown | | Duration (minutes) | |
| input: SINGLE POSTFILE or QMAX POSTFILE AERMOD output Post File | P:\ERCBtools\AERflare\Examples\Ex4b\laermod_2_elev.bin | ... | 60.0 | |
| input: QAVE POSTFILE AERMOD output Post File | | ... | | <input type="checkbox"/> Blowdown |
| input: QMIN POSTFILE AERMOD output Post File | | ... | | |

In the User Selectable Statistics table, enter nth highest or percentile values of interest. For instance, in the table below the first, eighth and ninth highest are selected to be calculated. These produce results for the 100% percentile (peak) concentration, with the remaining two being helpful to examine because the top eight values are typically discarded leaving the 9th highest. The difference between latter two assists in understanding decisions based upon the 9th highest concentration. In the **INPUT%** column, the table below shows a typical selection of percentile useful for plotting a probability density function (PDF) chart for the predicted concentrations.

| User Selectable Statistics | | | | | |
|----------------------------|-------|--------------------------|---------------|---------|--------------------------|
| VARIABLE | INPUT | $\mu\text{g}/\text{m}^3$ | VARIABLE | INPUT % | $\mu\text{g}/\text{m}^3$ |
| Nth Highest 1 | 1 | | Percentile 1 | 50 | |
| Nth Highest 2 | 8 | | Percentile 2 | 60 | |
| Nth Highest 3 | 9 | | Percentile 3 | 70 | |
| Nth Highest 4 | | | Percentile 4 | 80 | |
| Nth Highest 5 | | | Percentile 5 | 90 | |
| Nth Highest 6 | | | Percentile 6 | 95 | |
| Nth Highest 7 | | | Percentile 7 | 96 | |
| Nth Highest 8 | | | Percentile 8 | 97 | |
| Nth Highest 9 | | | Percentile 9 | 98 | |
| Nth Highest 10 | | | Percentile 10 | 98.5 | |
| Nth Highest 11 | | | Percentile 11 | 99 | |
| Nth Highest 12 | | | Percentile 12 | 99.5 | |
| Nth Highest 13 | | | Percentile 13 | 99.6 | |
| Nth Highest 14 | | | Percentile 14 | 99.9 | |
| Nth Highest 15 | | | Percentile 15 | 99.99 | |

Press **Post-Process** to start the post-process calculations. The calculations for a single source are the same as those used during **oMODELLING** calculations. For instance, on the **oAERSCREEN** page, the results are (results for SO2 are displayed).

| | | | Worst Case Complex Terrain | | | Worst Case Complex Terrain | | | Worst Case Complex Terrain | Worst Case Complex Terrain | N |
|---|----------------|--------------------------|----------------------------|------|------|----------------------------|--|--|----------------------------|----------------------------|------|
| Maximum Concentration | cmax | $\mu\text{g}/\text{m}^3$ | 1127 | 792 | 276 | | | | NA | NA | 8759 |
| Distance to Maximum Concentration | xmax | m | 1716 | 1337 | 1337 | | | | | | |
| Wind Speed | ws | m/s | 1 | 1 | 1 | | | | | | |
| PG Stability Class | PG | PG | E | E | E | | | | | | |
| Distance Concentration drops below Ob#1 | xobj1 | m | 1716 | 1716 | -1 | | | | | | |
| Distance Concentration drops below Ob#2 | xobj2 | m | -1 | -1 | -1 | | | | | | |
| Distance Concentration drops below Ob#3 | xobj3 | m | 1716 | 1716 | 1716 | | | | | | |
| Concentration CMAX (99.9th) | winter or yr 1 | $\mu\text{g}/\text{m}^3$ | 541 | 420 | 214 | | | | NA | NA | 8760 |
| | spring or yr 2 | $\mu\text{g}/\text{m}^3$ | 395 | 380 | 159 | | | | NA | NA | 8760 |
| | summer or yr 3 | $\mu\text{g}/\text{m}^3$ | 713 | 478 | 171 | | | | NA | NA | 8784 |
| | fall or yr 4 | $\mu\text{g}/\text{m}^3$ | 736 | 469 | 200 | | | | NA | NA | 8760 |
| | month or yr 5 | $\mu\text{g}/\text{m}^3$ | 597 | 430 | 187 | | | | NA | NA | 8759 |
| Concentration RBC (99.0th) | winter or yr 1 | $\mu\text{g}/\text{m}^3$ | 179 | 114 | 37 | | | | NA | NA | 8760 |
| | spring or yr 2 | $\mu\text{g}/\text{m}^3$ | 185 | 129 | 47 | | | | NA | NA | 8760 |
| | summer or yr 3 | $\mu\text{g}/\text{m}^3$ | 184 | 129 | 54 | | | | NA | NA | 8784 |
| | fall or yr 4 | $\mu\text{g}/\text{m}^3$ | 250 | 155 | 53 | | | | NA | NA | 8760 |
| | month or yr 5 | $\mu\text{g}/\text{m}^3$ | 200 | 136 | 47 | | | | NA | NA | 8759 |

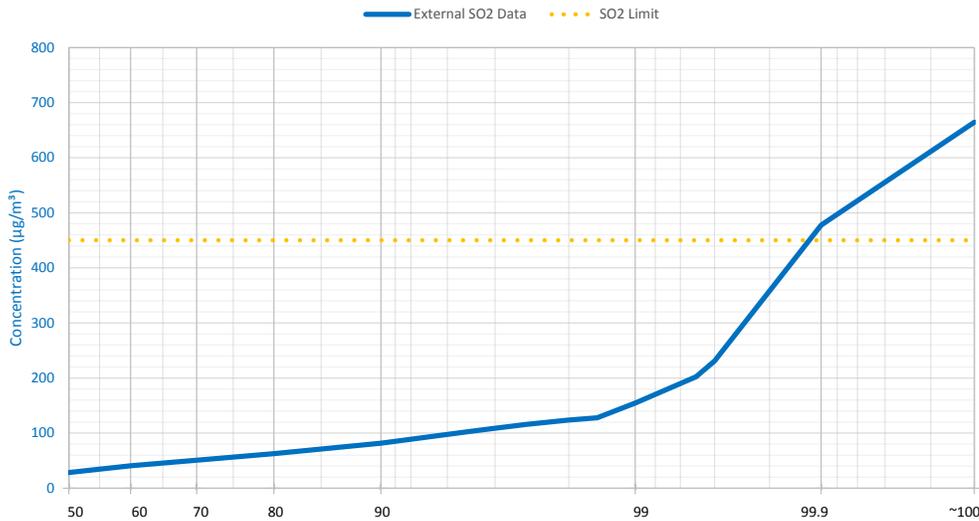
And the results on the **oPOSTPROCESS** page for the **Qave** source strength are:

| SUMMARY OUTPUT | | | Units | Maximum (QMAX) | Number of Data Points in Sample |
|---|----------------|--------------------------|-------|----------------|---------------------------------|
| Maximum Concentration | cmax | $\mu\text{g}/\text{m}^3$ | | 792 | 43823 |
| Distance to Maximum Concentration | xmax | m | | 1337 | |
| Wind Speed | ws | m/s | | 1 | |
| PG Stability Class | PG | PG | | E | |
| Distance Concentration drops below Ob#1 | xobj1 | m | | 1716 | |
| Distance Concentration drops below Ob#2 | xobj2 | m | | -1 | |
| Distance Concentration drops below Ob#3 | xobj3 | m | | 1716 | |
| Concentration CMAX (99.9th) | winter or yr 1 | $\mu\text{g}/\text{m}^3$ | | 420 | 8760 |
| | spring or yr 2 | $\mu\text{g}/\text{m}^3$ | | 380 | 8760 |
| | summer or yr 3 | $\mu\text{g}/\text{m}^3$ | | 478 | 8784 |
| | fall or yr 4 | $\mu\text{g}/\text{m}^3$ | | 469 | 8760 |
| | month or yr 5 | $\mu\text{g}/\text{m}^3$ | | 430 | 8759 |
| Concentration RBC (99.0th) | winter or yr 1 | $\mu\text{g}/\text{m}^3$ | | 114 | 8760 |
| | spring or yr 2 | $\mu\text{g}/\text{m}^3$ | | 129 | 8760 |
| | summer or yr 3 | $\mu\text{g}/\text{m}^3$ | | 129 | 8784 |
| | fall or yr 4 | $\mu\text{g}/\text{m}^3$ | | 155 | 8760 |
| | month or yr 5 | $\mu\text{g}/\text{m}^3$ | | 136 | 8759 |

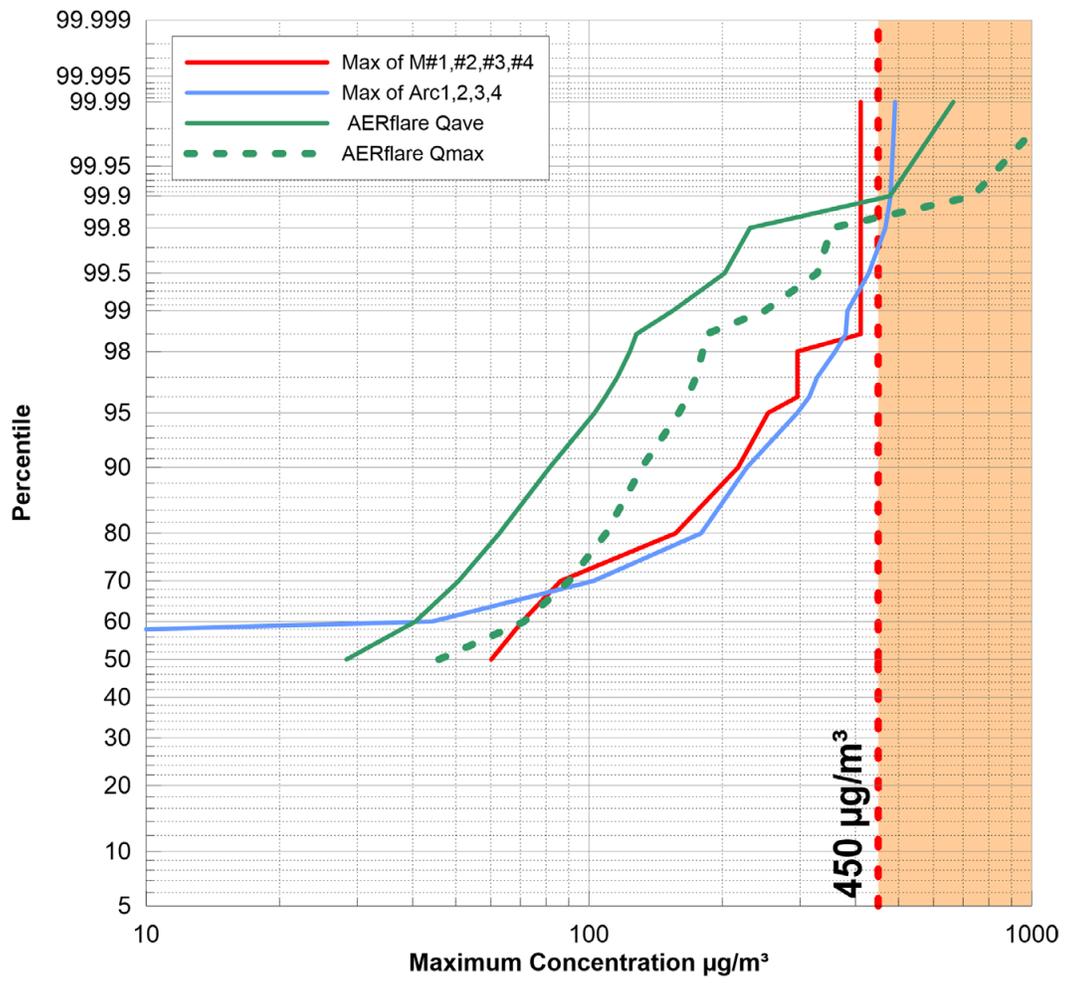
The n^{th} highest and percentile concentrations are now displayed adjacent to the user inputs:

| User Selectable Statistics | | | | | |
|-----------------------------------|-------|--------------------------|---------------|---------|--------------------------|
| VARIABLE | INPUT | $\mu\text{g}/\text{m}^3$ | VARIABLE | INPUT % | $\mu\text{g}/\text{m}^3$ |
| Nth Highest 1 | 1 | 791.58 | Percentile 1 | 50 | 28.33 |
| Nth Highest 2 | 2 | 664.52 | Percentile 2 | 60 | 40.56 |
| Nth Highest 3 | 9 | 499.42 | Percentile 3 | 70 | 50.78 |
| Nth Highest 4 | | | Percentile 4 | 80 | 62.74 |
| Nth Highest 5 | | | Percentile 5 | 90 | 81.53 |
| Nth Highest 6 | | | Percentile 6 | 95 | 102.94 |
| Nth Highest 7 | | | Percentile 7 | 96 | 108.81 |
| Nth Highest 8 | | | Percentile 8 | 97 | 115.83 |
| Nth Highest 9 | | | Percentile 9 | 98 | 123.68 |
| Nth Highest 10 | | | Percentile 10 | 98.5 | 127.91 |
| Nth Highest 11 | | | Percentile 11 | 99 | 154.66 |
| Nth Highest 12 | | | Percentile 12 | 99.5 | 202.40 |
| Nth Highest 13 | | | Percentile 13 | 99.6 | 231.05 |
| Nth Highest 14 | | | Percentile 14 | 99.9 | 477.80 |
| Nth Highest 15 | | | Percentile 15 | 99.99 | 664.52 |

The percentile data are displayed in a chart (see below). Also provided are detailed tables of predicted concentration versus meteorology matrices, and the predictions for each year in the assessment period.



The *AERflare* predictions can be compared to the real-time monitoring data collected during the well test. The chart below shows monitoring data at the 4 monitoring locations (red solid line) compared to the predictions using *Qave* and *Qmax* from *AERflare* (green line and green dash line, respectively). The blue solid line is hour-by-hour prediction using *ABflare* at *Qave* (*ABflare* is the same source model as *AERflare*) and *CALPUFF* dispersion model. It is difficult to draw specific conclusions based upon these results alone regarding the validity of *AERflare* and *AERMOD* predictions in highly complex terrain. *AERMOD* uses a simplistic complex terrain adjustment for concentrations compared to *CALPUFF*, which is conservative as shown in this example.



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Appendix A

The *AERflare* spreadsheet was designed to use a platform that provided transparency for all calculations. This transparency allows the user to follow the calculations and as necessary repeat the calculations using external means. There are instances where the benefits of programming were used to perform calculations that would not be possible in a simple spreadsheet or make the spreadsheet unnecessarily complex. In these instances, a programmed function was created to perform the calculations. Otherwise, *AERflare* uses combinations of cell and worksheet references for all calculations.

| Function | Description |
|-------------|---|
| calmaxcr | Calculates a real 1 hour time average from a sequence of modelled sub-hourly duration events modelled as continuous sources producing modelled 1 hour time averages |
| wsstkht | Calculates the wind speed at stack height given the wind speed at reference height. |
| fneq90 | Uses Gordon (et al 1971) function 90 to calculate the molar heat capacity |
| fneq91 | Uses Gordon (et al 1971) function 91 to calculate the molar enthalpy |
| NR_Texhaust | Uses the Newton-Raphson method to find the flare flame temperature |
| NR_XL | Uses the Newton-Raphson method to find the Brzustowski flare model XL parameter |
| p_sat | Calculates the saturation pressure for steam using the Gibbs free energy formulation |
| t_sat | Calculates the saturation temperature for steam using the Gibbs free energy formulation |
| FNz | Uses Redlich-Kwong formulation to determine the compressibility factor for gases |

FUNCTION calmaxcr(...)

This function calculates the maximum 1 hour average concentration from a list of sequential 1 hour average modelled concentration and implied durations for the results. Typical dispersion models operate on 1 hour time average basis, whereas the desired modelling duration may be sub-hourly. Sub-hourly duration emissions are modelled by ignoring the real duration, and adopting the model's 1 hour average resolution. The results of the modelling (C_{hour}) are subsequently corrected by prorating the modelled 1 hour time average by desired real duration (D_2). C_2 is the corrected 1 hour time average.

$$C_2 = \frac{\min(60, D_2)}{60} C_{hour} \quad (A.1)$$

Spreadsheet function call:

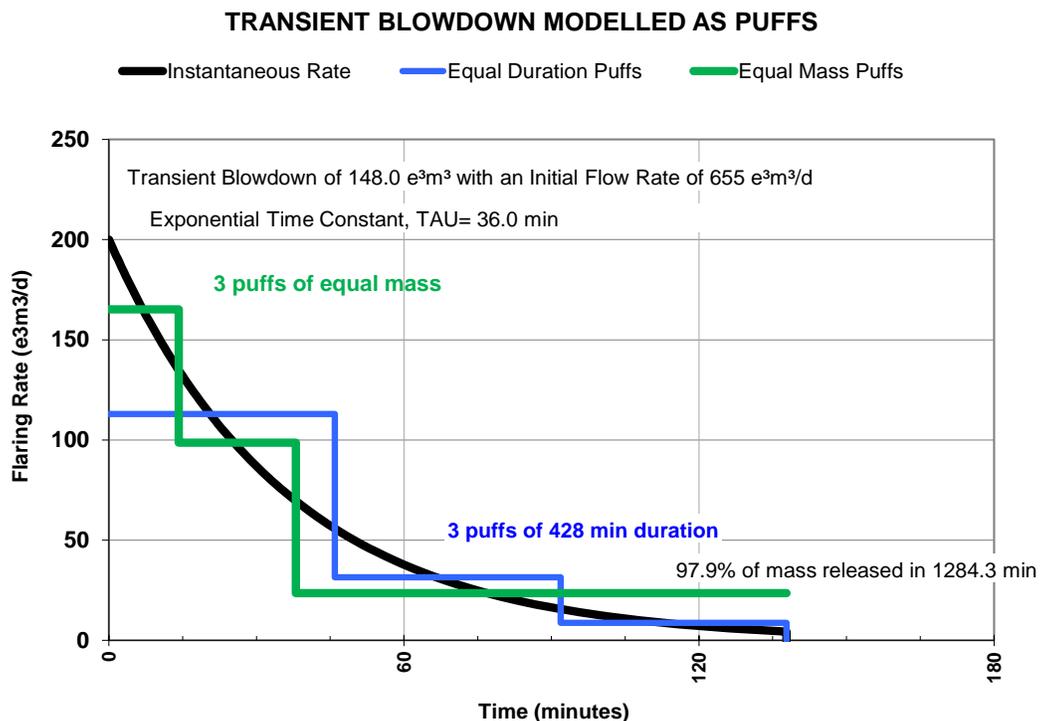
=CalcMaxCr(rcdat, rtdat, tlim)

Where *rcdat* is a range variable (eg, A1:C1) representing the modelled output concentrations assuming 1 hour time average, *rtdat* is a range variable (eg A2:C2) representing the real duration, *tlim* is total real duration. If the units of *rtdat* are minutes, then *tlim* should be entered in minutes *tlim*=60.

This function can be used for a single prediction:

=CalcMaxCr(A1, B1, 60)

Where A1 is the modelled 1 hour average concentration, B1 is the real duration in minutes.



This function can also be used with inputs of consecutive predictions. For instance, for the blowdown sequence above, the green line represents the real durations (14 min, 24 min, and 100 min) for three modelling runs at rates (165 e3m³/d, 99 e3m³/d and 24 e3m³/d, respectively). Each rate is modelled independently assuming a continuous emission duration. The modelled output is provided as 1 hour average concentration for each emission rate, (eg, 100 μg/m³;

75 $\mu\text{g}/\text{m}^3$; 25 $\mu\text{g}/\text{m}^3$, respectively). Using the *CalcMaxCR(...)* function the real 1 hour average (worst case) concentration is calculated to be 62.5 $\mu\text{g}/\text{m}^3$:

```
Range(A1:C1) = (100; 75; 25)
Range(A2:C2) = (14; 24; 100)
62.5=CalcMaxCR(A1:C1,A2:C2,60)
```

CalcMaxCR(...) determines the worst 1 hour average concentration. In the example above, a 1 hour period is assumed to start at the beginning of the three-step sequence. Therefore, a 1 hour period is composed of 14 min at 100 $\mu\text{g}/\text{m}^3$, 24 min at 75 $\mu\text{g}/\text{m}^3$ and 22 min (ie the fraction of the 1 hour period remaining) at 25 $\mu\text{g}/\text{m}^3$. Alternatively, a 1 hour period could be composed of 24 min at 75 $\mu\text{g}/\text{m}^3$ and 36 min at 25 $\mu\text{g}/\text{m}^3$, or 60 min at 25 $\mu\text{g}/\text{m}^3$.

In the above example, it doesn't appear necessary to examine all of the sequential combinations since the maximum concentration of 100 $\mu\text{g}/\text{m}^3$ is at the start of the sequence. However, because of non-linearity included in the modelling that takes into account the hour-by-hour emission rates, downwash, and terrain effects, the maximum sequence element concentration could be at any step in the sequence. For instance:

```
Range(A1:C1) = (50; 100; 70)
Range(A2:C2) = (14; 24; 100)
82=CalcMaxCR(A1:C1,A2:C2,60)
```

```

' -----
' CALMAXCR() function
'
' B.W.Zelt, Ph.D., P.Eng.
'
' 27-Sep-2012
'
' User input of ranges
' then call the CalcMaxC() function
Function CalcMaxCr(rcdat As Range, rtdat As Range, tlim)
    Dim cdat() As Double
    Dim tdat() As Double
    isize = 0
    For Each a In rcdat
        isize = isize + 1
    Next
    ReDim cdat(isize)
    ReDim tdat(isize)
    isize = 0
    For Each a In rcdat
        isize = isize + 1
        cdat(isize) = a.value
    Next
    isize2 = 0
    For Each a In rtdat
        isize2 = isize2 + 1
        If (isize2 <= isize) Then
            tdat(isize2) = a.value
        End If
    Next
    If (isize <> isize2) Then
        CalcMaxCr = "Ranges are different size"
    Else
        CalcMaxCr = CalcMaxC(cdat(), tdat(), isize, tlim)
    End If
End Function

```

```

' -----
' CALMAXC()  function
'
' B.W.Zelt, Ph.D., P.Eng.
'
' Calculates the maximum period (TLIM) average concentration from
' a time series of C() and durations T().
'
' 27-Sep-2012
'
' UPDATES:
'
'
Function CalcMaxC(cdat() As Double, tdat() As Double, ndat, tlim)
  cmaxi = 0
  For i = 1 To ndat
    T1 = 0
    cmaxj = 0
    For j = i To ndat
      If (T1 + tdat(j) > tlim) Then
        If (tlim - T1 > 0) Then
          cmaxj = cmaxj + cdat(j) * (tlim - T1) / tlim
        End If
        GoTo done1
      Else
        cmaxj = cmaxj + cdat(j) * tdat(j) / tlim
      End If
      T1 = T1 + tdat(j)
    Next j
  done1:
    If (cmaxj > cmaxi) Then
      cmaxi = cmaxj
    End If
  Next i
  CalcMaxC = cmaxi
End Function

```

FUNCTION wsstkht(...)

This function calculates the windspeed at stack height given the input variables reference windspeed (m/s), reference windspeed height (m), Pasquill-Gifford stability class, and stack height (m).

Spreadsheet function call:

$$=wsstkht(wref, Zref, iPG, hs)$$

This function performs the following calculation:

$$WS = WS_{ref} \left(\frac{\max(h_s, 10 \text{ m})}{h_{ref}} \right)^{plx0} \quad (\text{A.2})$$

Where the exponent plx0 is determined by the following lookup data as displayed on the **PROPERTIES** page.

| Pasquill-Gifford Stability | Plx0 |
|----------------------------|------|
| A | 0.07 |
| B | 0.07 |
| C | 0.10 |
| D | 0.15 |
| E | 0.35 |
| F | 0.55 |

FUNCTION fneq90(...)

This function performs the basic calculation of the molar specific heat capacity:

$$\frac{c_{po}(T)}{R} = a_1 + a_2T + a_3T^2 + a_4T^3 + a_5T^4 + a_{1*} \quad (\text{A.3})$$

The constants are chemical specific and are listed on the **PROPERTIES** page (see section label Table D1). The low temperature constants (a_1 , a_2 , a_3 , a_4 , and a_5) are listed at a reference temperature of 25 °C along with a high temperature range (b_1 , b_2 , b_3 , b_4 and b_5). Correction factor a_{1*} , is used to make the low range values match at the GPSA reference temperature of 15 °C. Correction factor b_{1*} , is used to make the high range values the same at the cross over temperature of 1000 K.

Spreadsheet function call:

```
=Fneq90(T, RANGE(a_low), RANGE(b_high),
use_correction(TRUE or FALSE))
```

Where c_{po} (kJ/(kmol·K)) is the molar heat capacity, R (kJ/(kmol·K)) is the universal gas constant, T is the temperature for molar heat capacity (Kelvin), $\text{RANGE}(a_low)$ is a range variable pointing to the chemical specific molar heat capacity a series low temperature parameters (see **PROPERTIES** page), $\text{RANGE}(b_high)$ is a range variable pointing to the chemical specific molar heat capacity b series high temperature parameters (see **PROPERTIES** page), and $use_correction$ is an optional parameter to use the correction or not use the correction (default is TRUE). The RANGE must include the a_6 parameter and a_{1*} (in the seventh position). The a_6 parameter is not used for molar heat capacity but is used in $fneq91()$ for the enthalpy calculation.

References:

Gordon,S., McBride, B.J., 1971, Computer Program for Calculation of Complex Chemical Equilibrium Composition, Rocket Performance, Incident and Reflected Shocks and Chapman-Jouguet Detonations, NASA SP-273.

FUNCTION **fneq91(...)**

This function performs the basic calculation of the enthalpy:

$$\frac{h_o(T)}{RT} = a_1 + \frac{a_2}{2}T + \frac{a_3}{3}T^2 + \frac{a_4}{4}T^3 + \frac{a_5}{5}T^4 + \frac{a_6}{T} + a_{1*} \quad (\text{A.4})$$

Where the lead constants a_1 , a_2 , a_3 , a_4 , a_5 , a_6 and a_{1*} are chemical specific and listed on the **PROPERTIES** page (see section label Table D1). The lead constants are corrected for a reference temperature of 15 °C and are available in a low temperature range and a high temperature range (b_1 , b_2 , b_3 , b_4 , b_5 , b_6 , and b_7 respectively) for chemical mixtures. There is a discontinuity between the two temperature ranges. To avoid this behaviour, a correction factor, b_7 is used to make the curves continuous at 1000K.

Spreadsheet function call:

```
=Fneq91(T, RANGE(a_low), RANGE(b_high),
        use_correction(TRUE or FALSE),
        use_rangedjust(TRUE or FALSE))
```

Where h_o (kJ/kmol) is the enthalpy, R (kPa·m³/(kmol·K)), T is the temperature (Kelvin), RANGE(a_low) is a range variable pointing to the chemical specific a series low temperature parameters (see **PROPERTIES** page), RANGE(b_low) is a range variable pointing to the chemical specific b series high temperature parameters (see **PROPERTIES** page), and *use_correction* is an optional parameter to use the correction or not use the correction (default is TRUE). The RANGE must include the a_6 parameter and a_{1*} (in the seventh position). The *use_rangedjust* parameter is an optional parameter (default is TRUE) to include or not include the a_6 parameter. The *use_rangedjust* is used for intermediate calculations to determine the *use_correction* range smoothing parameter.

References:

Gordon,S., McBride, B.J., 1971, Computer Program for Calculation of Complex Chemical Equilibrium Composition, Rocket Performance, Incident and Reflected Shocks and Chapman-Jouguet Detonations, NASA SP-273.

FUNCTION NR_Texhaust(...)

This function performs the basic calculation of the exhaust temperature of gases from the flame using Newton-Raphson method. The exhaust temperature is a function of molar heat capacity and enthalpy of the gases. These parameters are a function of temperature. Therefore an iterative solution is required to solve for temperature.

Spreadsheet function call:

```
=NR_Texhaust(Tguess, Enthalpy_Goal, RANGE(a_low),  
             RANGE(b_high))
```

The basic code for the function is:

```
Public Function NR_Texhaust(guess As Double, goal As Double, alo As Range, ahi As Range)  
    Dim a As Double  
    Dim H1 As Double  
    Dim cp As Double  
    Dim diff As Double  
    Dim slope As Double  
    Dim intercept As Double  
    Dim Ru As Double  
    Dim Tref As Double  
    Dim H0 As Double  
    Dim err As Double  
    Dim maxloops As Integer  
    Dim i As Integer  
  
    maxloops = 100  
    err = 0.0001  
    Ru = ThisWorkbook.Worksheets("oCALCULATIONS").Range("k_RU").value  
    Tref = 273.15 + ThisWorkbook.Worksheets("oCALCULATIONS").Range("Tref").value  
  
    H0 = fneq91(Tref, alo, ahi) * Ru * Tref  
    cp = fneq90(guess, alo, ahi) * Ru  
    H1 = fneq91(guess, alo, ahi) * Ru * guess - H0  
    intercept = H1 - cp * guess  
    diff = H1 - goal  
  
    isdone = -1#  
    i = 0  
    While (isdone < 0)  
        guess = (goal - intercept) / cp  
  
        cp = fneq90(guess, alo, ahi) * Ru  
        H1 = fneq91(guess, alo, ahi) * Ru * guess - H0  
        intercept = H1 - cp * guess  
        diff = H1 - goal  
  
        If (Abs(diff) < err) Then isdone = 1  
        i = i + 1  
        If i >= maxloops Then isdone = 1  
    Wend  
    guess = (goal - intercept) / cp  
    NR_Texhaust = guess  
  
End Function
```

FUNCTION NR_XL(...)

The Brzustowski Flare Model is used in the *AERflare* to determine the position and dimension of the flare flame. The position parameter XL is a function calculated based upon a guess of the position and a dimensionless flare position parameter SL.

Spreadsheet function call:

=NR_XL(XL_guess, SL_goal)

```
Public Function NR_XL(guess As Double, goal As Double)
    Dim a As Double
    Dim b As Double
    Dim C As Double
    Dim diff As Double
    Dim slope As Double
    Dim intercept As Double
    Dim err As Double
    Dim maxloops As Integer
    Dim i As Integer

    maxloops = 100
    err = 0.1

    a = 1.04 * guess ^ 2
    b = 2.05 * guess ^ 0.28
    C = a + b
    diff = C - goal
    slope = 2 * 1.04 * guess + 0.28 * 2.05 * guess ^ (0.28 - 1)

    isdone = -1#
    i = 0
    While (isdone < 0)
        guess = guess - diff / slope

        a = 1.04 * guess ^ 2
        b = 2.05 * guess ^ 0.28
        C = a + b
        diff = C - goal
        slope = 2 * 1.04 * guess + 0.28 * 2.05 * guess ^ (0.28 - 1)

        If (Abs(diff) < 0.1) Then isdone = 1
        i = i + 1
        If i >= maxloops Then isdone = 1
    Wend
    guess = guess - diff / slope
    NR_XL = guess

End Function
```

References:

Brzustowski, T.A.. 1976. Flaring in the Energy Industry. Prog. Energy Combust. Sci. pp. 129-141.

FUNCTION p_sat(...)

The saturation pressure of steam can be calculated given the temperature using Gibbs free energy formulation. The Gibbs coefficients are listed on the **PROPERTIES** page.

Spreadsheet function call:

=p_sat(temperature)

Where Temperature (Kelvin) is the temperature of the steam.

The basic code for the function is:

```
'ref: The International Association for the Properties of Water and Steam, 2007
'Revised Release on the IAPWS Industrial Formulation 1997 for the Thermodynamic
Properties of Water and Steam
'Dimensionless saturation equations
Function p_sat(T As Double, gibbs As Range) As Double
    Dim sum As Double
    Dim ni As Double
    Dim agibbs As Variant
    Dim a As Double
    Dim b As Double
    Dim C As Double
    Dim v As Double

    agibbs = gibbs.value

    v = T + agibbs(9, 2) / (T - agibbs(10, 2))

    a = v * v + agibbs(1, 2) * v + agibbs(2, 2)
    b = agibbs(3, 2) * v * v + agibbs(4, 2) * v + agibbs(5, 2)
    C = agibbs(6, 2) * v * v + agibbs(7, 2) * v + agibbs(8, 2)
    ' Psat in MPa
    p_sat = 2# * C / (-b + Sqr(b * b - 4# * a * C))
    p_sat = p_sat * p_sat
    p_sat = p_sat * p_sat
    p_sat = p_sat * 1000# ' return kPa
End Function
```

Reference:

The International Association for the Properties of Water and Steam, 2007
'Revised Release on the IAPWS Industrial Formulation 1997 for the
Thermodynamic Properties of Water and Steam
<http://www.iapws.org/>

FUNCTION t_sat(...)

The saturation temperature of steam can be calculated given the pressure using Gibbs free energy formulation. The Gibbs coefficients are listed on the **PROPERTIES** page.

Spreadsheet function call:

=t_sat(Pressure)

Where Pressure (kPa) is the pressure of the steam.

The basic code for the function is:

```
'ref: The International Association for the Properties of Water and Steam, 2007
'Revised Release on the IAPWS Industrial Formulation 1997 for the Thermodynamic
Properties of Water and Steam
'Dimensionless saturation equations
Function t_sat(p As Double, gibbs As Range) As Double
    Dim sum As Double
    Dim ni As Double
    Dim agibbs As Variant
    Dim d As Double
    Dim e As Double
    Dim f As Double
    Dim g As Double
    Dim b As Double

    agibbs = gibbs.value

    ' p in MPA
    b = (p * 0.001) ^ 0.25

    e = b * b + agibbs(3, 2) * b + agibbs(6, 2)
    f = agibbs(1, 2) * b * b + agibbs(4, 2) * b + agibbs(7, 2)
    g = agibbs(2, 2) * b * b + agibbs(5, 2) * b + agibbs(8, 2)

    d = 2# * g / (-f - Sqr(f * f - 4# * e * g))
    ' t_sat in K
    t_sat = agibbs(10, 2) + d - Sqr((agibbs(10, 2) + d) ^ 2# - 4# * (agibbs(9, 2) +
agibbs(10, 2) * d))
    t_sat = t_sat * 0.5
End Function
```

Reference:

The International Association for the Properties of Water and Steam, 2007
'Revised Release on the IAPWS Industrial Formulation 1997 for the
Thermodynamic Properties of Water and Steam
<http://www.iapws.org/>

FUNCTION FNz(...)

This function calculates the compressibility of a gas given its critical temperature and critical pressure using the Redlich–Kwong equation of state. The Redlich–Kwong equation of state is an empirical, algebraic equation that relates temperature, pressure, and volume of gases.

Spreadsheet function call:

```
=fnZ(Temperature, Pressure, Critical_Temperature,  
     Critical_Pressure)
```

Where T (Kelvin) is temperature, P (kPa) is pressure, Critical Temperature (Kelvin) and Critical Pressure (kPa)

The basic code for the function is:

```
' http://www.chem.mtu.edu/~tbco/cm3450/Compressibility_from_Redlich_Kwong.pdf  
' Redlich-Kwong equation  
' based on Cutlip and Shacham, 2008, pp. 101-103 (see Seader, Henley & Roper,  
3rd Ed, 2011)  
Function fnZ(T As Double, p As Double, Tc As Double, Pc As Double)  
    Dim Tr As Double  
    Dim Pr As Double  
    Dim a As Double  
    Dim b As Double  
    Dim q As Double  
    Dim r As Double  
  
    On Error GoTo error_handler  
    Tr = T / Tc  
    Pr = p / Pc  
  
    a = 0.42747 * Pr / Tr ^ (5# / 2#)  
    b = 0.08664 * Pr / Tr  
    r = a * b  
    q = b * b + b - a  
  
    fnZ = mcroot(1, -1, -q, -r)  
    Exit Function  
  
error_handler:  
    fnZ = "***ERROR**"  
End Function
```

```

Function mcroot(a3 As Double, a2 As Double, a1 As Double, a0 As Double)
'
' Computes the maximum real root of the cubic equation
' a3 x^3 + a2 x^2 + a1 x + a0 = 0
'
Dim a As Double
Dim b As Double
Dim C As Double
Dim d As Double
Dim z As Double

a = a2 / a3
b = a1 / a3
C = a0 / a3
p = (-a ^ 2 / 3 + b) / 3
q = (9 * a * b - 2 * a ^ 3 - 27 * C) / 54
Disc = q ^ 2 + p ^ 3
If Disc > 0 Then
h = q + Disc ^ (1 / 2)
Y = (Abs(h)) ^ (1 / 3)
If h < 0 Then Y = -Y
z = Y - p / Y - a / 3
Else
theta = Atn((-Disc) ^ (1 / 2) / q)
c1 = Cos(theta / 3)
If q < 0 Then
s1 = Sin(theta / 3)
c1 = (c1 - s1 * 3 ^ (1 / 2)) / 2
End If
z1 = 2 * (-p) ^ (1 / 2) * c1 - a / 3
M = a + z1
r = (M ^ 2 - 4 * (b + M * z1)) ^ (1 / 2)
z2 = (-M + r) / 2
z3 = (-M - r) / 2
z = z1
If z2 > z Then z = z2
If z3 > z Then z = z3
End If
mcroot = z
End Function

```

Reference:

Cutlip and Shacham, 2008. Based on Seader, Henley & Roper, 2011. Separation Process Principles, 3rd Ed.

http://www.chem.mtu.edu/~tbco/cm3450/Compressibility_from_Redlich_Kwong.pdf

Credits

Mapping Code

Projection transformation to and from latitude/longitude and Universal Transverse Mercator (UTM) coordinates were based upon code from General Cartographic Transformation Package (GCTP). The General Cartographic Transformation Package (GCTP) is a system of software routines designed to permit the transformation of coordinate pairs from one map projection to another. The GCTP is the standard computer software used by the National Mapping Division for map projection computations.

Reference:

<ftp://edcftp.cr.usgs.gov/software/gctpc/>

Nearest Neighbour Code

The nearest neighbour algorithms are translated for VBA by Sergey Bochkonov using the ALGLIB project code. This program is free software; it can be redistributed it and/or modify under the terms of the GNU General Public License as published by the Free Software Foundation (www.fsf.org). ALGLIB is a cross-platform numerical analysis and data processing library. It supports several programming languages (C++, C#, Pascal, VBA) and several operating systems (Windows, Linux, Solaris).

Nearest neighbor search is an important task which arises in different areas - pattern recognition. ALGLIB package includes nearest neighbour subpackage, which implements nearest neighbor search by means of kd-trees. Kd-trees allow to perform efficient search in low-dimensional spaces (from 1 to 5), but have lesser performance in high-dimensional spaces.

Reference:

<http://www.alglib.net/>