# AERflare

# An Air Dispersion Model Source Preprocessor Including Flaring, and Incineration Source Calculations

**User Guide, AERflare Version 3.01**

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# An Air Dispersion Model Source Preprocessor Including Flaring, and Incineration Source Calculations

**User Guide, AERflare Version 3.01**

A Report Prepared for

Alberta Energy Regulator (AER)

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*AERflare* was developed for
Alberta Energy Regulator (AER) of Alberta, Canada

by:


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# Minimum System Requirements for AERflare

*AERflare* is a Windows® based software application requiring Microsoft® Excel x64 as a user interface. The recommended system requirements* are:

- Windows 10, x64
- Microsoft® Excel. (Office x64 REQUIRED)
- Monitor as required
- 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, An Air Dispersion Model Source Preprocessor Including Flaring, and Incineration Source Calculations*

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* tool was developed to assist users and regulators with the following aspects of air dispersion modelling:

1.  Combustion and efficiency calculations

2.  Emission rates characterization

3.  Consistency of screening (rapid) through refined (sophistication) modelling

The *AERflare* tool was originally 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 focus of the *AERflare* model was related to the hot external-combustion associated with elevated open flares and sour gas destruction.  At the core of the *AERflare* model are combustion calculations and a plume rise model incorporating continuity and energy conservation. This basis makes the source characterization universally applicable and extendable to other combustion sources such as incinerators, boilers, heaters and engines. The current version of *AERflare* explicitly assists the user in developing air dispersion model source parameters each of these hot sources and varying stack exhaust composition. The combustion calculations directly relate to the combustion exhaust flowrate and temperature. *AERflare* relates the exhaust flow to a consistent conservation of mass, momentum and buoyancy which are the important variables for the accurate model of plume height. *AERflare* achieves this through properly chosen pseudo-parameters.

The *AERflare* tool was also developed to assist in the interpretation of real-world emission scenarios that vary from steady, to variable, to intermittent; from continuous, to periodic, to blow-down; and various combinations. Historical

modelling guidance tends to recommend modelling the maximum flowrates scenarios. These scenarios are typically associated with maximum pollutant rates. However, from an environmental or health perspective, those scenarios do not necessarily correlate to worst ground level predictions. The reason is because the maximum flowrate scenario is generally associated with maximum heat released and maximum efficiency; and therefore, results in the maximum (best case) plume rise. In the real-world engines and boilers may operate at maximum rates continuously, whereas flares and incinerators operate either episodically or with variable loads. The *AERflare* tool was designed to model these sources at a maximum, average and typical low flowrate to account for the potential lower plume rise, poor efficiency, stack downwash, etc.

The *AERflare* tool was also designed to assist the user in gather necessary modelling data (elevation and meteorology) within the Alberta and available Canadian data modelling context.

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. *AERMOD* (U.S. EPA 2021)

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

| Module | Description |
|---|---|
| *AERflare.xlsm* | a Microsoft®-*Excel* (Office 2019 x64) application software for Windows® containing macros and a user interface to external calculations using AERMOD. |
| *AERflare_RUNBATCH.bat*<br>*AERflare_POSTBATCH.bat* | Digital security in corporate environments changes regularly in the fight against virus and hacking. This struggle limits the ability of applications such as *AERflare* to call external applications such as AERMOD, AERMET and MAKEMET, and create/read input and output files. In order to perform this activity within the current security frameworks, *AERflare* uses these two batch files to bridge commands passed from *AERflare*. |
| *MakeMet.exe* | Modified source code and executable adapted from AERSCREEN. *MakeMet* was modified to read inputs from a file as opposed to the original version which prompted the user for inputs. *MakeMet* can be used to create screening meteorological data files. |
| User Guide.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 (Directive 060):

https://www.aer.ca/regulating-development/rules-and-directives/directives/directive-060

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:

https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models#aermod

# Model Changes

A complete list of changes and updates are provided in the model change document *WhatsNew.pdf* provided with the model distribution.

The major changes in the *AERflare* v3.01 update from v2.x include:

- Revised pseudo-parameter calculations which are applied to flares and incinerator sources parameterization. The pseudo-parameters are determined based upon conservation of buoyancy, momentum and mass. The pseudo-parameters approach ensures that the proper plume rise is applied in the model based upon the entry of source parameters Us, Ts and Ds (velocity, temperature and diameter). The pseudo-parameter approach is appropriate for all sources. This approach is most important for hot exhaust (>400 °C) since these releases exceed the assumptions (molecular weight the same as ambient air, constant specific heat the same as ambient air) of the simplified approach adopted in most dispersion models.

- Flares are modelled using the hour-by-hour parameterization to account for the effects of meteorology. A revised simplified approach has been adopted using the native AERMOD wind speed categories and initial conditions that ensure conservative predictions. It is best to model every individual meteorological hour variation, however, using AERMOD hour-by-hour source parameterization is not available for all variables therefore some simplifications are required. In *AERflare* v2.x, the full meteorological data set was simplified based upon the calculated parameters which were further reduced to 9-categories. The default method used in *AERflare* v3.x adopts the more user friendly 6-wind speed categories source variations available AERMOD. This methodology greatly reduces the pre-processing time required to generate AERMOD input-ready files.

- Revised modelling options. The 'button' approach has been removed and replaced with 'Screening', 'Intermediate' or 'Refined'. These options allow for combinations of land-use (meteorological) and terrain input sophistication. All flares use hour-by-hour approach.

- Land-use classification file processing has been updated to use the contemporary bigTIFF format. The North American land-use files are distributed in this format. This format requires x64 computation, hence *AERflare* is now dependent on Excel x64 and is released for this operating system only. A full suite of mapping datum and projections are now included in *AERflare* for processing a wide range of land-use and DEM files. Processing was optimized to reduce pre-processing time.

- Updated the meteorological screening process. Removed the distributed single-land-use screening files. The new method uses land-use for each 10km x 10km grid cell determined for Alberta, British Columbian and Saskatchewan using the Canadian 2015 dataset. The four-season albedo, Bowen ratio and roughness were determined for each grid cell (centre) and tabulated. The AERflare screening now uses the predetermined land-use characterization and runs MAKEMET meteorological screening automatically. For backwards compatibility, the domain can be processed with a single land-use type.

# User Qualifications

*AERflare* is freely distributed to assist in AER Directive 060 (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. The inputs to *AERflare* may require sound engineering judgement or other technical expertise. It uses site-specific thermodynamics, fluid dynamics, and air dispersion modelling. Air dispersion modelling 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 engineering, meteorology 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 *AERflare* |
| **2 Installation and Setup** | How to install the *AERflare* 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 *AERflare* going beyond screening air dispersion modelling |
| ***7 AERflare* Batch Operation** | Description of the operation of *AERflare* 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 principal factor affecting the average concentration at a downwind location is the plume rise. A plume will rise only as high until it reaches an equilibrium with a matching level in the atmosphere. Air dispersion models calculate the plume rise from the energy of source expressed in terms of the momentum flux and the buoyancy flux.
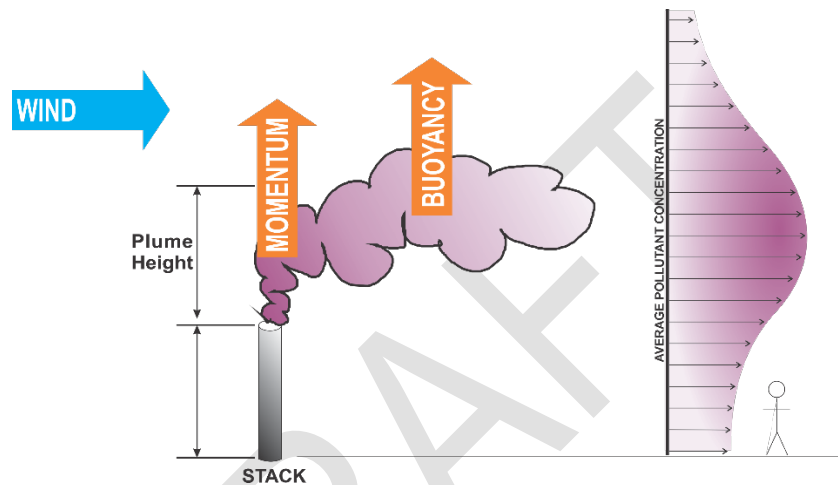


The momentum flux and buoyancy flux, two expressions of energy, can be expressed mathematically from the chimney stack flow rate and temperature relative to the ambient air. Air dispersion models use the inputs describing the stack (diameter, velocity, temperature and height) to calculate the momentum flux (FM) and buoyancy flux (FB).
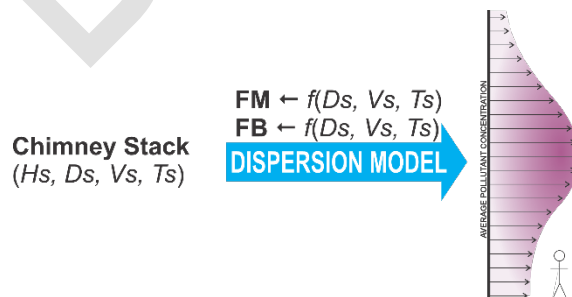


The basic premise of *AERflare* is to determine the momentum and energy for a source. *AERflare* then uses the buoyancy and momentum energy and back-calculates chimney-type equivalent source parameters that can be used as inputs in typical air dispersion models. These parameters are the height, diameter, velocity and temperature of the source.  The equivalent source parameters are frequently called pseudo-parameters.  The parameters are called pseudo-

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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. *AERflare* calculates the FM and FB based upon fundamentals and then solves for stack pseudo-parameters. The pseudo-parameters are based upon the simplified FM and FB equations used in the dispersion model. Therefore, when the stack pseudo-parameters are entered into the dispersion model, the FM and FB will be re-calculated using the simplified equations but their values will match the correct fundamental values.
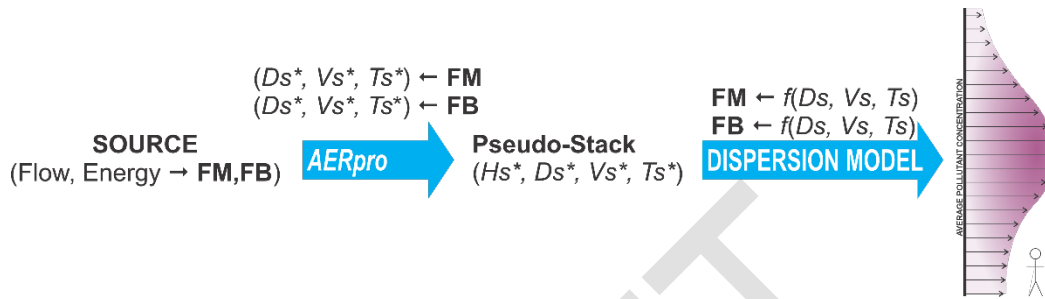


The basis for calculation of FM and FB in terms of chimney parameters ($D_s$, $V_s$, $T_s$) was simplified (Briggs 1969) based upon the assumption of common chimney emissions namely relatively warm emissions (around 200 ºC), low velocity (around 20 m/s) and chemistry similar to air. For emissions that go beyond these assumptions or with arbitrary selection of the chimney parameters, the energy is not conserved and the wrong plume rise will result either higher or lower, resulting in poor predictions of concentration either higher or lower. For many sources considered in air dispersion modelling today, the basic assumptions of the FM and FB formulation are exceeded. These sources include hot plumes (> 400 ºC), high speed jets (>30 m/s) or exhaust that differs from air. *AERflare* calculations use the fundamental equations for FM and FB, avoiding the simplifications, so that the correct FM and FB are represented in the plume rise in the atmosphere, and provide the same FM and FB when in range of the historical simplifications. Emission sources such as flares and incinerators are very hot sources, with a wide range of velocities, and often times a gas composition that differs with respect to molecular weight or how the specific heat ($c_p$) varies with temperature differs from ambient air.

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. *ERCBflare* provided only the estimated pseudo-parameters for a flare leaving the modeller with the responsibility to apply them correctly in a dispersion model. 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*). *AERflare* version 3.x includes enhancements and modifications of the *AERflare* system. Based upon the air dispersion modelling reports submitted for approval to AER, the AER determined that a mor inclusive tool was required, rather than just the calculation of the pseudo-parameters. The tool needed to assist users in meteorological inputs, terrain inputs, receptor and post-processing of the results. In essence, the tool needed to bridge the gap for less-sophisticated modellers while still consistent for more refined modelling assessments.

The purpose of *AERflare* version 3.x is to provide scientifically sound source inputs for existing air dispersion models using 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:

1. Predict scientifically consistent source parameters for open and closed combustion sources

2. Provide a tool than implements those source parameters for rapid (screening) assessment for routine and non-routine emissions

3.    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 2019 x64 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 2019 x64.

*AERflare* requires Office x64.

# Overview of the Installation Process

If you have not already done so, download the installation software from the AER Directive 060 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:

https://www.aer.ca/regulating-development/rules-and-directives/directives/directive-060

There are two download files provided

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

The AERflare_vxxxxx.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_vxxxxx.xlsm` | The *AERflare* spreadsheet tool |
| `[mydir]AERFLARE_RUNBATCH.bat` | The cmd window batch file for bridging commands from *AERflare* |
| `[mydir]AERFLARE_POSTBATCH.bat` | (optional) The cmd window batch file for bridging commands from *AERflare* that run commands during Batch mode operations. |
| `[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:

https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models#aermod

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

https://www.epa.gov/scram/meteorological-processors-and-accessory-programs#aermet

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

*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* spreadsheet 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.
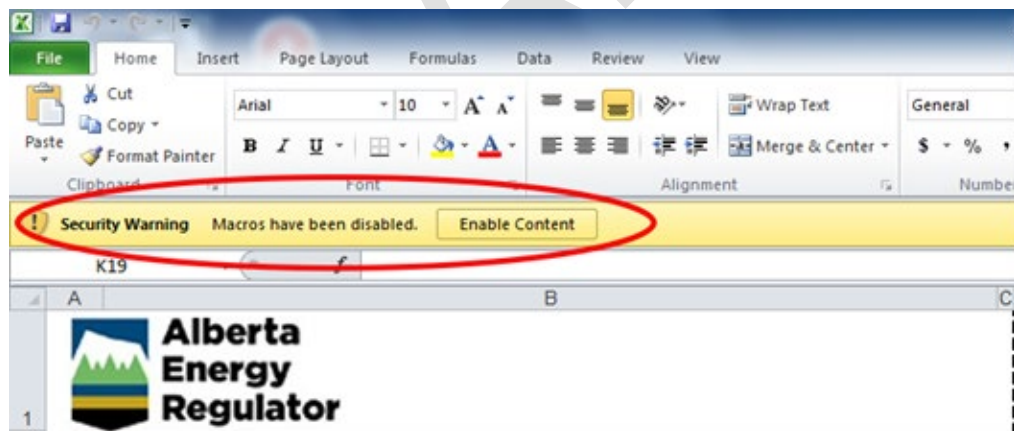


**3.** Click on the **iSTART** page. Select "Show" for the *Hide iBIN Page* option.

**4.** Click on the **iBIN** page. For the entry for **RUNBAT**, type the full path and file name of the AERFLARE_RUNBATCH.bat file (previously installed). The Browse… button can be used to navigate your file folder tree using common Windows Explorer methods.

**5.** 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.

**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.

**WORKING FOLDER:** On the **iBIN** page, for the row entry for *Working (output) Folder*, enter the full path for the location of that *AERflare* can read/write files or use the BROWSE button to navigate to the installation folder. *AERflare* can output files to the current spreadsheet (parent) folder or to a specific output folder, the working folder. The user can select between two options using selections on the **iSTART** page.

**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.

**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. LCC files are progressing from mapsheets to country wide (very large) files. *AERflare* accepts both formats. The mapsheet format will soon be phased out.

**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.

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 11) 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**, **iSOURCE**, **iTERRAIN**, **iNOTES**, and mode selections on the **iSTART** page.

**4.** Click on the **iSOURCE** tab to confirm that the **iBATCH** entries were copied to the **iSOURCE** and other pages.

**5.** Click on the Remodel button at the top of the **iSOURCE** 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 flaring modelling options and on the right are non-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. Click on the `Set Mode Screening` button. This will create input files based upon the screening meteorological files. Click on `EXECUTE` button to run 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*.xlsm contains the user-interface for the calculations, allowing the user to input information and view calculation results. The *AERflare* application consists of the *AERflare*.xlsm 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*.xlsm is an Excel spreadsheet file (.xlsm) 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. Temporary files can also be re-directed to a working folder using the museparentfolder option and setting entering the working folder on in the iBIN page

# Graphical User-Interface

## *Overview – The AERflare GUI in Excel*

All user input and output are controlled using an *AERflare*.xlsm file for Microsoft Excel. The Graphical User-Interface (GUI) file (.xlsm) 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 Source type to be modelled. Flare is for all flaring modelling and Incinerator is for closed combustion sources such as an incinerator.

- Selection of Permit (Non-Routine Planned) mode or Evaluation (Routine or unplanned) mode. Specific inputs and outputs are expected for permitting a non-routine assessment. A non-routine assessment could be either a flare or an incineration event. The Evaluation mode allows selection between unplanned or routine emission scenarios. Unplanned (emergency release) scenarios are associated with typically high volume and high emission releases and have specific regulations for meeting criteria (risk based) and reporting requirements. Routine or continuous flaring is flaring that may occur more than 720 hours per calendar year.

- 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*.xlsm 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.

All Flaring use the hour-by-hour methodology, except if following other regulatory parameterizations, such as EPA, ONT or BC.

# 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. Most of the detailed output information for the inputs is saved to the iBATCH and oBATCH pages, when new information is input, and the inputs and outputs are restored from the database. 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)
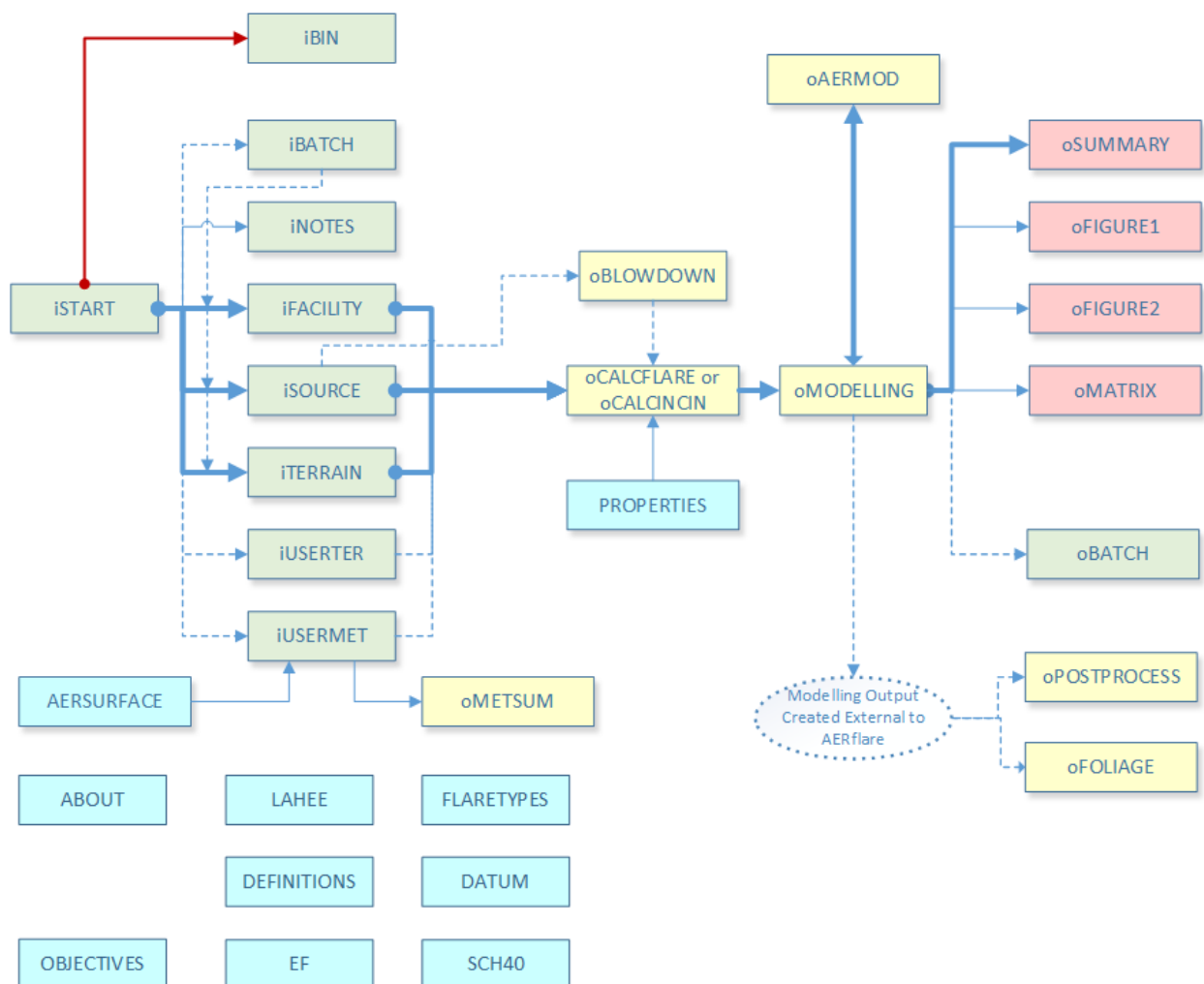
**Figure 1:** *AERflare* **Page Name and Typical Linkage**

# The AERflare Excel Pages

*AERflare* has 33 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 *yellow*; technical pages are *pink* and informational pages are *cyan*.

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. |
| FLARETYPES | Reference (Technical) | The FLARETYPES page describes the various flare types and the parameters used to describe the flare tip for the purposes of AERflare preprocessing. |
| 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 *AERflare.xlsm* 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. |
| 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 permit process. If the routine flaring mode is selected, then many of iFACILITY entries are greyed-out and are not required entries. |
| iSOURCE | Input | The iSOURCE 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 iSOURCE 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. The blowdown curve is represented by three steps which replace the Qmax, Qave and Qlo and the air dispersion modelling results are combined during post-processing to be interpreted as a sequential curve |
| 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 |

| Page Name | Purpose | Description |
|---|---|---|
| | | 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. |
| AER_FIGURE4 | Output | The AER_FIGURE4 is a representation the AER D060 Figure 4 flowchart for temporary flaring/incineration permit process. |
| 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. |
| oCALCFLARE | Technical Output of Intermediate Source Calculations (Technical) | The oCALCFLARE page is a technical listing of the combustion calculations for open flame flare. It also lists the source mass and energy balance intermediate calculations. The results of these calculations are summarized on the oMODELLING page. |
| oCALCINCIN | Technical Output of Intermediate Source Calculations (Technical) | The oCALCINCIN page is a technical listing of the combustion calculations. It also lists the source mass and energy balance intermediate calculations for closed combustions for incinerators. The results of these calculations are summarized on the oMODELLING page. |
| oBLOWDOWN | Technical Output of Intermediate Blowdown Source Calculations | The oBLOWDOWN page displays the source parameters for a transient (facility) blowdown curve. The blowdown curve is represented by three steps which replace the Qmax, Qave and Qlo and the air dispersion modelling results are combined during post-processing to be interpreted as a sequential curve |
| oMETSUM | Technical Output of Summary Statistics of the Meteorological Data (Technical) | The oMETSUM page can be used to generate tabulated and graphical summary of the meteorological data file |
| 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. |
| oAERMOD | Technical Output of Air dispersion modelling Intermediate Results | The oAERMOD 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 |

| Page Name | Purpose | Description |
|---|---|---|
| | (Technical) | 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. |
| oFOLIAGE | Foliage Impacts from SO2 EXTERNAL Results (Technical) | The oFOLIAGE page can be used to post-process air dispersion modelling result files (POSTFILE) to create tabulated and graphical statistical summaries of SO2 damage to foliage by season |
| 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 |
| EF | Reference (Technical) | The EF page tabulates emission factors |
| DATUM | Reference (Technical) | The DATUM page lists the coordinate conversion datum and projection parameters |
| OBJECTIVES | Reference (Technical) | The OBJECTIVES pages lists SO2 objectives for various regulatory agencies |
| SCH40 | Reference (Technical) | The SCH40 page tabulates physical piping sizes |

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.



### Flare or Incinerator Mode

*AERflare* can be switched from FLARE (open flame) combustion mode to INCINERATOR (closed flamed) combustion mode. There are subtle differences in the required inputs that describe the physical source (such as diameter or excess air vs entrained air), plus the combustion calculations are different specifically in reference to how air is added for combustion. The combustion calculations are performed on **oCALCFLARE** or **oCALCINCIN** pages, for the flare or incinerator combustion, respectively. The source type also determines the *AERflare* air dispersion methodology being either hour-by-hour (flare mode) or static source (incinerator mode).

---

# 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 ($\mu$g/m³) | SO$_2$ Max ($\mu$g/m³) | H$_2$S RBC ($\mu$g/m³) | H$_2$S Max ($\mu$g/m³) |
| Routine -- Continuous or Intermittent Flaring for more than 720 hours per year | ○ Locked | 99.9 | -- | 450 | -- | 14 | -- |
| Non-Routine -- Planned Flaring | ◉ | 99 | 99.9 | 450 | 900 | 14 | 7652 |
| Non-Routine -- Unplanned Flaring | ○ Locked | 90 | 99.9 | 450 | 9923 | 14 | 7652 |

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

| 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 ℃, 101.325 kPa
- 3.789 ppm is derived from SO2 evacuation criteria of 5 ppm over 15 minutes adjusted to 60 minutes=5*(15/60)^0.2
- 5.493 ppm is derived from H2S evacuation criteria of 10 ppm over 3 minutes adjusted to 60 minutes=10*(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 SO$_2$ concentration at each receptor must be less than or equal 450 $\mu$g/m³ (or 0.172 ppm). The 99.9% 1h average SO$_2$ concentration at each receptor must be less than or equal to 900 $\mu$g/m³ (or 0.344 ppm). The same RBC is applied for predictions of H$_2$S, the modelled 99% 1h average H$_2$S concentration at each receptor must be less than or equal 14 $\mu$g/m³ (or 0.01 ppm). The 99.9% 1h average H$_2$S concentration at each receptor must be less than or equal to 7652 $\mu$g/m³ (1h equivalent concentration for the threshold of 10 ppm for 3min). The upper limit of the H$_2$S is based upon the evacuation criteria for H$_2$S used in the *AERH2S* emergency response planning.

For emergency/upset flaring, air dispersion modelling uses the 90% RBC 1h average SO$_2$ concentration at each receptor must be less than or equal to 450 $\mu$g/m³ (0.172 ppm). The emergency/upset flaring maximum concentration (99.9%) 1h average SO$_2$ concentration at each receptor must be less than or equal to 9923 $\mu$g/m³ (1h average or 3.789 ppm; based upon 5 ppm for 15min). The maximum SO$_2$ represents the evacuation criteria for SO$_2$ used in the *AERH2S*

emergency response planning.  For H$_2$S, 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 H$_2$S concentration must be less than or equal to 7652 µg/m³ (10 ppm) representing the evacuation criteria for H$_2$S.

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 **oAERMOD** 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 26.

## 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 | Comment |
|---|---|---|---|---|---|
| Use the quick flare method (1-Yes, 0-No) | mquick | -- | 1 | 1 | |
| Re-create run.bat file each time (1-Yes, 0-No) | mrunbat | -- | 1 | 1 | |
| Use spreadsheet parent folder for saved output (1-Yes, 0-No) | museparentfolder | -- | 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 | |
| Batch mode: dump output on oAERSCREEN (1-Yes, 0-No) | mexportout | -- | 0 | 0 | |
| Use DEBUG switch in AERMOD input files (1-Yes, 0-No) | mdebug | -- | 0 | 0 | |
| Use DEBUG dump HBH switch (1-Yes, 0-No) | mdebugdump_hbh | -- | 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 | -- | 1 | 1 | BETA MMETUSTAR=1 must be used for both iUSERMET and oMODELLING. It has no effect on screening |
| Use ALPHA adjustment of low winds method 1 (1-Yes, 0-No) (use SVmin,WSmin,FRANmax settings below) | mlowwind | -- | 0 | 0 | |
| Use daily 1h maximum instead of max hourly (1-Yes, 0-No) | md1hm | -- | 0 | 0 | |
| Use variable radiative heat loss, Ont. MOE (1-Yes, 0-No) | mvarrad | -- | 0 | 0 | BETA testing |
| Alternative Pseudo-Parameter Models | mpseudo | -- | 1 | 1 | BETA 1:AERflare; 2=US EPA; 3=Ont; 4=BC |
| Force Alternative models to use hour-by-hour processing. Adapting to variations in ambient Temperature and Velocity | mforcehbh | -- | 0 | 0 | |
| Force NOSTD for alternative Models. AER always uses NOSTD. (0-NOSTD not used,1-NOSTD) | mnostd | -- | 0 | 0 | |
| Multi-Source (do no use NOSTD) (0-NOSTD will be used,1-NOSTD not used) | mmultisource | -- | 0 | 0 | NOSTD is used and pseudo-height Hs already compensated |
| 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 | |
| Force Terrain (1=Parallel only; 2=Elev only; 0=Both Default) | mforceterrain | -- | 0 | 0 | |
| Flame-out Sour Gas Venting Source (0-combustion, 1-flameout) | mflameout | -- | 0 | 0 | |
| H2S emissions are odour units/s (0-(g/s), 1-(OU/s)) | modourunits | -- | 1 | 1 | H2S Emissions are (OU/s) |
| Force all stripped H2S to cold stream (1-Yes, 0-No) | mforcestrip | -- | 0 | 0 | |
| Use Delta-T Method for Flares (1-Yes, 0-No) | mdeltat | -- | 0 | 0 | |
| Fuel Gas Rate (1=Proportional; 2=Constant) | mfgr | -- | 1 | 1 | Fuel Gas is Proporional |
| DEM always download files (1-Yes, 0-No) | mdemget | -- | 0 | 0 | |
| LCC always download files (1-Yes, 0-No) | mlccget | -- | 0 | 0 | |
| Temperature at Minimum Orifice Diameter (at Exit) is Forced to Ambient Temperature (1-Yes, 0-No) | mmindialoc | -- | 0 | 0 | Blowdown uses choked temperature, Tei |
| Use Canadian 2002 Land Coverage Files (1-Yes, 0-No) | mLandUse2002 | -- | 0 | 0 | |
| Default Calculation Mode (0-Automatic, 1-SemiAutomatic) | mCalculationMode | -- | 1 | 1 | |
| Prevents message box dialogues (1-Yes, 0-No) | mquiet | -- | 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.

## iSTART Page
## Program settings and switches

**1 ADVANCED SETTINGS**

| Are these flaring calculations for an ambient air quality evaluation or for a | ⊙ Permit | Sele perm |
|---|---|---|

## MQUICK

## MRUNBAT

The *AERflare* model creates a small batch file that is used to call the *AERMOD* program and link it to the temporary filed 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.

## MUSEPARENTFOLDER

## 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 mrunbat=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.

# MEXPORTOUT

The mexportout option applies to batch mode operations. Setting mexportout causes *AERflare* to create additional output files. The output files contain the predicted concentrations at each receptor point for each of the modelled scenarios (see **RUNFLAGS**). An output file is produced for un-adjusted time averages and an output file is created for the adjusted time averages for the one-hour predicted concentrations. The adjusted time averaged predictions account for flaring events with a duration less than one hour.

## MDEBUG

The mdebug setting turns on the DEBUGOPT debug setting to the AERMOD input files. This setting can be useful for outputting additional information during modelling runs. Additional output files are created in the parent or working folder with suffixes of `_debug_model.lst` or `_debug_meteor.lst`.


## MDEBUGDUMP_HBH

The mdebugdump_hbh setting is used to create debug output for the hour by hour meteorological processing. The file lists the hour by hour source characterization and efficiency.


## 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, MLOWWIND

The mmetustar, mlowwind settings are used to control the beta configuration of AERMET and AERMOD low wind processing options. mmetustar, and mlowwind 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 wsmin, however, these latter values can be user selected for testing purposes in the Non-Defaults Settings area.

# MD1HM

The md1hm setting is used to change from typically 24h average concentration predictions to daily first highest maximum concentration output. The D1HM is becoming a common threshold statistic in some regulatory environments.

# MVARRAD

The mvarrad setting is used for alternative modelling. The mvarrad setting uses variable radiation heat loss for flares that is a function of the heating value of the flared gas. This methodology follows the Ontario MOE (Ontario 2021) flaring guidance. The default for *AERflare* does not use this setting but uses a fixed value of flarerad=0.25. The mvarrad setting is automatically selected when using the mpseudo=3 option for Ontario MOE pseudo-parameters.

| MW (kg/kmol) | f, fraction of Heat Loss |
|:---:|:---:|
| ≤20 | 0.25 |
| ≤35 | 0.3 |
| ≤50 | 0.35 |
| ≤65 | 0.4 |
| ≤80 | 0.45 |
| ≤95 | 0.5 |
| >95 | 0.55 |

Table 1: Technical Bulletin: Modelling Open Flares under O.Reg. 419/05 (2017)

# MPSEUDO

The mpseudo settting is used to select alternative regulatory pseudo parameters for flare sources. The default setting is to use the *AERflare* methodology that conserves mass, momentum flux and buoyancy flux. The alternative models (US EPA, Ontario MOE and British Columbia MOE) methods do not conserve momentum flux or buoyancy flux and will result in the incorrect plume heights used for the assessment. Additional details of each of the pseudo parameter settings can be found in the *AERflare* technical reference document.

| mPSEUDO | Parameters | Reference |
|---------|-----------|-----------|
| 1 | (DEFAULT) *AE Rpro* | *AERflare* technical reference document |
| 2 | US EPA | US EPA 1986 |
| 3 | Ontario MOE | MOE 2017 (draft 2021) |
| 4 | British Columbia, MOE | BC MOE 2015 |

# MFORCEHBH

In conjunction with the mpseudo setting, the mforcehbh setting can be used to the modelling to use hour by hour processing. Because the flare source parameters are function of the meteorology, principally the wind speed, the hour by hour processing more accurately represents the source and impacts from flare source. The mforcehbh setting forces the modelling to use the hour by hour approach. This setting uses the hour by hour wind speed and temperature for the calculation of the source parameters. Models such as U.S. EPA, Ontario MOE and BC MOE do not vary the effective height as a function of wind speed, but instead calculate it based upon a fixed 45º angle which may not be representative for all flares (especially lower exit speed flare emissions or high wind speeds).

# MNOSTD

The mnostd setting is used to force the use of the AERMOD control NOSTD. The use of flare source pseudo-parameters requires that NOSTD must set in the AERMOD input file. AERMOD uses the user input of stack diameter to calculate the effects of stack tip downwash. Because the pseudo parameter for a flare is not the real-world stack diameter, the down wash calculated based upon the pseudo diameter (which may be large) will grossly over predict the impacts of down to the point of bring the effective stack height to ground level. *AERflare* adjusts the effective height of the stack on an hour by hour basis accounting for the down wash using the real-world diameter. When mnostd setting is used, AERflare makes the stack tip down wash adjustment for the hour by hour wind speed for all of the psedo-parameter models or using the average wind speed (see average wind speed setting on **iSTART** page) for non-hour by hour assesments.

# MMULTISOURCE (*BETA*)

The mmultisource is a beta option that that adjusts the effective stack when flares are modelled with other non-flare source in the same AERMOD modelling run and where the NOSTD option is not used. In this case, the flare being

modelled with pseudo source parameters must have the effective height pre-adjusted higher according to the effect of stack tip downwash using the pseudo diameter. When modelled in AERMOD, the flare effective height would be adjusted lower for stack tip down wash according to the pseudo diameter, thus reversing (cancelling) the adjustment. The mmultisource setting assumes non-hour by hour assessment, and makes the adjustment based upon the peak wind speed (by default this wind speed is peakwind=30 m/s). The peak wind speed should be site-specific.

# MSCREEN

The mscreen 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 mscreen setting only affects the AERMOD-XXX button calculations.

# MELEV

The melev setting is used in connection with the `Get DEM Data` 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.

# MFORCETERRAIN

The mforceterrain setting forces the modelling to only use elevated terrain (mforceterrain=2), only use flat terrain (mforceterrain=1). The default setting is (mforceterrain=0), is to perform both the elevated and flat terrain modelling

for the screening modelling. AERMOD uses a model that keeps the plume height at a constant elevation for terrain heights lower than the stack base elevation height. This phenomenon may occur in a strongly stratified atmosphere (very stable) but not always. Otherwise, the plume elevation above ground will appear to be terrain following. Therefore, the elevated terrain option can underpredict concentrations in these cases. AERMOD modelling guidance recommends that the model be run, using both flat terrain and elevated taking the conservative predictions for results. This modelling guidance is not enforced in *AERflare* for refined terrain assessments but is strongly recommended.

> AERMOD modelling guidance recommends that the model be run, using both flat terrain and elevated taking the conservative predictions for results.

## MFLAMEOUT

The mflameout setting can be used to model the flares in the flame-out scenarios. It is recommended that a hazard model (such as HGSYSTEMS) be employed for near source impacts and flammability in addition to AERMOD modelling that accounts for other atmospheric phenomenon not included in hazard models.

When mflameout setting is used, the $SO_2$ modelling group is changed to a total mixture pollutant with the relevant objective being the LFL (lower flammability limit). The lower flammability limit is typically expressed as in volume concentration units (ppm) but the AERMOD output is in mass concentration ($\mu g/m^3$). A threshold value in mass concentration is calculated on the **oCALCFLARE** page in the *Combustion Products* group.

AERMOD modelling uses units of $mg/m^3$ instead of $\mu g/m^3$ to accommodate the higher concentrations in the input/output fields.

## MODOURUNITS

The modourunits setting changes the AERflare emissions modelling from mass emissions to odour units (dilution) emissions. Odour units modelling is proving be better represent the impacts from odours than mass emissions modelling. Odour modelling requires the reference threshold concentration to be specified (see odourthreshold setting). The objectives for odour units are not well defined, however, outputs greater than 1 indicate an odour. An objective of 3 OU/m³ representing the range (1-10) and represents strong odours. Absolute maximum tolerable levels are in the range 50-1000 and vary by pollutant. A limit in

*AERflare* set at 500 OU.m$^3$ for non-routine unplanned and 30 OU/m³ for other non-routine modelling.

AERMOD modelling uses units of mg/m³ instead of µg/m³ to accommodate the higher concentrations in the input/output fields for Odour units.

## MFORCESTRIP

Stripped gas from the flare tip is divided into a hot stream and cold stream. The hot stream is assumed to have buoyancy and travels with the exhaust gases. The cold stream does not have buoyancy and may contribute to ground level odour issues. The mforcestrip setting is an advanced setting to force all of the stripped gas to be in the cold stream.

## MDELTAT

The mdeltaT setting is used for AERMOD modelling forcing the source temperature of the source to be a constant value above ambient temperature. This AERMOD feature has not yet recommended for *AERflare* flare sources but may be used in some incinerator scenarios. When using pseudo-source parameters for flares are are based upon combustion calculations where the exit temperature maintains the same difference relative to ambient temperature. The pseudo-parameters are calculated based upon the estimated temperature, therefore, the temperature cannot be specified independent of the other parameters.

## 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.

# MMINDIALOC

For a blowdown scenario, the mmindialoc setting controls the temperature at minimum orifice diameter is forced to ambient temperature (1-Yes, 0-No).  The minimum orifice diameter is the limiting area that controls the flow the flow. The location of the orifice being either the flare tip or some other location.  When the the mmindialoc=0 and the blowdown (mblowdown=2) and the source is a vessel (mTransient=1), the gas temperature is calculated from initial conditions at the exit for the vessels.  The calculations are performed on the **oBLOWDOWN** page.

# MLANDUSE2002

The mlanduse2002 setting is used to force *AERflare* to use the Canadian circa 2002 land use map sheets. Recently, 2010 and 2015, the land use files for North America have been updated to use single country-wide raster land use files. These files can be downloaded and *AERflare* have been optimized to scan these large files efficiently. In the event that the older 2002 files are still required, the mlanduse2002=1 setting tells *AERflare* to download and process the shapefiles. It is anticipated that the 2002 land use files (see URL link on the **iBIN** will be phased out)

# MCALCULATIONMODE

The mcalculationmode setting sets the default EXCEL calculation model to be either automatic or semi-automatic. *AERflare* turns off calculations on spreadsheets during some operations to increase speed and returns the calculation mode to the previous setting.  However, if an error occurs, or if the user has selected the manual mode for some other reason, *AERflare* cannot function appropriately.  Therefore, *AERflare* will force the calculation model to be either automatic (all fields are calculated) or semi-automatic (all fields except data tables).  The *AERflare* spreadsheet includes some data tables which require extra processing and can significantly delay calculations. It is recommended to use the semi-automatic calculation mode as the default setting and update data tables as required by pressing F9, when viewing the data table.

# MQUIET

The mquiet setting is used to prevent the display of message boxes. This setting can be useful when in running batch mode so that *AERflare* keeps running even

though an error occurred. The user should carefully review of the **oBATCH** output if the results are still valid.

## 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).

## 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 **oAERMOD** page (row 3). The run flags are set internally according to the Non-Routine flare air dispersion modelling (3 scenarios of $SO_2$ and 3 scenarios of $H_2S$ are performed) or Routine flare air dispersion modelling (1 scenario of $SO_2$ and 1 scenario of $H_2S$ 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 **oAERMOD** 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 **oAERMOD** 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 though 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.



The non-default settings block is shown in the figure below.

| Description | Variable | Units | Inputs | Default | |
|---|---|---|---|---|---|
| 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/m³ | 450 | 450 | |
| SO$_2$ 24h Air Quality Objective | obj_24h_so2 | µg/m³ | 125 | 125 | |
| SO$_2$ Annual Air Quality Objective | obj_annual_so2 | µg/m³ | 20 | 20 | |
| H$_2$S 1h Air Quality Objective | obj_h2s | µg/m³ | 14 | 14 | |
| H$_2$S 24h Air Quality Objective | obj_24h_h2s | µg/m³ | 4 | 4 | |
| H$_2$S Odour 1h Air Quality Objective | obj_h2s_odour | OU/m³ | 3 | 3 | |
| H$_2$S Odour 24h Air Quality Objective | obj_24h_h2s_odour | OU/m³ | 1 | 1 | |
| H$_2$S odour threshold | obj_odour | ppb | 1 | 1 | |
| Risk Based Criteria for Modelling Predictions (Routine) | rbc | -- | 99.9087 | 99.9087 | |
| Risk Based Criteria for Modelling Predictions (Unplanned) | rbc_planned | -- | 99 | 99 | |
| Risk Based Criteria for Modelling Predictions (Planned) | rbc_unplanned | -- | 90 | 90 | |
| Receptor Resolution for Maximum Concentration | dxmin | m | 20 | 20 | |
| Raw, Fuel and Lift Gas Temperature before Combustion | tginit | °C | 5 | 5 | |
| Flare Radiative Heat Loss | flarerad | -- | 0.25 | 0.25 | |
| 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 | -1 | -1 | |
| Modelling minmum distance for receptor grid | rmindist | m | 100 | 100 | |
| 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 | |
| Minimum number of data point in 24h periods to apply RBC | mndata24 | -- | 328 | 328 | |
| Number of virtual sources for HbH modelling | nsources | -- | 9 | 9 | |
| Flag pole receptor height | zflag | m | 0 | 0 | |
| Radius for AERSURFACE roughness | rrough | m | 3000 | 3000 | |
| Radius for AERSURFACE albedo and bowen ratio | ralbbow | m | 5000 | 5000 | |
| Tag Name for Flare Source in Emissions File | srctag | -- | SOURCE | SOURCE | |
| Incinerator Stack Heat Loss | qlstack | -- | 0.1 | 0.1 | |
| Incinerator Kinetic Design Factor | kfactor | -- | 1 | 1 | |
| Canopy Height for Foliage Damage Assessment | zfoliage | -- | 15 | 15 | |
| Loss factor sudden contraction | kcontraction | -- | 0.5 | 0.5 | |
| Loss factor sudden expansion | kexpansion | -- | 1 | 1 | |
| Flue roughness | eroughness | m | 0.0001 | 0.0001 | |
| Energy Efficiency: Boiler | eta_boiler | -- | 0.8 | 0.8 | |
| Energy Efficiency: Heater | eta_heater | -- | 0.75 | 0.75 | |
| Energy Efficiency: Unknown Engine | eta_engine | -- | 0.35 | 0.35 | |
| Energy Efficiency: Unknown Turbine | eta_turbine | -- | 0.35 | 0.35 | |
| Energy Efficiency: Unknown Incinerator | eta_incinerator | -- | 0.0001 | 0.0001 | |
| Excess Air Peak Efficiency | ea_peakefficiency | -- | 0.1 | 0.1 | |
| Excess Air: Boiler | ea_boiler | -- | 0.5 | 0.5 | |
| Excess Air: Heater | ea_heater | -- | 0.25 | 0.25 | |
| Excess Air: Unknown Engine | ea_engine | -- | 0.4 | 0.4 | |
| Excess Air: Unknown Turbine | ea_turbine | -- | 0.75 | 0.75 | |
| Excess Air: Unknown Incinerator | ea_incinerator | -- | 0.25 | 0.25 | |
| Heat Loss: Boiler | hl_boiler | -- | 0.1 | 0.1 | |
| Heat Loss: Heater | hl_heater | -- | 0.1 | 0.1 | |
| Heat Loss: Unknown Engine | hl_engine | -- | 0.4 | 0.4 | |
| Heat Loss: Unknown Turbine | hl_turbine | -- | 0.25 | 0.25 | |
| Heat Loss: Unknown Incinerator | hl_incinerator | -- | 0.1 | 0.1 | |
| Air Assist - (Air/Air) far entrainment ratio, wt/wt | rairair | -- | 0.35 | 0.35 | |
| HP Fuel Assist - (Air/Fuel) far entrainment ratio, wt/wt | rairfuel | -- | 0.35 | 0.35 | |
| Steam Assist -- (Air/Steam) far entrainment ratio, wt/wt | rairsteam | -- | 0.35 | 0.35 | |
| Run Flags (see switch table above) | myrun | -- | 0 | 0 | |
| User Period Selection (Annual or Month) | mflmon | -- | 1 | 1 | |
| Blowdown Distribution of Mass Option | mdist | -- | 0 | 2 | |
| Draft Air (1=Forced (default), 2=Natural (incinerators)) | mdraftair | -- | 0 | 1 | |
| Blowdown User Entry of Qmax | qmax | -- | blank | blank | |
| Blowdown User Entry of Qtotal | qtotal | -- | blank | blank | |
| Flare Tip High Speed Exit Velocity Check | flagsonicue | -- | 0 | 0 | |
| Manual Override on iUSERMET creation of meteorology | mmanualentry1 | -- | FALSE | FALSE | |
| Changes to these settings are intended for testing or calculations performed outside of Alberta, Canada | | | Min | Max | Min |

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, is used in the calculation of the source parameters at average conditions.

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

$1/8^{th}$ of the maximum design flowrate. *AERflare* uses qmin=qmax/8=0.125 as the flow rate by default. For non-default assessments, a different value can be entered for the qmin flowrate.

# SO2 1h Air Quality Objective

The one hour average ambient air quality objective for $SO_2$ 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.

# SO2 24h Air Quality Objective

The 24 hour average ambient air quality objective for $SO_2$ in Alberta is 125 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.

# SO2 Annual Air Quality Objective

The annual average ambient air quality objective for $SO_2$ in Alberta is 20 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 $H_2S$ 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.

# H2S 24h Air Quality Objective

The 24 hour average ambient air quality objective for $H_2S$ in Alberta is 4 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 Odour Objective

The one hour average odour unit objective for $H_2S$ is 3 based upon strong odours 1-5 range. For other jurisdictions, the ambient objective can be changed. This changes the linkages to references the objective in the RBC and graphics.

## H2S 24h Odour Objective

The 24 hour average odour unit objective for $H_2S$ is 1. For other jurisdictions, the ambient objective can be changed. This changes the linkages to references the objective in the RBC and graphics.

## H2S Odour Threshold

The odour threshold is the $H_2S$ concentration threshold when the odour becomes detectable, 1 ppb. Other health limits such as nuisance or recognition levels can be substituted here.

## Risk Based Criteria – (Routine)

In Alberta, the Air Quality Modelling Guidelines allow for the removal of the eight highest predictions for each calendar year from the predictions for the comparison to the 1h ambient air objectives. The predicted ground-level concentration resulting from routine emissions must meet the ambient air quality guidelines in Alberta at a level less than the 8th highest in nominally 8760 hours of predictions, or equivalent 99.9087th percentile.

## Risk Based Criteria – Planned (non-Routine)

Planned (non-routine) emissions will occur during specific time of day and periods of the year where the impacts can be more specifically predicted. AER Directive 060 allows a lower threshold of 99th percentile for 1h average predictions when comparing to the ambient objective for $SO_2$. The operator must meet the Directive 060 guidelines for using this threshold and the maximum hourly predicted concentration must be less than the Routine criteria

## Risk Based Criteria – Unplanned (non-Routine)

Un-planned (non-routine) emissions are those emissions typically resulting from emergency pressure relief. Directive 060 allows a threshold of 90th percentile of 1h ground level predictions for these rare events when comparing to ambient objective for $SO_2$.

## 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.

# Flare Radiative Heat Loss

The *AERflare* default radiative heat loss for the wide range of typical natural gas typical flames is 25% (API 521). The radiative heat fraction is used for the

purposes of determining the heat loss from the plume for the calculation ground level heat intensity impacts following API 521. The heat loss from the plume is also used in the calculation of the net energy available for plume rise.

## 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, wsmin, 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 SQRT(2*svmin*svmin) used in previous versions. *AERMOD* allows a range of wsmin=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 mlowwind1 or mlowwind2 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 hhdx=200m to determine the maximum terrain elevation near receptors. Therefore, small peaks (less than hhdx) 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. Setting the value to -1, causes *AERflare* to use the native resolution of the terrain elevation data, that is, check every elevation.

## Modelling Minimum Distance for Receptor Grid

The minimum receptor grid distance in Alberta is 20 m to be applied along the fenceline and in the neighbourhood of the maximum concentration. For some applications where the fenceline dividing the publicly accessible airspace from the

on-site industrial airspace is very long and the concentration gradient is low, the minimum distance may be enlarged. This will avoid the numerical issues of excessive large receptor grid files for modelling.

## 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 $2 \times (\texttt{rmaxdist+dombuf})$ by $2 \times (\texttt{rmaxdist+dombuf})$.

## Minimum Number of Data Point in A Period To Apply RBC for a 1h Assessment

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 99.9[th] 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*.

## Minimum Number of Data Point in A Period to Apply RBC for a 24h Assessment

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 99.9[th]

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 (365 hours) a minimum of 90% meteorological data validity is used, mndata24=328. If the number of meteorological daily data points within a year is less than mndata24=365, warning flags are displayed and the meteorological data should be considered suspect for systematic errors.

## 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.

When using the AERflare spreadsheet calculations nsources=3, only. Alternative values can be used when performing advanced modelling using external post-processing.

## Flag pole Receptor Height

The flag pole receptor height is the elevation above local ground level for the predicted concentration outputs. The flag pole receptor height is normally set to zero, ground level. It may be of interest to determine the concentrations at tree top level (15m) for foliage analysis of $SO_2$ impacts.

# Radius for AERSURFACE Roughness

The characterization of the surface roughness for the purposes of determining parameters to describe the meteorology when creating input files for AERMET is performed using a radius with a default of 3 km around the source location. The surface roughness is an important parameter that contributes to the description of atmospheric turbulent mixing for entire modelling domain.  The near source ground level concentrations will be a function of both the upwind and downwind turbulence profiles. The land use files are analyzed on an area basis using the native file format of shape polygons or raster pixel areas based upon the interpretation of the land use and parameterization (see **AERSURFACE** page).

# Radius for AERSURFACE Albedo and Bowen ratio

The characterization of the albedo and Bowen ratio for the purposes of determining parameters to describe the meteorology when creating input files for AERMET is performed using a radius of 5 km around the source location. The land use files are analyzed on an area basis using the native file format of shape polygons or raster pixel areas based upon the interpretation of the land use and parameterization (see **AERSURFACE** page)

# Tag Name for Flare Source in Emissions File

The AERMET modelling input and output files use a tag name for the source. By default *AERflare* uses the name 'SOURCE'. The tag name can be changed to reflect other modelling performed by the user, but has no bearing on the modelling predictions or modelling input/out summary descriptions.

# Incinerator Stack Heat Loss

The closed combustion process of an incinerator occurs typically at near ground level.  The resulting exhaust flows up a stack that is exposed to meteorological convective heat loss. The default heat loss for an incinerator stack is 10%. This assumption may not be valid for some very large incinerators operating at low flow rates, or tall unlined incinerator stacks.

# Incinerator Kinetic Design Factor

The default kinetic design factor for an incinerator is 1.0.  Large incinerators with multi-chamber combustion or post-combustion heaters may have higher kinetic design factors that will increase the conversion of $H_2S$ to $SO_2$ (Klint 2005). *AERflare* uses the formulation of Kilin (2005) based upon larger incinerators in

Alberta to determine the residual $H_2S$ in the emissions. The default value of 1 reflects the lowest level of conversion of efficiency, and it is up to the operator to defend alternative values for this parameter.

## Loss Factor Sudden Contraction

The loss factor sudden contraction is flow loss factor used for the calculation of natural draft for incinerator stacks. The contraction factor expresses the pressure loss for air flow at the damper entrance. The default value is 0.5.

## Loss Factor Sudden Expansion

The loss factor sudden expansion is the flow loss factor used for the calculation of natural draft for incinerator stacks. The expansion factor expresses the pressure loss for air flow exiting the damper. The default value is 1.0.

## Flue roughness

The calculation of natural draft for incinerator stacks incorporates the surface drag of air as it travels up the stack. The flue roughness parameter is an important variable that impacts the natural draft. Corrosion or dirty exhaust may coat the stack and increase the surface roughness. A relatively clean default value of eRoughness=1mm is used. Alternative values of eRoughness are listed in the side margins on page **oCALCINCIN**.

## Excess Air Peak Efficiency

Closed combustion sources require a small amount of excess air (air beyond the stoichiometric requirements) to operate with a peak efficiency. The air for peak efficiency is typically 105%-110% of stoichiometric air, or 5% to 10% excess air. *AERflare* uses a default value of 10% excess for peak efficiency. Normally, much more air is provided. In cases where in-sufficient air is provided, *AERflare* accounts for the in-efficiency by venting the non-combusted gas fraction less than this peak.

## Air Assist - (Air/Air) far entrainment ratio, wt/wt

A high-speed air jet (air in air) will entrain air on a mass basis at a rate that is proportional to the cone angle of the jet. For most jets, the cone angle is very close to 2 tan(8º to 10º). This results in an entrainment ratio of 0.35 in the far field (Medrano et al 2017).

## HP Fuel Assist - (Air/Fuel) far entrainment ratio, wt/wt

A high-speed air jet (air in air) will entrain air on a mass basis at a rate that is proportional to the cone angle of the jet. For most jets, the cone angle is very close to 2 tan(8º to 10º). This results in an entrainment ratio of 0.35 in the far field (Medrano et al 2017).

## Steam Assist -- (Air/Steam) far entrainment ratio, wt/wt

A high-speed air jet (air in air) will entrain air on a mass basis at a rate that is proportional to the cone angle of the jet. For most jets, the cone angle is very close to 2 tan(8º to 10º). This results in an entrainment ratio of 0.35 in the far field (Medrano et al 2017).

# 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 **iSOURCE** 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 **iSOURCE** 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 ($H_2S$), 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 $H_2S$, 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 $H_2S$ release rate during the drilling stage.

The potential $H_2S$ release rate is determined by both the percentage of $H_2S$ 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 $H_2S$ content but still be critical if it is very close to a town. But a gas well with 10 per cent $H_2S$ 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.<br>Acceptable values: W4M, W5M, W6M |

# Mapping Datum and Projection

Mapping projection and datums have been updated in *AERflare* to accept most contemporary options. This change allows *AERflare* the capability to convert digital terrain and land use files in various global formats. The preferred modelling projection used by *AERflare* is UTM. Coordinate conversion datum and projection data are listed on the **DATUM** page.  Datums have both names and codes.  NAR-B is the Canadian datum assigned to datum code 4269, which uses the NAD83 metrics.

# UTM Zone

*AERflare* requires all coordinates to be in UTM projection.  Using UTM projection, 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.
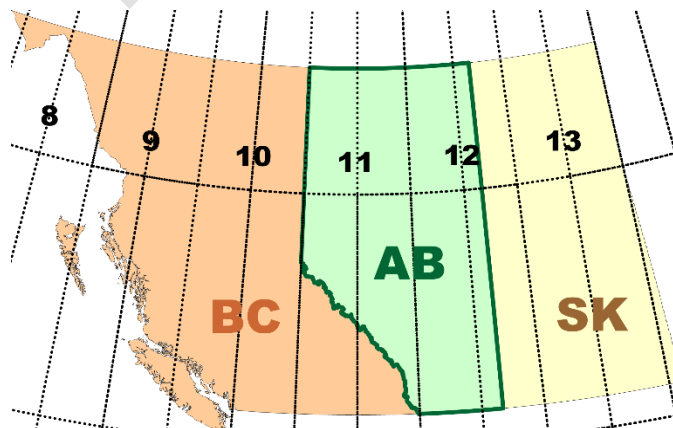


**Figure 2:      UTM Zones for Western Canada**

# 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 datum and 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. Press **REFRESH** to copy the coordinates from the **iFACILITY** page. The **iLOCATION** converts the X,Y coordinates into Longitude/Latitude, UTMX/UTMY pairs and 10TM pairs. The 10TM coordinate projection is an Alberta specific projection useful for mapping and government submissions.

|  | UTM Flare Location | 10TM Flare Location |
|---|---|---|
| X UTM | 481234.0 | -146129.8 |
| Y UTM | 6112345.0 | 6112261.5 |
| UTM Zone | 11 | 10TM |
|  | Conversion to Geographic Coordinates | |
| Longitude | -117.2945 | |
| Latitude | 55.1574 | |
|  | Map File | |
| Map File | 083n | |
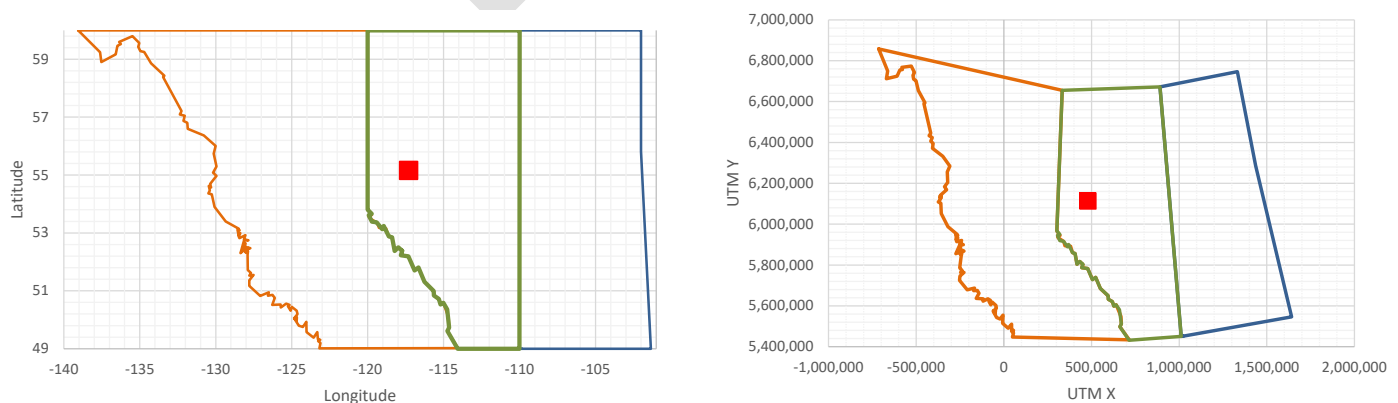


**Figure 3:** **Visual check for X,Y Flare Location Entry in Longitude/Latitude (left) and UTMX/UTMY (right)**

## Source 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. AERflare is configured to use contemporary GeoTiff formatted land-use files that are user selectable. Currently available data set for North America is (www.geobase.ca; circa 2015; based upon Canadian Forestry datasets and Canada Agriculture datasets).

For a screening approach, 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 all locations within BC, AB and SK. The albedo, Bowen ratio and surface roughness was determined for each grid cell and tabulated. Using these screening values, AERflare creates a screening meteorological dataset using land-use profiles that are generally consistent with refined modelling methods. The tabulated method allows for rapid screening.

*AERflare* uses the flare location coordinates to perform a search for the closest land cover sample in the database. 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 create screening dataset using a select of land cover. For approvals using the *AERflare* spreadsheet, the default land cover is required.

Previous versions of AERflare (v2.x) used a simplified land cover (see Figure 5) that reduced the land cover to a single value for the location. That methodology created a large inconsistency between screening and refined modelling, and is no longer used.)
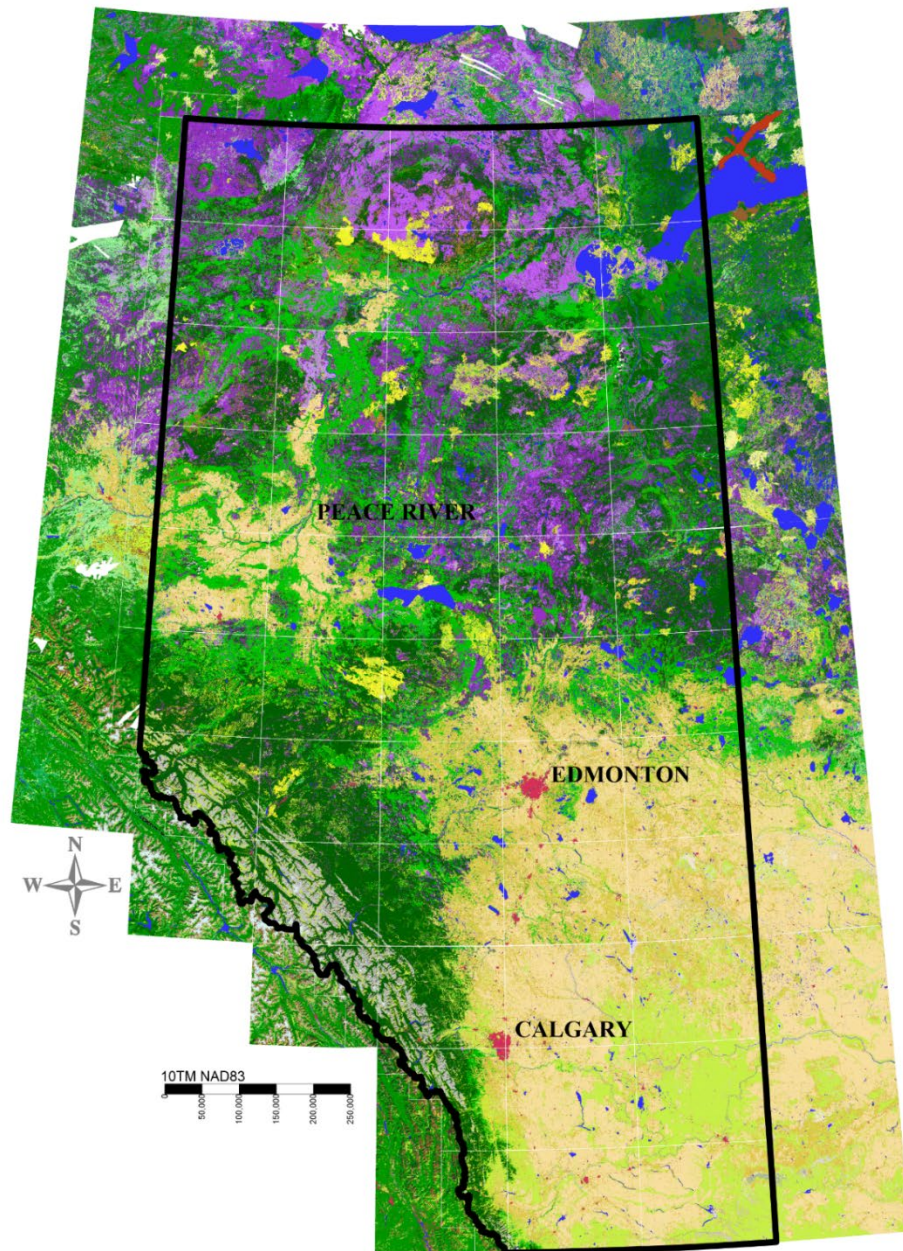
**Figure 4:** High Resolution Land Cover for Alberta (circa 2002)

**Table 1:**  **Land Cover Classification (circa 2002)**

| | 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 | | |

Listed land Cover Codes are from the Canadian (circa 2002) classification
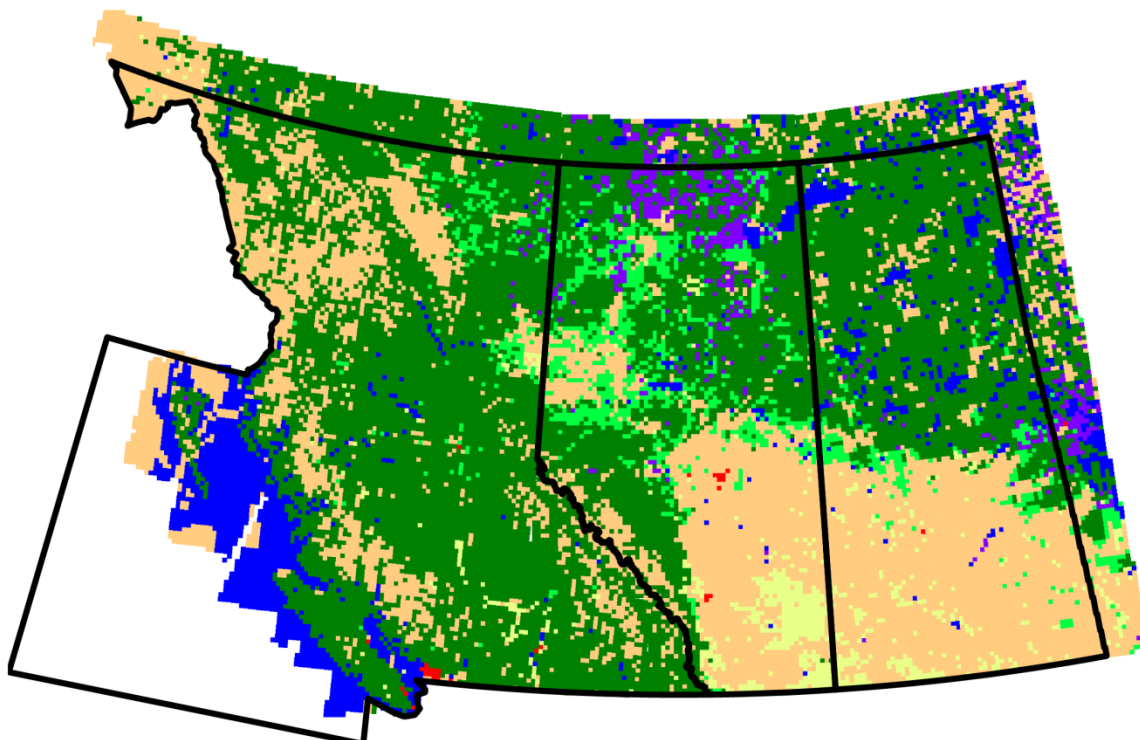
**Figure 5:** **AERflare v2.x Screening Land Cover for Western Canada (Circa 2002)**

**Table 2:** **AERflare v2.x Screening Land Cover Classification (Circa 2002)**

| | | 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 *AERSURFACE* 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 and Table 4. For testing, or application of AERflare outside of Alberta the

temperature ranges listed in Table 4 can be adjusted on the **iSTART** page. The MAKEMET.exe utility creates approximately 2500 variations of meteorology. AERflare creates the screening meteorological files (surface and profile data) in the working folder or spreadsheet parent folder.

**Table 3:**     **Land Cover Codes Used for Single Type Land-Use for Creating Screening Meteorological Datasets with MAKEMET**

| Land Cover | AERMOD Land-Use Code |
| --- | --- |
| Coniferous Forest | 42 |
| Deciduous Forest | 41 |
| Mixed Forest | 43 |
| Shrubland | 51 |
| Cultivated Land | 82 |
| Grassland | 71 |
| Urban | 22 |
| Swamp/Wetland | 92 |
| Water | 11 |
| Quarries/Strip Mines/Gravel | 32 |
| Barren/Rock/Earth Clay | 31 |
| Perennial Snow Cover | 12 |

See page AERSURFACE for Albedo, Bowen Ratio and Surface Roughness for the complete range of land cover, and settings from AERMOD and used within AERflare.

**Table 4:**     **Meteorological Variables Used for Creating Screening Meteorological Datasets with MAKEMET**

| Season | Temp | Minimum | Maximum |
| --- | --- | --- | --- |
| Spring | °C | -48.5 | 38.4 |
| Summer | °C | -10.1 | 39 |
| Fall | °C | -43.9 | 21 |
| Winter | °C | -52.6 | 23 |

- Minimum windspeed 0.5 m/s
- Seasonal Minimum and Maximum temperatures used to create the Screening and Screening[+] meteorology files  (Env. Canada 2002-2006, for Alberta, British Columbia, Saskatchewan)

# 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 $H_2S$ is the product of the gas composition and the estimate absolute open flow (AOF) for the well.

```
[H2S Release Rate] = [AOF] × [mole fraction of H2S]
```

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 **iSOURCE** 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.

# iSOURCE

The **iSOURCE** page is the page where the *AERflare* source parameters are entered for the specific source (flare or incinerator) event being assessed. Whereas, the **iFACILITY** page contained global considerations of the overall work-over operations, the focus on the **iSOURCE** page is on the conditions of an individual emissions source.

The iSOURCE page is divided into several sections

- Source Details – where 'SOURCE' may be 'Flaring' or 'Incineration'. This group contains the inputs to describe the stack heights, diameter, flow rates, pollutant, emission factors, etc.

- Fuel Gas – flares and incinerators may require addition of fuel gas in excess of the raw gas being combusted

- Lift gas – the stream flow for well tests may include injected gas used to promote (lift) gas from the formation or a secondary flow.

- Flare Assist (for flares only) – flares may have additional streams of vapours to the combustion zone including steam, air, or high-pressure fuel

- Gas Composition – the vapour composition of the raw, lift and fuel gas is input.

## Quick Controls

At the top of the iSOURCE page are a group of buttons that allow some commonly used operations.

- ReModel – is a button that opens the oMODELLING page

- SaveToBatch – is a button that saves the current configuration (all inputs and outputs) to a row on the iBATCH page. This provides a complete backup of all the inputs and outputs for later recall.

- ClearAllInputs – is a button that will erase the inputs fields on the iSOURCE page allowing the user to start the configuration of empty

- Reset – is a button that resets internal macro variables and flags to default conditions. This button is useful following an error-state or cancelled operation in which the cursor may be left in 'wait' mode, for example

- LoadFromBatch – is a button that will load the indicated row of data as described by the scenario name from the iBATCH (and outputs from the oBATCH) pages to the inputs and outputs fields throughout the workbook.

# Source Details

The Source Details group will be displayed as 'Flaring Details' or 'Incinerator Details' depending upon the source type selection on the iSTART page.

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

| Flaring Details | UNITS | ENTRY |
|---|---|---|
| Subject Zone or Source of sour gas | | Leduc |
| Scenario Name | such as cleanup or variable such a | Example 1-Same as ERCBflarev1.05 Released |
| Time of Year to Model the Event | -- | Annual ▼ |

## Subject Zone/Source

The well work over may involve several zones. On the **iSOURCE** 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 and used for file names if the output is kept using the mkeep option. In this case, it is helpful if the Scenario Name is selected to be 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 the 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 **oAERMOD** 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.

The SCREENING modelling button (see **oMODELLING**) will be disabled when the monthly assessment option is used. Note that monthly assessment using screening meteorological data sets will produce erroneous results since the format of the meteorological data dates and times do not match calendar dates.

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.

# Pollutant

*AERflare* was originally designed for processing sour gas operations with a particular focus on sulphur dioxide ($SO_2$) dispersion. The $SO_2$ emissions are a function of the sour gas composition ($H_2S$) and the conversion efficiency achieved in the open flame combustion process (flare) or closed flame incineration process. *AERflare* now allows also includes $NO_x$, CO, $PM_{2.5}$, VOC or user pollutants. These pollutants are estimated based upon emission factors and are not calculated based upon combustion conversion calculations.

The emission factors can be expressed in terms of energy input or flow. *AERflare* converts the emission factors to g/GJ (HHV) of the combusted mixture stream.

| User Pollutant Name | -- | | | |
|---|---|---|---|---|
| Emission Factor Group Name | EPA-Flaring | 1 | EPA-Flaring  ▼ | |
| | | User Over-Ride | Emission Factor | Emission Factor Used |
| NOx, Emission Factor | g/GJ | | 33.150 | 33.150 |
| CO, Emission Factor | g/GJ | | 151.127 | 151.127 |
| VOC, Emission Factor | g/GJ | | 68.251 | 68.251 |
| PM2.5, Emission Factor | g/GJ | | 58.501 | 58.501 |
| User, Emission Factor | g/GJ | | | 0.000 |
| | | | | |
| | | | | |
| | | | | |

The emission factor drop-down selection box can be used to select the source type or emission factor grouping. The emission factors are listed on the EF page. The EF page lists several default emission factors based upon AP 42 emission factors. The user can add site-specific values to the EF page using the existing entries as a guide paying close attention to the format of the units and Basis for Emission Factor. The Basis for Emission Factor is listed for AP 42 emission factors is generally a 'typical' natural gas HHV value. The AP 42 emission factors must be adjusted to the site-specific HHV as performed in the AERflare calculations for the user.

Some regulatory environments request the emission factors listed in g/kW-h units; and this conversion is provided on the **oMODELLING** page.

For sour gas operations, the Requested Maximum Raw Gas $H_2S$ Concentration is a required entry. The requested $H_2S$ concentration may be different than the $H_2S$ concentration entered (see later) in the raw gas composition. The raw gas composition is re-normalized to the requested $H_2S$ concentration. For the Subject Zone, the maximum $H_2S$ concentration of the gas composition (entered in percent, %). The maximum $H_2S$ concentration does not have to match the reference composition provided in the gas composition (lower portion of **iSOURCE** page) but should be greater than or equal to it in typical situations.

# Physical Source Parameters

## Stack Tip Exit Height

The flare stack height above grade elevation is entered.

The meteorological conditions at the 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.

| Physical Source Parameters | | | |
|---|---|---|---|
| Stack Tip Exit Height | m | 30.5 | |
| Stack Tip Diameter, $D_f$ | mm | 305 | |
| Unobstructed Flow Diameter, $D_{unob}$ | mm | 305 | |
| Lift Gas, Secondary Stream, $D_{lift}$ | mm | | ☑ Individual Stream for Lift |
| Fuel Gas, Secondary Stream Diameter, $D_{fuel}$ | mm | | ☑ Individual Stream for Fuel |

## Stack Tip Exit Diameter

The stack tip exit (inside) diameter is a physical parameter that effects the real exit velocity at the stack tip. The outside diameter will impact the stack tip downwash, although most dispersion models use the inside diameter.  AERflare requires the unobstructed effective inside diameter $D_{unobs}$ which is used to in the calculation of momentum and real velocity.  AERflare also requires the 'effective physical diameter' at the stack tip $D_f$ which is used in the calculation of stack tip downwash.

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. Flare stack tip designs vary considerably, and may include multiple injection tubes, support bars or flow stability tabs. The **FLARETYPES** page provides images of the common flare types as well as sample calculations to assist in the calculation of $D_{unobs}$.

For flares, the lift gas stream or the fuel gas stream can be injected as an independent stream to the top of the stack. This may occur if: ring-burner like fuel is provided; or a combined LP/HP system with a separate HP annulus flow configuration is used.  In these cases, the momentum of the gas stream for each stream must be accounted for. For additional input variations, the Lift gas inputs can be used for various fuel gas streams. In these cases, the check boxes are checked for Individual Stream for Lift (mDLIFT) and/or Individual Stream for Fuel (mDFUEL).

## Non-Flare Source Types: Incinerator

For non-flare source types including incinerators, the input group shown below is un-grayed providing inputs to describe the source. The source type is selected

from the drop-down box. A check box (see far right) can be used to synchronize the emission factors entered previously in the **Pollutants** entry group.

| | | | | |
|---|---|---|---|---|
| Emission Source Type | -- | Incinerator ▼ | | ☑ SYNC Source Type and Emission Factors |
| Equipment Make and Model | -- | ACME | | Enter 'BOILER', 'HEATER' or 'ENGINE' or incinerator make |
| Incinerator Burner Height | m | 1 | | Highest burner height above grade |
| Stack Inside Diameter at Burner | mm | 2000 | | May be different than stack exit diameter |
| | | | | |
| mDraftAir (1=Forced,2=Natural) | -- | ⦿ 1. Forced Draft ○ 2. Natural Draft | Enter Excess Air Below | |
| Rain Cap or Horizontal | -- | ⦿ 1. Vertical ○ 2. Rain Cap ○ 3. Horizontal | | |
| Heat Loss Before Stack Bottom | % | 0.01% | User Selectable | Enter the work energy heat lost. For incinerators this energy may be negligible. |
| Is the Stack Top Temperature controlled? mSTTControl (1=No, 2=Yes) | -- | ⦿ No ○ Yes, STT Control | | |
| Is the Oxygen in exhaust flow controlled? mO2Control (1=No, 2=Yes) | -- | ○ No ⦿ Yes, O2 Control | | |
| Is the excess air flowrate controlled? mControl (1=No, 2=Yes) | -- | ○ 1. Fixed for Qmax flow ⦿ 2. Variable | Air flow is controlled as a function of flow rate | |
| | **Qmax** | **Qave** | **Qmin** | |
| Heat Loss before Stack Top May be adjusted by calcs | 10.000% | 22.643% | 8.632% | |
| Controlled Stack top temperature (°C) | | | | |
| Controlled Oxygen Level in Exhaust | 10.0% | 15.0% | 15.0% | If the incinerator exhaust O2 levels are controlled: enter the O2 levels, then press Calculate Excess Air for %O2 to calculate required excess air |
| Excess Air (%) | 82.2% | 225.6% | 225.6% | Excess air will increase as flow rate decreases unless secondary air damper adjusted Ratio of {(actual air - stoichiometric air) / stoichiometric air} Varies with flow rate, 100% is typical |
| Natural Draft Damper Area (Fraction of Burner Region Area) | | | | |
| Are Excess Air Calculations Current? | TRUE | TRUE | TRUE | Excess Air Calculations |
| Estimated Exhaust dry % O2 | 10.0% | 14.9% | 14.9% | |
| Estimated Stack Top Temperature (°C) | 1135.83 | 604.91 | 705.68 | |
| Air required at Pref and Tref (scfm) | 19740 | 14108 | 4409 | |

# Equipment Make and Model

This field is text description of the equipment (incinerator) make and model for reference. It is a good idea to include the energy rating and tags that may describe other specifications such as lean burn, low NOx, turbo charging, or catalytic conversion.

# Burner Height

The burner height above grade elevation is used in the calculation of residence time for the estimation of hydrogen sulphide ($H_2S$) conversion efficiency. The distance between stack top and burner height divided by the stack velocity is the residence time. Longer residence time allow the time dependent conversion of $H_2S$ to $SO_2$ at lower temperatures. A negative burner height can be entered to account for side or bottom burner duct designs.

## Stack Inside Diameter at the Burner

The stack inside diameter at the burner dimension is used to determine active incinerator volume. The volume is determined from a cone from the top of the stack burner to the stack top using the nominal inside diameter of both ends.

## Fractional area of the flue of burner at Burner Height (mDRAFT = Natural Draft)

The calculation natural draft for an incinerator requires the free-flow area. The burner area that obstructs the flow up the chimney is entered here as a fraction of the total flow area at the burner. Typical values may be 30% to 50%.

## Draft Air Method (mDRAFT)

The induced air required for incineration combustion may be forced air (fans) or natural draft. The natural draft relies upon the stack effect flow of hot gases up the chimney to draw air into the stack burner through natural draft dampers. The careful setting of the damper area controls the air available for combustion and the temperature of the incinerator.

When forced draft is selected, the excess air must be specified by the user in the fields below.  When natural draft is selected, the flow in the stack must be solved by iteration to determine the excess air achieved by the damper settings. The damper contraction and expansion coefficients are set on the **iSETTINGS** page (kcontraction and kexpansion). Check the 'Are Excess Air Calculations Current'. The button Excess Air Calculations is used to calculate natural draft flows. The calculations can be viewed on the **oCALCINCIN** page in a calculation group of the same name.

The calculation of natural draft may return an error when a solution cannot be found for the given configuration. In general, when the proposed flow of raw gas is large compared to the stack height, diameter and/or damper area, then a solution for natural draft cannot be found. Try lowering the flow rate of combustion gas in the stack or increasing/decreasing the damper area until a solution is found; then iterate the flow or other setting to determine the allowable operation envelope.

## Rain Cap or Horizontal

For non-incinerator stacks the stack may be vertical, horizontal or may have a rain-cap.  The mRainCap setting selects between these options. This setting in turn sets the *AERMOD* source control setting.

A rain cap deflects the vertical flow and effectively removes the initial source momentum after the exit and before plume rise. Stack-tip down wash calculations are applied to rain cap emissions.

The horizontal source option assumes that horizontal release is aligned with the wind direction for each hour. The horizontal source velocity is used in the PRIME integral plume rise calculation used in the determining the effects of building downwash and dilution.

# Heat Loss Before Stack Bottom

The energy (fuel) input of the source contributes to plume rise through the heat released from combustion. Work energy (boilers, engines, turbines) may be extracted from the energy input and may otherwise be lost through heat (engines water jacket, oil coolers, etc). The heat loss before the stack bottom is reflected in the efficiency of the process. For 100% efficient process, all of the input energy is transferred to useful work and no heat energy goes up the stack, and for a 0% efficient process, none of the input energy is transferred to useful work energy and all of the energy goes up the stack. Typical values are listed in the table below. For incinerators, the heat lost before stack bottom is set to a non-zero but negligible value since all or most of the heat is directed up the stack. For boilers and heaters, 80% or 75%, respectively, are typical efficiencies for the input energy consumed in useful work.

| Recommendations | Efficiency | Excess Air | Stack Heat Loss |
|---|---|---|---|
| Boiler | 0.8 | 0.5 | 0.1 |
| Heater | 0.75 | 0.25 | 0.1 |
| Unknown Engine | 0.35 | 0.4 | 0.4 |
| Unknown Turbine | 0.35 | 0.75 | 0.25 |
| Unknown Incinerator | 0.0001 | 0.25 | 0.1-0.3 |

# Stack Top Temperature Control

The mSTTControl setting allows the user to select between the option of Stack Top Temperature is controlled to a user setting (see below) or no control. When mSTTControl is selected, the excess air is adjusted until the Stack Top temperature matches the user setting.

If the mO2Control setting is set to control dry O2% in the exhaust, then the mSTTControl will adjust the stack heat loss so that the Stack Top temperature matches the user setting. Typical stack heat loss will range between 10% to 30%;

therefore, it may be necessary to add or remove fuel gas in order to find a solution.

# Exhaust Oxygen Control

The mO2Control setting allows the user to select between the option of oxygen in exhaust control or no control. When the mO2Control is selected, the excess air is adjusted so that the dry O2% in the exhaust matches the user setting.

# Excess Air Flowrate Control

When neither the mSTTControl nor the mO2Control settings are used, the user may enter the excess air fraction for each of the Qmax, Qave and Qmin flows when the excess is controlled, see mControl setting. When mControl setting is set to Variable, the incinerator is either manually or automatically controlled so that excess air is a function of the Qmax, Qave and Qmin flows. When mControl setting is set to Fixed, the excess air for the incinerator is set to a fixed value for the operation at Qmax flow, and the air delivered for Qave and Qmin will be the same amount, resulting in high excess air percentages.

# Excess Air Calculations

## *Heat Loss Before Stack Top*

Process engineering refers to the term *stack losses* as energy not transferred to work energy. Any energy not producing useful work energy, is a loss and are lumped together in the term stack loss. However, in the context of air dispersion modelling, stack losses are the energy lost from the flue gases between the stack bottom and stack top. Stack losses in this context is the energy transmission from the stack due to radiation and convection, and not available for useful plume rise and lower ground level concentrations.

Flue gases lose energy from stack heat losses through conduction, convection and radiation to the ambient environment. Typical heat losses from stacks are listed in the table above and are stated as a fraction of the input energy. Tall stacks without insulation may result in much higher losses, resulting in less energy available for plume rise. The heat loss from stacks is a function of ambient wind speed. Stack losses from engines include heat loss in the muffler and catalytic converter.

If both temperature and dry O2% are controlled, then the solver determines both the excess air required and the heat loss from the stack. Other wise the default or user entered heat loss from the stack is used.

## Controlled Stack Top Temperature (°C)

When the temperature at the stack top is controlled, enter the stack top temperature for each of the Qmax, Qave and Qmin flowrates. The Excess Air Calculations button will calculate the required excess air so that the combustion and heat losses result in the prescribed stack top temperature for each flow rate.

If mControl is set to 'fixed for Qmax Flow', then only the stack top temperature at the Qmax flow is entered. In this case, The Excess Air Calculations button will calculate the required excess air for the Qmax flowrate, and the Qave and Qmin flowrates will adopt the same amount of excess air. Generally, if the excess air for the incinerator is not controlled, the excess air for the Qmax and Qmin flowrates will be too large resulting in low stack top temperatures.

## Controlled Stack Top Dry Oxygen (%)

When the dry $O_2$% at the stack top is controlled, enter the dry $O_2$% for each of the Qmax, Qave and Qmin flowrates. The Excess Air Calculations button will calculate the required excess air so that the combustion and heat losses result in the prescribed dry $O_2$% in the exhaust for each flow rate.

If mControl is set to 'fixed for Qmax Flow', then only the dry $O_2$% at the Qmax flow is entered. In this case, The Excess Air Calculations button will calculate the required excess air for the Qmax flowrate, and the Qave and Qmin flowrates will adopt the same amount of excess air. Generally, if the excess air for the incinerator is not controlled, the excess air for the Qmax and Qmin flowrates will be too large resulting in high dry $O_2$%.

## Excess Air (fraction)

When neither the stack top temperature nor dry O2% in exhaust controls are in place, then the excess air fraction for internal combustion equipment is a user entry and can be tuned for peak performance of site-specific operations. Typical excess air values (stated as a fraction of stoichiometric air) are listed in the table above. Excess air must be stated for each of the Qmax, Qave and Qmin operation levels. For heaters, boilers, engines and turbines, only the Qmax rate is relevant since the equipment is typically operated at full rate.

If mControl is set to 'fixed for Qmax Flow', then only the excess air at the Qmax flow is entered. In this case, The Excess Air Calculations button will calculate the required excess air for the Qmax flowrate, and the Qave and Qmin flowrates will adopt the same amount of excess air.

## Natural Draft Damper Area

The natural draft damper area is the total inlet area available for air inlet to the stack for natural draft calculations.  The draft area is stated as a fractional area of the burner area at burner height. If more than one damper port is present, enter the cumulative damper area for all ports.

If mControl is set to 'fixed for Qmax Flow', then only the dry $O_2$% at the Qmax flow is entered. In this case, The Excess Air Calculations button will calculate the required excess air for the Qmax flowrate, and the Qave and Qmin flowrates will adopt the same amount of excess air.

## Calculations Current Flag

The Calculations Current Flag is used determine if the current set of source parameters has affected the calculations for excess air. When any of the Qmax, Qave or Qmin flags are set to FALSE, then the user should press the Excess Air Calculations button to calculate the required excess air.

## Estimated Exhaust Dry O2%

For reference, the estimated exhaust dry $O_2$% for each of Qmax, Qave and Qmin are displayed.  The calculations may be found on the **oCALCINCIN** page.

## Estimated Stack Top Temperature (°C)

For reference, the estimated stack top temperature for each of Qmax, Qave and Qmin are displayed.  The calculations may be found on the **oCALCINCIN** page.

## Air Required at Pref and Tref (scfm)

For reference, the estimated flow rate of air required for each of Qmax, Qave and Qmin are displayed.  The calculations may be found on the **oCALCINCIN** page.

## Excess Air Calculations - Button

The Excess Air Calculations button should be pressed whenever the 'Are Excess Air Calculations Current?' flag(s) is set to FALSE. This button executes a solver to determine the excess air required to match the user selected stack top temperature or dry $O_2$% in the exhaust.  If both temperature and dry $O_2$% are controlled, then the solver determines both the excess air required and the heat loss from the stack.  Other wise the default or user entered heat loss from the stack is used.

# 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?** | ⊙ Continuous or Steady<br>○ Transient |

## Continuous or Short-Term Steady

For non-routine flaring assessments three emissions modelling scenarios are considered: maximum ($Qmax$), average ($Qave$) and a low rate ($Qmax/8$); therefore, two sets of inputs are required to define $Qmax$, $Qave$, and $Qmin$. The user must enter the $Qmax$ 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 $Qmax$ entry is $15 \times 10^3 m^3/d$. The user has entered two of the remaining fields, Average Flow Rate=$Qmax/2$=$7.5 \times 10^3 m^3/d$ and the duration of flaring, Duration=72 hours. The total flared Volume=$22.5 \times 10^3 m^3$ is calculated from Average Flow Rate and Duration.

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

## 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 (sm$^3$, reference conditions 15 'C and 101.325 kPa) to be flared during the flaring of this zone.

## Average Flow Rate

The flow rate ($\times 10^{3}$°m³/d, reference conditions 15 'C and 101.325 kPa) is the average flow rate during flaring of this zone.  An estimate of the average flow rate is Qmax/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 Qmax, Qave and Qmin scenarios.

| Fuel Gas | UNITS | ENTRY | WARNINGS |
|---|---|---|---|
| Is Fuel Gas Added? | Last resort, see D060 7.4(4a) | ◉ Yes   ○ No | Adjust Fuel Gas to Raw Gas Ratio manually in Cell C93-E93, then check dispersion results |
| Is the fuel gas rate controlled mfgr (1=Fixed, 2=Controlled, 3=Fixed Rate) | -- | ○ 1. Fixed for Qmax flow<br>◉ 2. Variable<br>○ 3. Fixed Rate | Enter the FGR for Qmax,Qave,Qmin flows |
| | Maximum (QMAX) | Average (QAVE) | Minimum (QMIN) |
| Fuel Gas to Raw Gas Volume Rate Ratio (default is zero) | 0.3 | 0.1 | 0.2 |
| Fuel Gas Rate 10³m³/d (15°C and 101.325 kPa) | 30 | 2 | 2.5 |
| | | | |
| Warnings | Required FGR: 1.418 | Required FGR: 1.418 | Required FGR: 1.418 |

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 **iSOURCE** entries such as gas composition, flow rates, lift gas and/or flare assist.

## MFGR

The mfgr setting selects between the fuel gas ratio (FGR) being proportional to the Qmax flow rate (mfgr=1), being variable (mfgr=2) controlled flow with Qmax, Qave or Qmin, or a fixed flow rate (mfgr=3). When the setting is expressed as a constant rate, the user enters the fuel gas flow rate $m^3$/d, and that fuel rate is added to the modelling scenarios for Qmax, Qave or Qmin. For advanced fuel gas control systems, the rate of fuel gas varies in proportion to the flow rate to the flare automatically (mfgr=1). In the latter case, the inputs to *AERflare* are the desired FGR for each flow ratio.

| Fuel Gas | UNITS | ENTRY | WARNINGS | ADDITIONAL INSTRUCTIONS |
|---|---|---|---|---|
| Is Fuel Gas Added? | Last resort, see D060 7.4(4a) | ◉ Yes    ○ No | Adjust Fuel Gas to Raw Gas Ratio manually in Cell C93-E93, then check dispersion results | MUST input Fuel Gas composition. |
| Is the fuel gas rate controlled mfgr (1=Fixed, 2=Controlled, 3=Fixed Rate) | -- | ○ 1. Fixed for Qmax flow<br>○ 2. Variable<br>◉ 3. Fixed Rate | Enter the Fixed Rate Fuel Flow | |
| | Maximum (QMAX) | Average (QAVE) | Minimum (QMIN) | |
| | | | | Select fuel gas to raw gas volume ratio based on dispersion modelling results. Adding fuel gas increases the heating value to improve combustion and increase plume rise. |
| | | | | |
| Fixed Rate Fuel Gas | 10³m³/d (15°C and 101.325 kPa) | 5 | | |
| Warnings | Acceptable NHV: 30.7 MJ/m³ | Acceptable NHV: 31.1 MJ/m³ | Acceptable NHV: 32.0 MJ/m³ | |

In the example above, the fuel gas is selected to be a fixed flow rate of $5\times10^3$ m³/d which gets added to each of the Qmax, Qave and Qmin raw gas flow rates.

To the right of the fuel gas entry group are two button that can be used to set the fuel gas required to: achieve 98% conversion efficiency; or achieve 20 MJ/m³ LHV of the combustion mixture. If the combustion mixture has a LHV that is greater than 20 MJ/m³, then the calculation result may produce a non-sensical negative fuel gas ratio or a negative fuel gas rate. In this case, turn off the addition of fuel gas.
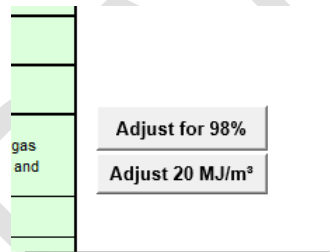


## *Lift Gas*

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 homogenously mixed with the raw gas brought to the surface. Typically, lift gas is a constant rate, and therefore the same value will be entered for each of Qmax, Qave and Qmin.

| Lift Gas (or Secondary Flow) | UNITS | ENTRY | | WARNINGS |
|---|---|---|---|---|
| Is CO₂ or N₂ used as Lift Gas to Initiate Raw Gas Flow in Well? | 10³m³/d (15°C, 101.325 kPa) | ◉ Yes    ○ No | | |
| | Maximum (QMAX) | Average (QAVE) | Minimum (QMIN) | |
| Lift Gas Flow Rate (See Lift Gas composition below) | | | | |

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 **iSOURCE** 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.

The lift gas stream can be re-purposed to be a secondary stream of combustible fuel gas such as ring-burner. See Individual Stream for Lift. In this case, the gas composition of the lift gas stream would change from inert to non-inert. The button to the right of the lift gas stream entry group can be used to solve the lift gas flow rate required to achieve 98% conversion efficiency, given all of the other configuration settings remaining the same.
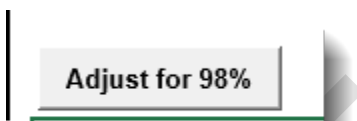


# Flare Assist

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 over-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 overall flaring efficiency.  Because both air and steam introduce composition components in excess of theoretical stoichiometric conditions, flare assist efficiency studies indicate a reduction of flare combustion efficiency.  While small rates of flare assist will initially increase achieved flare efficiency, higher steam to raw gas rates 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? | -- | ⦿ Yes   ◯ No | |
| Steam Assist? | -- | ☐ Steam | |
| Air Assist? | -- | ☐ Air | |
| High Pressure Fuel Assist? | -- | ☐ Fuel | |

STEAM ASSIST

# Steam Assist

Steam assisted flares are flares designed to dispose of heavier hydrocarbon gases which have a tendency to smoke. In order to prevent smoke formation, steam is injected into the waste stream using peripheral steam rings, center stream spargers and/or inner induction tubes. Steam flares are used in applications where high-pressure steam is available on site. Steam flares are typically found in downstream facility applications.

The steam injection will result in high-speed injection velocities that will be at sonic velocity (an assumption). It follows from this assumption that the geometry (diameters) of the steam injection is largely irrelevant, and is represented by the effective diameter of the flow at sonic speed. The number of ports or placement of ports (injector ring or co-flowing) also becomes irrelevant since only the total momentum and air entrainment is important from a well-mixed combustion model point of view. In practice, the orientation and location of the steam injection ports plays an important role in the flame envelope turbulence mixing and achievable combustion efficiency of the real-world (non-well mixed) processes. It is this difference between model and real-world that results in high efficiencies and smokeless operation for a well tuned steam assisted flare at relatively low injection rates. At higher injection rates, there is little difference between the well-mixed model and real-world, and the flare becomes over-assisted (low efficiency and poor combustion). An over-assisted flare may also be smokeless because poor combustion is not producing the heat the to convert the reactants to soot and the flare stack has become a vent stack.

## 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*

Similar to steam-assisted flares, air assisted flares are flares designed to dispose of heavier hydrocarbon gases which have a tendency to smoke. In order to prevent smoke formation, air is injected into the waste stream using peripheral injector rings, center stream spargers and/or inner induction tubes. Air assist is commonly used when steam is not available. Air assisted flares are typically found in downstream facility applications.

| AIR ASSIST | | | |
|---|---|---|---|
| | Maximum (QMAX) | Average (QAVE) | Minimum (QMIN) |
| Air Assist Rate 10³m³/d (15°C and 101.325 kPa) | 10 | 2 | 1 |
| Flammability Check | Acceptable | Acceptable | Acceptable |

Similar to steam, the air injection will result in high-speed injection velocities that will be at sonic velocity (an assumption). It follows from this assumption that the geometry (diameters) of the steam injection is largely irrelevant, and is represented by the effective diameter of the flow at sonic speed. The number of ports or placement of ports (injector ring or co-flowing) also becomes irrelevant since only the total momentum and air entrainment is important from a well-mixed combustion model point of view. In practice, the orientation and location of the steam injection ports plays an important role in the flame envelope turbulence mixing and achievable combustion efficiency of the real-world (non-well mixed) processes. It is this difference between model and real-world that

results in high efficiencies and smokeless operation for a well tuned air assisted flare at relatively low injection rates. At higher injection rates, there is little difference between the well-mixed model and real-world, and the flare becomes over-assisted (low efficiency and poor combustion). An over-assisted flare may also be smokeless because poor combustion is not producing the heat the to convert the reactants to soot and the flare stack has become a vent stack. In practice, because large amounts of air are required for the combustion process, it is more difficult to over-assist an air-assisted flare.

*AERflare* displays a warning when air assist levels lead to un-acceptable combustion by comparing the conversion efficiency achieved to recommended conversion efficiency of 98%.

## Air Assist Rate

The air assist flow rates are entered as a volume flow rate at reference conditions ($\times 10^3$ m³/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.

# *HP Fuel Assist*

Flare assist can incorporate high pressure fuel injector ports at the flare stack exit similar to air or steam injection. HP fuel assist provides momentum, turbulent entrainment and fuel. The HP fuel assist stream is a separate stream and not included in the fuel gas (FGR) stream calculation. The HP fuel assist is assumed to be injected at sonic velocity.

The HP fuel assist flow rates are entered as a volume flow rate at reference conditions ($\times 10^3$ m³/d, 15°C and 101.325 kPa). *AERflare* allows flow rates to vary with flaring scenario rates (Qmax, Qave and Qmin).

| HIGH PRESSURE FUEL ASSIST | | | |
|---|---|---|---|
| | Maximum (QMAX) | Average (QAVE) | Minimum (QMIN) |
| HP Fuel Assist Rate 10³m³/d (15°C and 101.325 kPa) | 3 | 2 | 1 |

# 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 $H_2S$ concentration as the flare modelled amount. The reason for this is to allow for regulatory $H_2S$ limit or fluctuating range of $H_2S$. The *AERflare* model will re-normalize the raw gas composition using requested $H_2S$ in place of the $H_2S$ 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 5.

**Table 5:** **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/m³ |
| Mercaptan Sulphur | -- | 0.25-1.0 gr/100scf | |
| Total Sulphur | -- | 5-20 gr/100scf | 115 mg/m³ |
| Water Vapour | -- | 7.0 lb/mmscf | 65 mg/m³ |
| Oxygen | -- | 0.2-1.0 ppmv | 0.4% by volume |

Lift gas composition may be inert (e.g., $CO_2$, $N_2$) 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

At the time *AERflare* was created the standard method flare modelling was manual entry of terrain based upon careful study of 1:50,000 topographical maps. Manual entry of map data been removed and all terrain processing is performed in *AERflare* using digital processing of the digital terrain (DEM) maps (see later 'Get DEM data' button).

| DEM Terrain Output Summary | | |
|---|---|---|
| Map Sheets | | 083n |
| Base elevation from DEM data | m | 669.1 |
| Maximum Elevation within 10km of stack | m | 798.0 |
| Distance to Maximum Elevation within 10km of stack | m | 7716.2 |
| **UTM X** | **UTM Y** | **Elev (m)** |
| 481234.0 | 6112345.0 | 669.0926067 |

## Map Sheets

For reference and verification of terrain processing, a list of 1:50,000 scale topographical map sheets used in the digital processing is provided.

## Base Elevation from DEM Data

The based elevation according to triangulation of the DEM elevations near the stack base is listed.

## Maximum Elevation

The maximum elevation within rmaxdist distance of the source location is listed. The range between the maximum elevation and the base elevation is used to determine a sensible contour interval.

## Distance to Maximum Elevation

The distance to the maximum elevation within rmaxdist distance of the source location is listed

# *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 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 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.


# *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 *DEM Terrain Output Summary* group has created a table of elevations, distance and criteria description.  The table displays common complex terrain criteria at each location/contour level pair.

| UTM X | UTM Y | Elev (m) | | |
|---|---|---|---|---|
| 481234.0 | 6112345.0 | 669.0926067 | | |
| UTM X | UTM Y | Elev (m) | Distance (m) | Elevated Terrain Criteria Regions |
| 481234.0 | 6112345.0 | 655.8701328 | 0.0 | -13 m (stack) |
| 481152.3 | 6112430.4 | 670 | 118.2 | 1 m (stack) |
| 480623.4 | 6112919.5 | 680 | 838.4 | 1.3 % (slope) |
| 480376.5 | 6114126.2 | 690 | 1976.8 | 21 m (plume) |
| 479327.8 | 6114038.2 | 700 | 2549.6 | 31 m (plume) |
| 478877.5 | 6114202.6 | 710 | 3000.7 | 41 m (plume) |
| 478679.9 | 6114504.9 | 720 | 3345.0 | 51 m (plume) |
| 478309.5 | 6114738.6 | 730 | 3779.1 | 61 m (plume) |
| 477872.2 | 6114856.6 | 740 | 4196.4 | 71 m (plume) |
| 477514.3 | 6114904.8 | 750 | 4515.4 | 81 m (plume) |
| 477169.7 | 6114976.1 | 760 | 4841.6 | 91 m (plume) |
| 476867.3 | 6115510.9 | 770 | 5393.6 | 101 m (plume) |
| 476634.0 | 6116555.4 | 780 | 6236.0 | 111 m (plume) |
| 476080.0 | 6117114.8 | 790 | 7022.4 | 121 m (plume) |
| 475765.5 | 6117788.9 | 798 | 7716.2 | 129 m (plume) |
| | | | | |
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| | | | | |

Below the *DEM Terrain Output Summary* 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 for each of the Qmax, Qave and Qmin flow rates. 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 shows the effective flame height for the average meteorological wind speed and temperature.
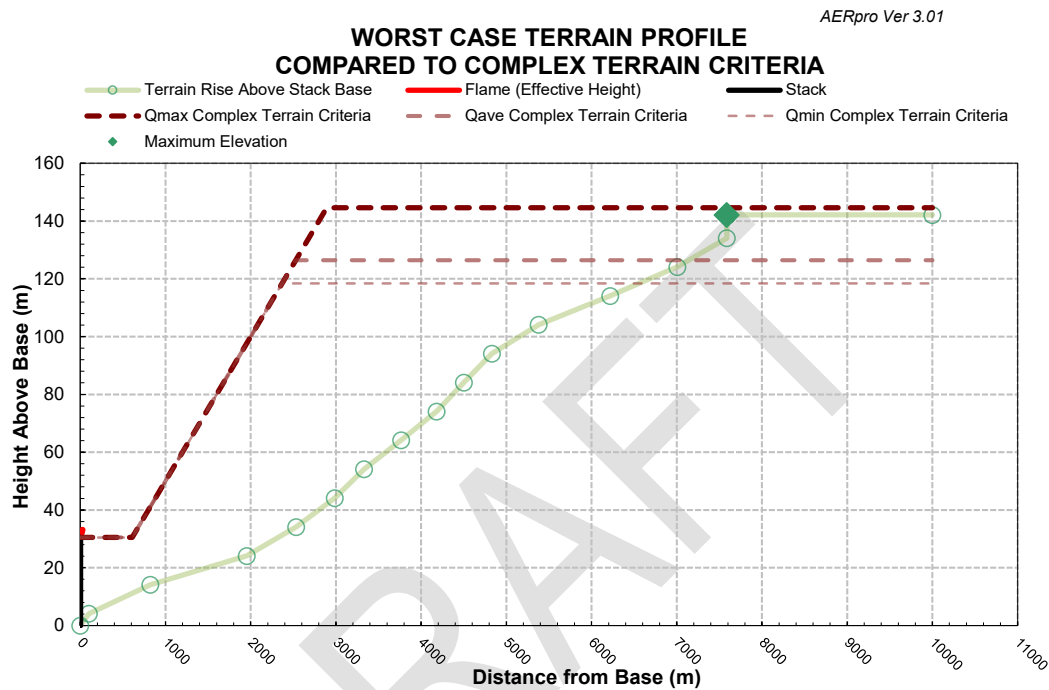


**Figure 6:** **Worst Case Complex Terrain Graphic Showing Terrain Elevations as a Function of Distance**

# 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 Summary | feet | metres |
|---|---|---|
| Maximum Terrain Elevation | 2618 | 798 |
| Stable Plume Criterion Elevation | 2516 | 767 |
| Stack Height Criterion Elevation | 2244 | 684 |
| Well Centre Elevation | 2195 | 669 |
| Maximum Terrain Height Above Flare Base | 423 | 129 |
| Stable Plume Criterion Height Above Flare Base | 321 | 98 |
| Stack Height Criterion Above Flare Base | 49 | 15 |
| | miles | kilometres |
| Stack Height Criterion Extends from Flare to | 0.19 | 0.30 |
| Slope Criterion Extends from Stack Height Criterion (above) to Stable Plume Height Criterion at | 1.60 | 2.58 |

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

# 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 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.

**DEM TERRAIN VISUAL CHECK**
**(Location of Worst Case Terrain Contours)**
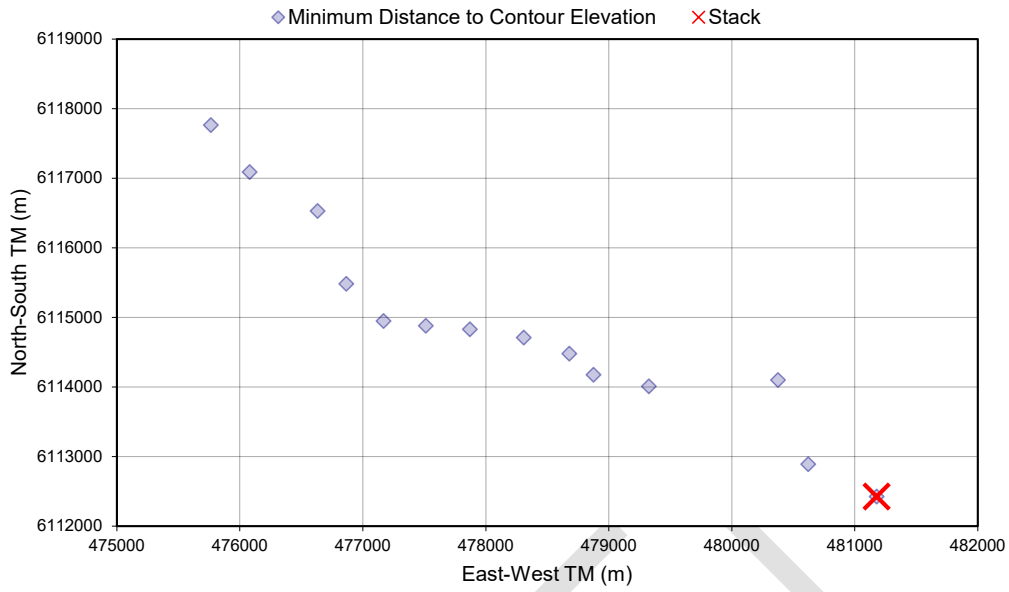
# iNOTES

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

In this chapter, the methods used to model the source are described: whether routine or non-routine; flare, incinerator, boiler, heater, or engine; steady or transient blowdown. Once the conceptual source model is selected, AERflare uses principal information entries to perform combustion calculations to determine the net energy available for plume rise and then determines air dispersion modelling parameters suitable to replicate the energy (buoyancy and momentum) available for plume rise. The source model outputs are available in both meteorologically varying (hour-by-hour) or average meteorological (static) formats suitable for flares or other sources, respectively. The *AERflare* source model is specifically adapted for use with the *AERMOD*.

# Source (Flowrate) Types

Secondary to the combustion calculations included *AERflare,* the emissions flowrates that are input into the tool to be modelled are important concepts requiring a fundamental understanding of the nature of the source types. The various source emission types are schematically illustrated *a* through *e*, in Figure 7. On the left side of each group, is a representative time series of the emission rate and on the right side, is how that flow rate would be represented in the *AERflare* modelled emission rate.
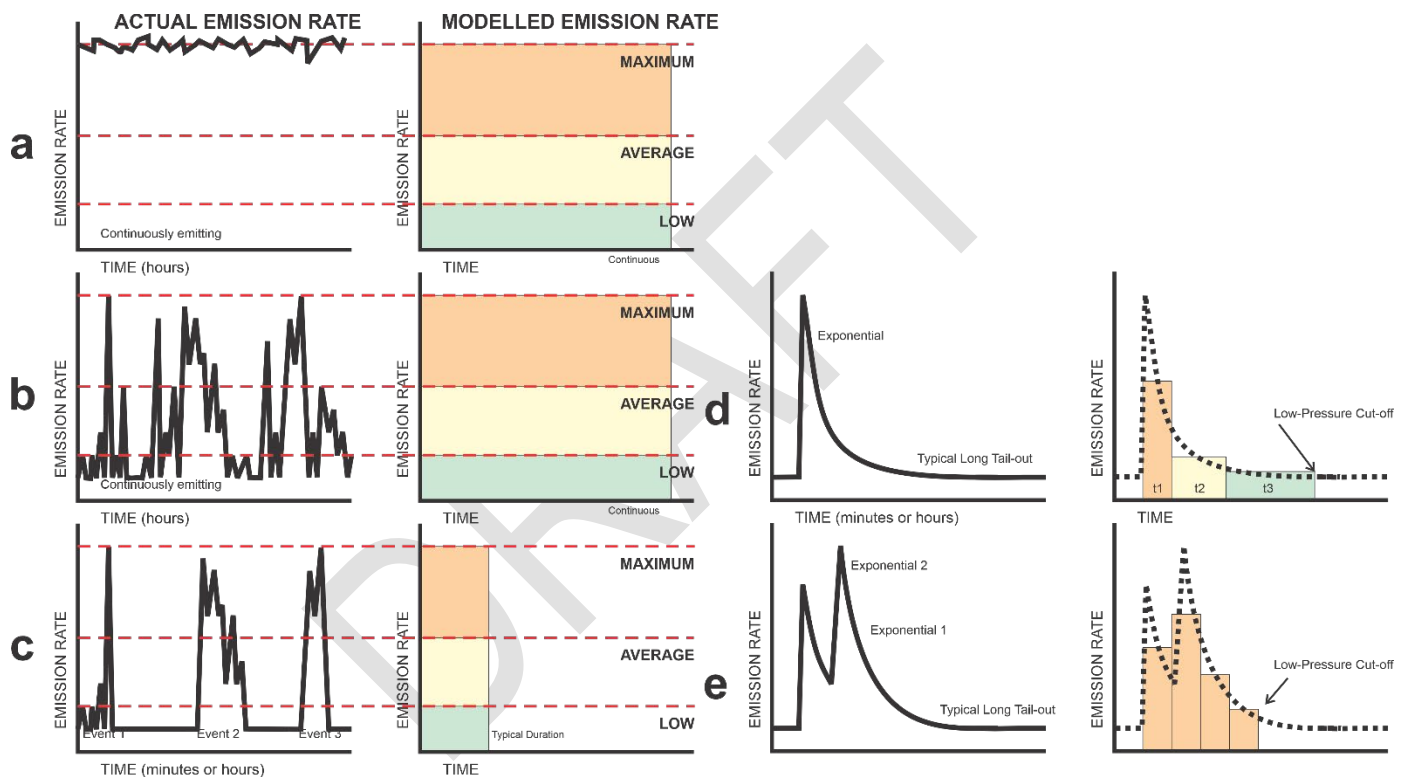


**Figure 7:     Stack Emission Rate Types**

# *Type A: Nearly Constant and Continuous*

The typical operation of a boiler or compressor engine, and the modelling of $NO_x$ emissions from them is a good example of a nearly constant and continuous source. In this scenario the engine is operated at fixed rate continuously and the fuel and pollutant output will be nearly constant over the course of a year and nearly continuous in operation. The typical operation of a steam generating boiler is also an example of this type with the exception of turn-down or stand-by

operations. Type A emissions are modelled as a continuous source and maximum hourly concentrations are direct outputs of the plume dispersion model.

## *Type B: Variable and Continuous*

Many flares and incinerators operate within this category of emission types or within Type C. The planned flaring or incineration of waste gas is associated with lower volumes that are not economical to or have not yet been tied into gas conservation collection systems. The flow rates are typically quite variable and may range from the maximum design flow to very low flow. Most flaring operations are observed to have an average operating flow rate at nearly $1/8^{th}$ the design maximum rate. These variable flow rate sources are modelled at maximum, average and minimum ($1/8^{th}$ of maximum) flowrates to ensure the maximum ground-level concentrations are assessed accounting for worst case gas composition, plume rise, conversion efficiency and stack tip downwash. Type B emissions are modelled as a continuous source and maximum hourly concentrations are direct outputs of the plume dispersion model.

## *Type C: Variable and Episodic*

Similar to Type B, the Type C are variable and the same three flow rates are included in the model. These emissions may be either planned (ie, expected regular emissions) or unplanned (ie, infrequent, or rare/emergency scenarios). Short-term and potentially sub-hourly event durations are not modelled directly with a (continuous) plume model such as AERMOD and therefore post-processing of the results is required. Whereas the short-term 'puff' nature of an event is directly modelled using the CALPUFF air dispersion model (both the finite duration and along-wind diffusion); the AERMOD is a plume model that does not include along-wind diffusion of a short-term event. A conservative estimate of the concentrations can be made by post-processing the AERMOD predicted concentrations on a continuous basis and accounting for sub-hourly duration. Distance and time since release are meteorology dependent variables that will reduce concentrations though along-wind diffusion. Along-wind diffusion is not included in the post-processing in this version of *AERflare*. Type C emissions are modelled as a continuous source and maximum hourly concentrations are adjusted to account for sub-hourly duration.

# Type D: Unplanned Single Event Blowdown

Many of the unplanned rare/emergency release events are facility or vessel related depressurization scenarios. These events are characterized by an initial very high flow rate and an exponential decrease in flowrate following the depressurization to safe levels. A depressurization event is usually defined by a reduction in pressure to 50% within a time frame (typically 15minutes). Type D scenario is modelled using the BLOWDOWN calculations to define the rates within *AERflare* making use of the three (maximum, average and minimum) flowrates as a continuous source and then post-processing the results to represent the blowdown.

It is important to remember, that although the depressurization is defined by a reduction of pressure from maximum to 50% within X-minutes, the flaring event duration will be much longer than X-minutes. That is, a depressurization event should not be modelled as a Type C event of X-minute duration.

# Type E: Unplanned Sequence of Events (Blowdown or PSV releases)

The most complex scenario is an event that is composed of several sub-events such as timed sequence of depressurizations into a common flare header. The sequence of events avoids an overly high flowrate or pressure. Type E events are not modelled within the AERflare system unless then can be represented within the context of a Type C or Type D recharacterization.  Type E events should be modelled using the *ABflare* tool which supports the CALPUFF time varying source emissions modelling method. The *ABflare* tool has the same processing abilities as the *AERflare* tool, but works with the CALPUFF model instead of the AERMOD model, respectively.

# Continuous Plume Predictions Conversion to Short-Term Event

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.

# Conversion Efficiency

The **oMODELLING** 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.  The conversion efficiency is determined using (Kostiuk et al 2004):

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

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/s$^2$]; $U_s$ is source exit velocity [m/s]; $D_s$ is source diameter [m].

The pseudo-source parameters for the $H_2S$ 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 approximately equal magnitude of emissions.  *AERflare* assumes the gases exiting path B remain as $H_2S$, whereas the fraction that exists through path A will likely have been heated sufficiently to oxidize the $H_2S$.

The source model for $H_2S$ 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 $SO_2$ source model energy is corrected for the small loss in energy lost by the stripping model used in the $H_2S$ model for completeness.  The inefficiency fraction of the raw gas combustion 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.

Wind flowing past the flame strips raw gases ~ combustion in-efficiency emissions

WIND

Inefficiency results in A (raw gas exiting warm) and B (raw gas exiting cool)
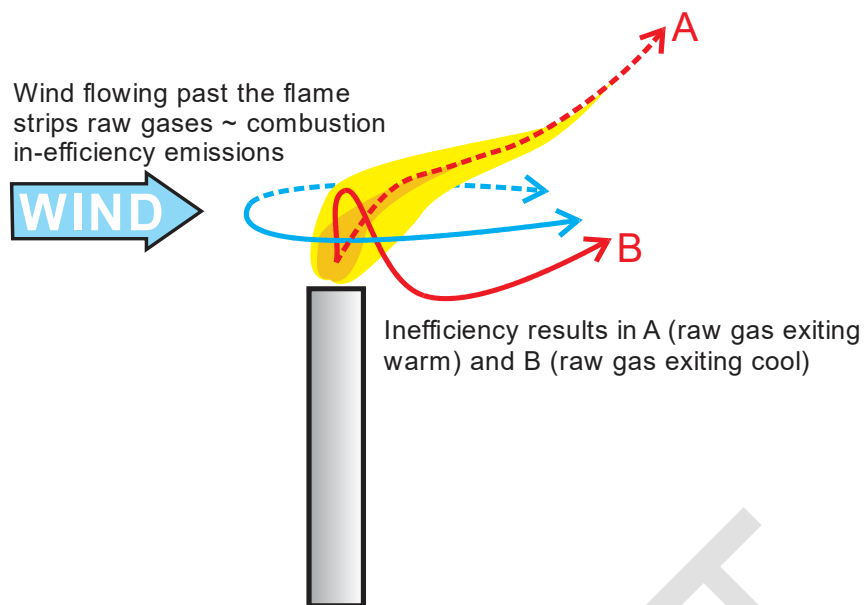
**Figure 8:** **H₂S Stripping Model for Source Parameters**

# Pseudo-Source Parameters

The *AERflare* calculations produce a set of pseudo-source parameters based upon conservation of mass, momentum and buoyancy. 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. The source parameters are called pseudo-source parameters (see Figure 9) since they mimic a source that will lead to the calculation of the FM and FB for the correct plume rise. In the figure, Ds, Hs, Us and Ts represent the actual source diameter, height, exit velocity and temperature. *AERflare* calculations pseudo-source parameters for $Ds^*$, $Hs^*$ and $Us^*$ to conserve the source mass, momentum and buoyancy. Ts is the estimate real source temperature. $Us^*$ includes the momentum provided by steam or air assist. $Hs^*$ is the estimated flame height including the stack height, Hs, and stack tip down wash. $Ds^*$ is back-calculated from buoyancy and momentum flux formulations used for plume rise calculations. The offset $Xs^*$ and $Ys^*$ are determined using the Brzustowski flare model based upon the wind speed, wind direction and flare parameters. The offsets are not used in the *AERflare* source modelling using AERMOD, but are applied in the *ABflare* source modelling using CALPUFF.

*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.
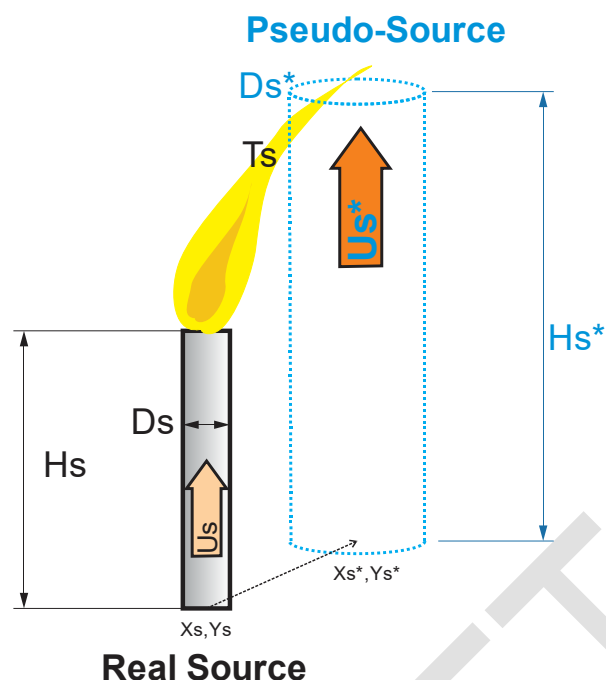
**Figure 9:** SO$_2$ Flare Model for Source Parameters

The pseudo-source parameters for the SO$_2$ 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. The pseudo-source parameters can change as quickly as the meteorology changes. The summary table shows the parameters for each of the Qmax, Qave and Qmin flow rate scenarios. Note that the SO$_2$ source model assumes that 100% of the raw gas sulphur is converted to SO$_2$. The effective height of the SO$_2$ 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 SO$_2$ source model assumes that 100% of the raw gas sulphur is converted to SO$_2$.

For SO$_2$ dispersion modelling, users must not apply combustion efficiency factors to reduce the SO$_2$ emissions to gain regulatory acceptance.

The table of the $H_2S$ pseudo-source parameters can be used for refined air dispersion modelling of the $H_2S$ source. The temperature for the $H_2S$ source model is a result of the energy and momentum back calculation.

| H₂S Dispersion Model Stack Exit Input Parameters | UNITS | Maximum (QMAX) | Average (Volume/Duration) | Minimum (QMIN) |
|---|---|---|---|---|
| H2S 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 Options

The generalized flowchart that represents the calculation process is shown in Figure 10. User inputs are gathered from the three principal *AERflare* input pages (**iFACILITY**, **iSOURCE** 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 worst-case terrain determined on the **iTERRAIN** page and is interpolated for a receptor grid from 100m to 10km (rdistmax). Once the maximum terrain elevation is reached, all points on the receptor grid remain at the maximum elevation. *AERflare* uses the *AERMOD* slope-based algorithm for determining hill height influences at each receptor location.
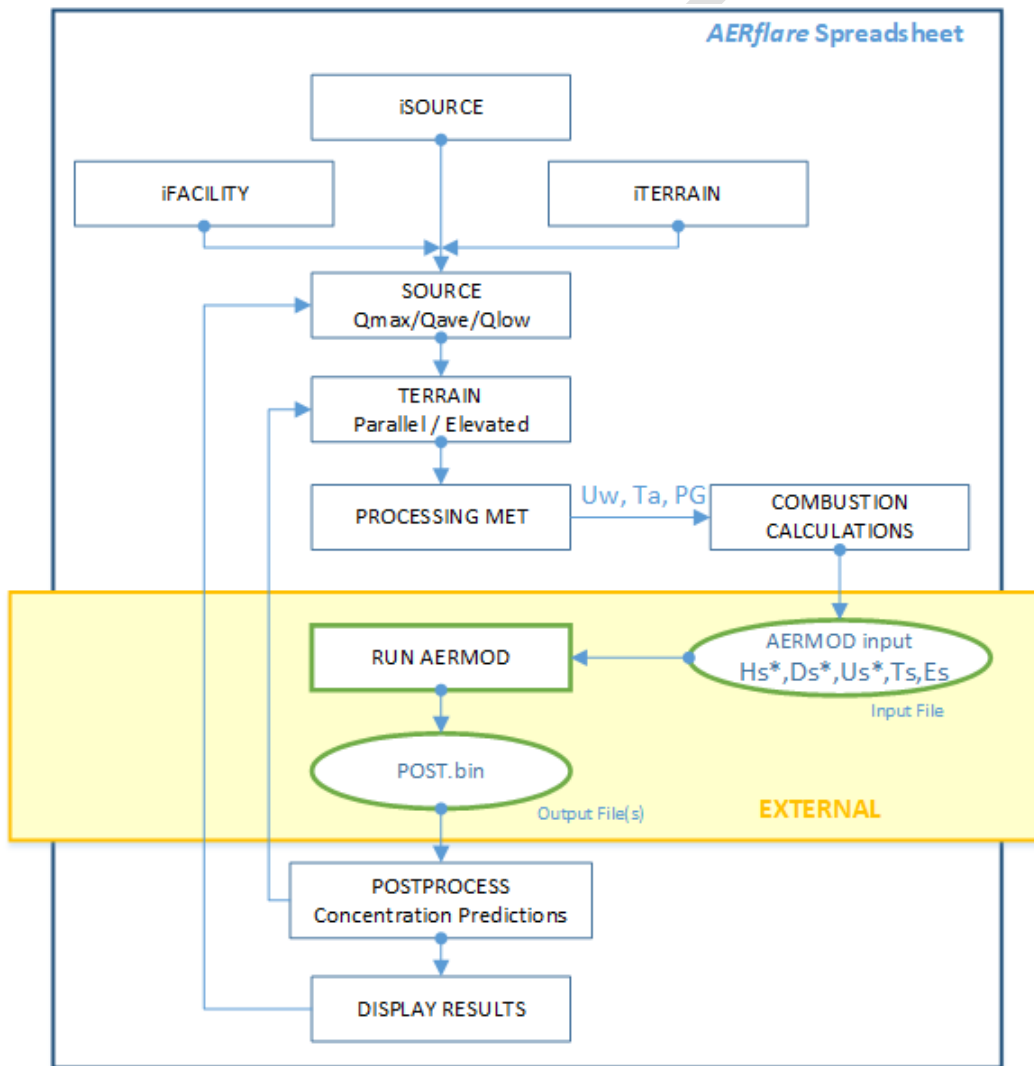


**Figure 10:    Calculation Flowchart**

All air dispersion modelling assessments for flare sources use the meteorologically varying (hour-by-hour) source parameter model. All other sources (incinerators, heaters, boilers) use the static average meteorological condition source parameter model, in which case the process outlined in Figure 10 is simplified because sources parameters are calculated for the meteorological average condition only.

Either a screening or a user specified site-specific *AERMOD* 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 buoyancy 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. Using the AERflare *quick method* only six meteorological cases are used based upon 6-category wind speeds emissions controls.

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 files are external to the *AERflare*.

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.

The difference between Non-Routine and Routine flare air dispersion modelling, the process outlined in Figure 10 is simplified with respect to information gathered for the permit or the risk-based criteria allowed for meeting ambient air quality objectives.

There are three calculation modes on the **oMODELLING** page (listed below) and discussed in the following sections. The 'set mode' buttons configure some of the AERflare calculation option settings to achieve the mode.

| Mode | Purpose | Calculation Options |
|---|---|---|
| 1.SCREENING | A screening model uses:<br>• A simplified land use profile that has been pre-determined for Alberta, Saskatchewan and British Columbia;<br>• Worst-case terrain (100 data points from source to 10 km)<br>• A screening meteorological dataset (range of worst-case possibilities to determine worst-case 1h averages. Daily and annual predictions <u>are not</u> available). The screening meteorological dataset is created automatically from the simplified landuse information or can be created by the user for a uniform landuse. | User Met File:     OFF<br>User Terrain/Receptor:  OFF<br><br>Meteorological File:    Grayed out<br>Receptor File:      Grayed out |
| 2.INTERMEDIATE | An intermediate model uses:<br>• A site-specific land-use analysis using the iUSERMET page<br>• A site-specific screening meteorological data set (range of worst-case possibilities to determine worst-case 1h averages. Daily and annual predictions <u>are not</u> available)<br>• A site-specific refined meteorological data set (created from MM5 or WRF, or other user provided input files, Daily and annual predictions <u>are</u> available) | User Met File:     ON<br>User Terrain/Receptor:  OFF<br><br>Meteorological File:    USER ENTRY<br>Receptor File:      Grayed out |
| 3.REFINED | A refined model uses:<br>• A site-specific land-use analysis using the iUSERMET page<br>• A site-specific refined meteorological data set (created from MM5 or WRF, or other user provided input files, Daily and annual predictions <u>are</u> available)<br>• A site-specific terrain and receptor file using iUSERTER page | User Met File:     ON<br>User Terrain/Receptor:  ON<br><br>Meteorological File:    USER ENTRY<br>Receptor File:      USER ENTRY |

NOTE: For Screening, Intermediate or Refined, the user has the option to run the AERMOD model when the EXECUTE button is pressed, or use the Create AERMOD Input File(s) only option.

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. SCREENING

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.

AERMOD modelling guidance recommends running both parallel and complex terrain assessments.  The parallel terrain predictions are a typical worst-case for wind that is terrain following, and the complex terrain predictions are a typical best-case for winds that maintain altitude above sea level in stratified layers.

*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.

For Flares, 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).

# 2. INTERMEDIATE

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 AEP 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.

For flares, 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.

# 3. REFINED

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 AEP 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.

*AERflare* does not perform both the parallel and complex terrain assessments automatically. This is left to the user to perform both assessments to ensure that the maximum ground level predictions are predicted.

For flares, 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.

> AERflare does not perform both the parallel and complex terrain refined assessments automatically. This is left to the user to perform both assessments to ensure that the maximum ground level predictions are predicted.

# *Create AERMOD files only*

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 batch operations of screening or 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.

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.

# Permit Air Dispersion Modelling

The Permit assessment begins with a selection of: PERMIT from the choice of PERMIT or EVALUATION on the **iSTART** page. Selection of PERMIT forces the classification to be Non-Routine—Planned, in either the flaring or incineration calculations mode. 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.

When Permit mode is used for *AERflare*, additional inputs are required on the **iFACILITY** page. In addition, when the Permit mode is used for *AERflare*, the Qave flow rate is calculated from the volume of gas to be flared/incinerated and the estimated duration of the flaring/incineration. For Evaluation mode, the Qave rate is 50% of the Qmax rate.

| Are these flaring calculations for an ambient air quality evaluation or for a tempoary permit application? | ● Permit  ○ 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) | SO₂ RBC (µg/m³) | SO₂ Max (µg/m³) | H₂S RBC (µg/m³) | H₂S Max (µg/m³) |
| Routine -- Continuous or Intermittent Flaring for more than 720 hours per year | ○ Locked | 99.9 | -- | 450 | -- | 14 | -- |
| Non-Routine -- Planned Flaring | ● | 99 | 99.9 | 450 | 900 | 14 | 7652 |
| Non-Routine -- Unplanned Flaring | ○ Locked | 90 | 99.9 | 450 | 9923 | 14 | 7652 |

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 Incineration** | |
|---|---|---|
| AERMOD Version Used | **19191** | Use the latest AERMOD release version https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models#aermod |
| Meteorological File Used | | P:\ERCBtools\AERflare\dev\test\newSourceModel_210723\AERMOD.SFC |
| Terrain Insert File Used | | DoNotUse |
| AERMOD Output File Base | | full_quick_39 |
| # Hours in Meteorological File | 43824 | |
| Source Type | 1 | 1: Steady  2: Transient |
| Dispersion Model Predictions These results account for the duration of the flaring event and 1h hour averaging time. | **Annual** | |
| Calculations terminated successfully | TRUE | blank=FALSE, TRUE=successful |

# Evaluation Air Dispersion Modelling

The Evaluation aid dispersion assessment begins with a selection of: Evaluation, on the **iSTART** page,.

| Are these flaring calculations for an ambient air quality evaluation or for a tempoary permit application? | ○ Permit ◉ 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/m³) | $SO_2$ Max (µg/m³) | $H_2S$ RBC (µg/m³) | $H_2S$ Max (µg/m³) |
| Routine -- Continuous or Intermittent Flaring for more than 720 hours per year ◉ | | 99.9 | -- | 450 | -- | 14 | -- |
| Non-Routine -- Planned Flaring ○ | | 99 | 99.9 | 450 | 900 | 14 | 7652 |
| Non-Routine -- Unplanned Flaring ○ | | 90 | 99.9 | 450 | 9923 | 14 | 7652 |

When Evaluation Mode is used for *AERflare*, the inputs on the iFACILITY are reduced (grayed-out). 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.

# oAERMOD Page

The source model inputs are calculated on the **oCALCFLARE** or the **oCALCINCIN** combustion modelling pages and are summarized on the **oMODELLING** page.  The **oAERMOD** 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 (Qs, Hs, Ds, Us, Ts) as well as the Brzustowski Flare Model effective source location (ZL, XL).  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 non-flare sources, 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.

| AERMOD Source Parameters | Variable | Units | Maximum (QMAX) | Average (Volume/ Duration) | Minimum (QMAX/8) |
|---|---|---|---|---|---|
| Run flags (1=run; 0=not run) | | | 1 | 1 | 1 |
| Modelling Case # | | | 1 | 2 | 3 |
| Species | | | SO2 | SO2 | SO2 |
| 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/m³ | 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 Flare Sources*

The pseudo-source parameters for the 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.

## Non-Quick Method

| Hour-By-Hour Source Parameters | | | SO2 Maximum (QMAX) | SO2 Average (Volume/Duration) | SO2 Minimum (QMAX/8) |
|---|---|---|---|---|---|
| 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.
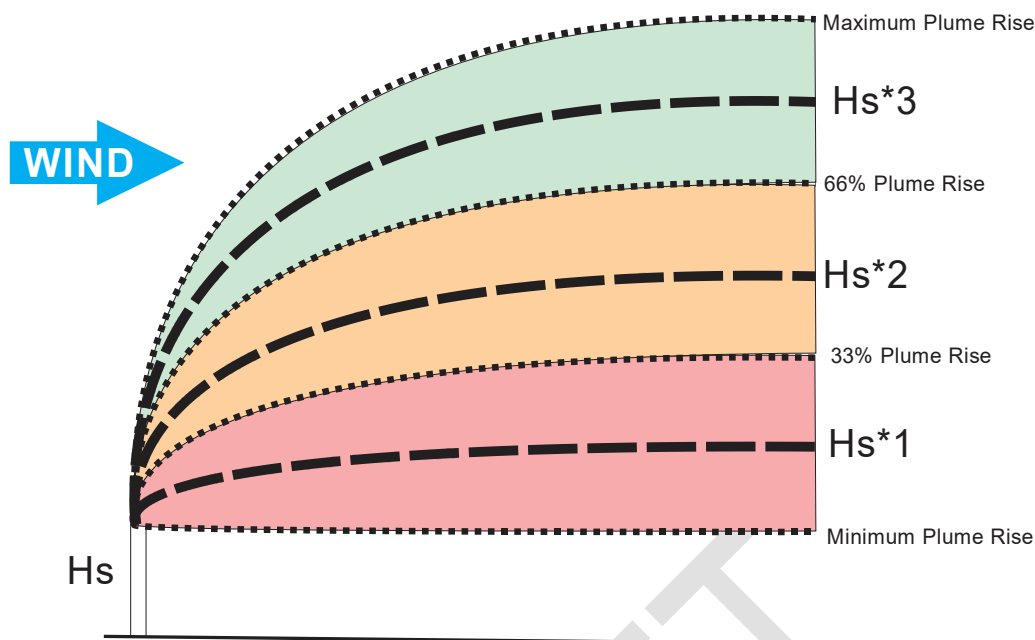
**Figure 11: Illustration of the Range of Plume Rise (centrelines) for An Hour By Hour Source Model**

The **oAERMOD** 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 ($5 \times 8760$ hours $\times \Delta t \approx 3$min) run time. The source processing must be completed for each of the Qmax, Qave and Qmin emission rates and for each of $SO_2$ and $H_2S$ sources (i.e., 6 times). For faster run times, the stand-alone *ABflare* refined model can be used.

# Quick Method

AERflare defaults (see **iSTART** page) to the Quick Method. Similar, to the non-quick method *AERflare* determines source parameters as a function of meteorological condition and *AERMOD* is run so that the source parameters vary hour-by-hour. In the Quick Method, the source pseudo-parameters are determined for 6-wind speed categories. *AERMOD* is then configured with co-located virtual sources with emissions that are on or off, as a function of wind speed using the *AERMOD* wind speed category emissions settings.

By default, the Quick Model wind speed categories and meteorological conditions are defined on the **iSTART** page. The selection of meteorological condition is based upon review of modelling results to produce worst-case modelling predictions. In the near field, the worst-case predictions occur as a result of neutral or unstable meteorology (Class D most often predicts the highest concentrations). In the far field, the worst case-case predictions occur as a result of stable meteorology (class F most often predicts the highest concentrations).

The worst-case plume rise will occur when the ambient temperature is the highest. The screening meteorological settings on the **iSTART** page use the maximum (Alberta) temperature.

| Evaluation Wind Speed (m/s) | Bin Wind Speed (m/s) | Stability Class | Temperature (°C) |
|---|---|---|---|
| 1 | 2 | 6 | 39 |
| 3 | 4 | 6 | 39 |
| 5 | 6 | 4 | 39 |
| 8 | 9 | 4 | 39 |
| 10 | 11 | 4 | 39 |
| 18 | 1000 | 4 | 39 |

The evaluation wind speed is the representative wind speed used to determined the source pseudo-parameters. The bin wind speed is the upper wind speed when *AERMOD* determines the wind speed bin during hour-by-hour meteorological processing.

# Air Dispersion Modelling Predictions

## *oAERMOD Output Summary*

After the *AERMOD* air dispersion modelling is completed, *AERflare* loads the output file and meteorological file, and post-processes the predictions. The **oAERMOD** 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 $SO_2$ and $H_2S$ 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/m³ | 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 |
| | winter or yr 1 | μg/m³ | 367 | 289 | 196 |
| | spring or yr 2 | μg/m³ | 244 | 161 | 128 |
| Concentration CMAX (99.9th) | summer or yr 3 | μg/m³ | 489 | 403 | 215 |
| | fall or yr 4 | μg/m³ | 458 | 377 | 208 |
| | month or yr 5 | μg/m³ | | | |
| | winter or yr 1 | μg/m³ | 264 | 199 | 134 |
| | spring or yr 2 | μg/m³ | 201 | 147 | 89 |
| Concentration RBC (99.0th) | summer or yr 3 | μg/m³ | 313 | 309 | 154 |
| | fall or yr 4 | μg/m³ | 321 | 275 | 133 |
| | month or yr 5 | μg/m³ | | | |

Note that this table is also used for sub-hourly blowdown air dispersion raw predictions, which are also hourly. The post-processed hourly average concentrations for blowdowns or sub-hourly emissions are provided on the **oMODELLING** page in the modelling summary section.

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

## cmax

The maximum concentration (cmax) representing the 100% (peak) concentration assuming a 1h emission duration.

## xmax

The distance (xmax) from the flare to the location of the maximum concentration (cmax). 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 (cmax).

## PG

The atmospheric stability class (PG: Pasquill-Gifford stability class) that resulted in the maximum concentration (cmax).

## xobj1

The distance (xobj1) where the predicted maximum concentrations drop below the Objective 1 listed in the **oAERMOD** page *Objectives and Limits* group. Objective 1 is ambient air quality objective. If the maximum concentration (cmax) prediction does not exceed Objective 1, then xobj1 is set to -1.

## xobj2

The distance (xobj2) where the predicted maximum concentrations drop below the Objective 2 listed in the **oAERMOD** 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 **oAERMOD** page *Objectives and Limits* group. Objective 3 is $1/10^{th}$ 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<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<mndata, the statistic is considered to be not valid for regulatory modelling approvals and applications.

Concentrations assume a 1h emission duration.

# *oMODELLING Output Summary*

After the *AERMOD* air dispersion modelling is completed, *AERflare* loads the output file and meteorological file, and post-processes the predictions. The **oAERMOD** 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 $SO_2$ and $H_2S$ source model predictions for Qmax, Qave and Qmin 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 *oAERMOD Output Summary* section.

| SO₂ 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/m³ | 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/m³ | 1366 | 881 | 342 | NA | climit |
| RBC Maximum Concentration (99.0th) | µg/m³ | 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 (C1h) is determined from the modelled concentration (Cmodelled) based upon continuous emissions by:

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

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 classication See D060-3.3.1[2a] for tier limits |
| H₂S gas concentration (%) | 3.3.1[1] | See Requirements | 16 | 5 | Permit is required |
| Volume per Zone (10³m³) | 3.3.1[2a] | PASS | 22.50 | 200 | Volume allowance is based upon well before re-classification |
| Total Volume (10³m³) | 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 |
| H₂S 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 (10³m³) | 3.3.2[2b] | PASS | 22.5 | 50 | NO permit is required |
| Conditions to Apply for a Blanket Permit: total volume per site (10³m³) | 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] | ○ Critical  ◉ Non-Critical | | | |
| H2S > 5% | 3.3.1[1] | ◉ Yes  ○ No | 16.00% | 5% | Permit is required |
| H2S > 1 % | 3.3.2[1a] | ◉ Yes  ○ No | 16.00% | 1% | Air quality evaluation is required (7.12) |
| Flared Volume > Volume Allowance (10³m³) | 3.3.1[2] | ○ Yes  ◉ No | 22.5 | 200 | NO volume exceedance permit is required |
| Small Volume Exemption limits exceeded? | 3.3.1[2a,2b,2c] | ◉ Yes  ○ No | | | |
| Is Temporary Flaring Permit Required? | 3.3.1 | ◉ Yes  ○ 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 ? | | ○ Oil    ◉ 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 $H_2S$ 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 is 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 **oMODELLING** 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/m³ | 32.0 |
| Heating Value of Fuel Gas | MJ/m³ | na |
| Heating Value of Mixture | MJ/m³ | 32.0 |
| Is Heating Value of Mixture Acceptable? | D060-7.1.1 | ◉ Yes   ○ No |

| Fuel Gas Addition | UNITS | VALUE |
|---|---|---|
| Is Fuel Gas required to compensate for Lift Gas? | | ○ Yes   ◉ No |
| Fuel Gas Supply Rate to meet 20.0 MJ/m³ while Lift Gas is Flowing Back | 10³m³/d (15°C,101.325 kPa) | -- |
| | GJ/h | -- |
| Is Fuel Gas Added for Dispersion or to meet Heating Value Requirements? | | ○ Yes   ◉ No |
| Proposed Fuel Gas to Raw Gas Volume Rate Ratio | | 0.000 |
| Fuel Gas Supply Capacity for Dispersion or to meet Heating Value Requirements | 10³m³/d (15°C,101.325 kPa) | -- |
| | GJ/h | -- |
| | 10³m³ (15°C,101.325 kPa) | -- |

| Thermal Radiation | UNITS | VALUE |
|---|---|---|
| Maximum Total Thermal Radiation at Ground Level | kW/m² | 1.2 |
| Is Thermal Radiation Acceptable? | D060-7.4.1 | ◉ Yes   ○ 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 | ◉ Yes   ○ 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? | | ◉ Yes ○ 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 SO2 Concentration using AERSCREEN and Screening Meteorology | | **Planned Non-Routine Flaring Modelling Results** | Concentration Criteria µg/m³ | |
| Maximum $SO_2$ Concentration | µg/m³ | 2108 | 450 | Adjust parameters/modelling approach |
| Maximum $H_2S$ Concentration | µg/m³ | 15 | 14 | Adjust parameters/modelling approach |
| Is Refined Dispersion Modelling Required? | | ◉ Yes ○ No | | Refined modelling is required |

| REFINED MODELLING Risk-based Predicted Ground Level SO2 Concentration using AERSCREEN and Site-Specific Meteorology | | Planned Non-Routine Flaring Modelling Results | Concentration Criteria µg/m³ | Percentile | COMMENTS |
|---|---|---|---|---|---|
| Minimum Number of Meteorological Data Points in a Year | -- | NA | | | |
| SO2 Modelling Completed for all three flowrates | -- | ☑ Qmax ☑ Qave ☑ Qmin | | | |
| SO2 Concentration Prediction 99.9th | µg/m³ | 0 | 900 | 99.9 | |
| SO2 Concentration Prediction 99th | µg/m³ | 0 | 450 | 99 | |
| H2S Modelling Completed for all three flowrates | -- | ☑ Qmax ☑ Qave ☑ Qmin | | | |
| H2S Concentration Prediction 99.9th | µg/m³ | 0 | 7652 | 99.9 | |
| H2S Concentration Prediction 99th | µg/m³ | 0 | 14 | 99 | |
| Is More Refined Dispersion Modelling Required? | -- | ○ Yes ◉ No | | | |

Screening modelling results are saved by default on the bottom of the **oAERMOD** page. They can be exported using the Export buttons provided. The predictions can be output in the raw format or in the adjusted format. The later adjusts the raw predictions for the potential of sub-hourly release duration or combining the Qmax, Qave and Qmin predictions for blowdown predictions.

# Flowchart AER_FIGURE4

The **AER_FIGURE4** page provides a decision and analysis flow chart for temporary flaring/incineration permit process. This figure updates automatically with changes to inputs on various AERflare input pages and **oSUMMARY** interpretation of permit conditions.
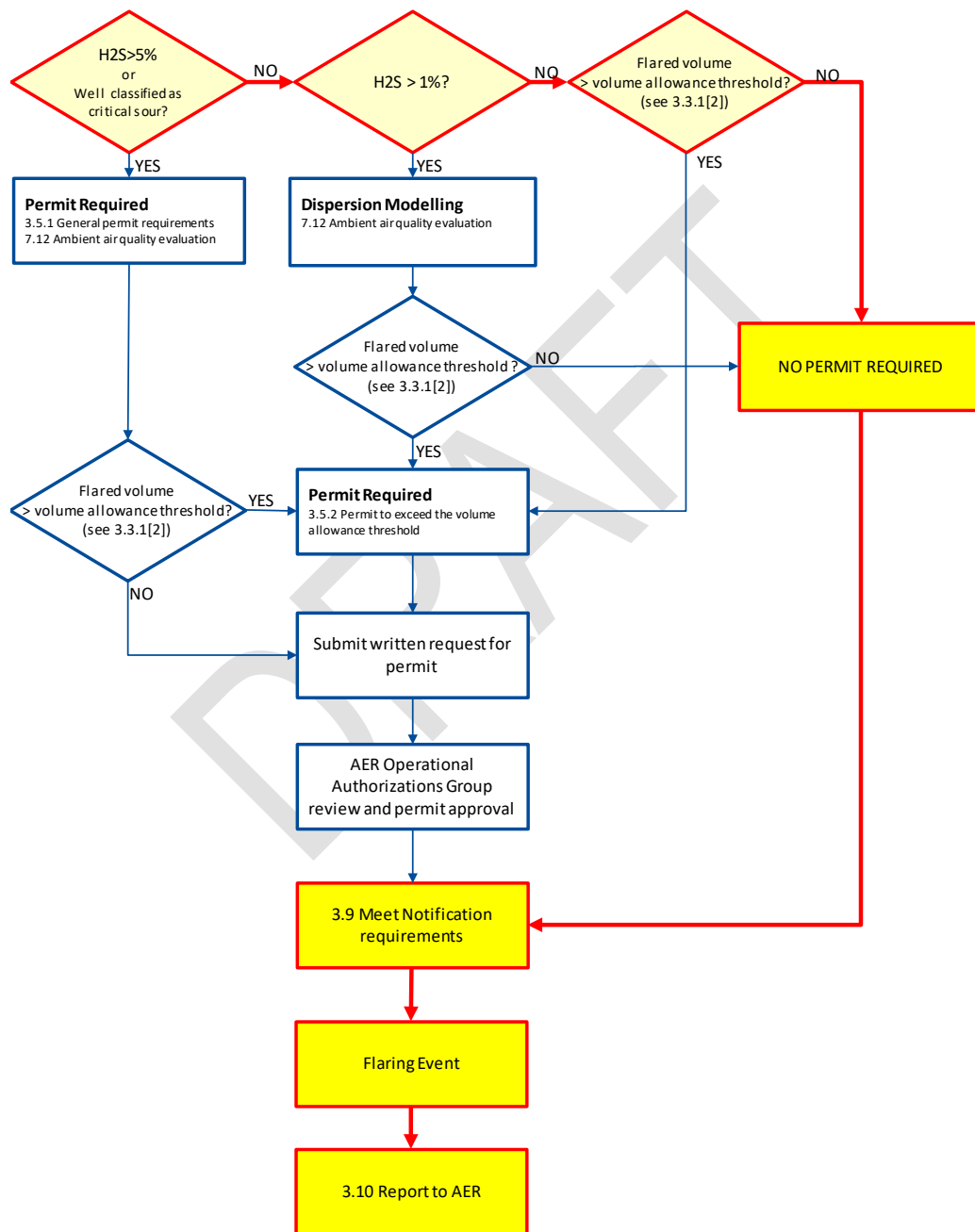
# Output Figure 1

The **oFIGURE 1** page presents the detailed output of the **oAERMOD** summary. **oFIGURE 1** can be used to select $SO_2$ or $H_2S$ 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 12, an air dispersion modelling output example is shown. Terrain elevation are shown in green using the right abscissa. The Qmax, Qave and Qmin 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 13 shows the wind speed that leads to the maximum concentration predictions. Figure 13 corresponds to the concentration predictions in Figure 12. Worse case meteorological conditions are a function of terrain elevation and distance from the source.
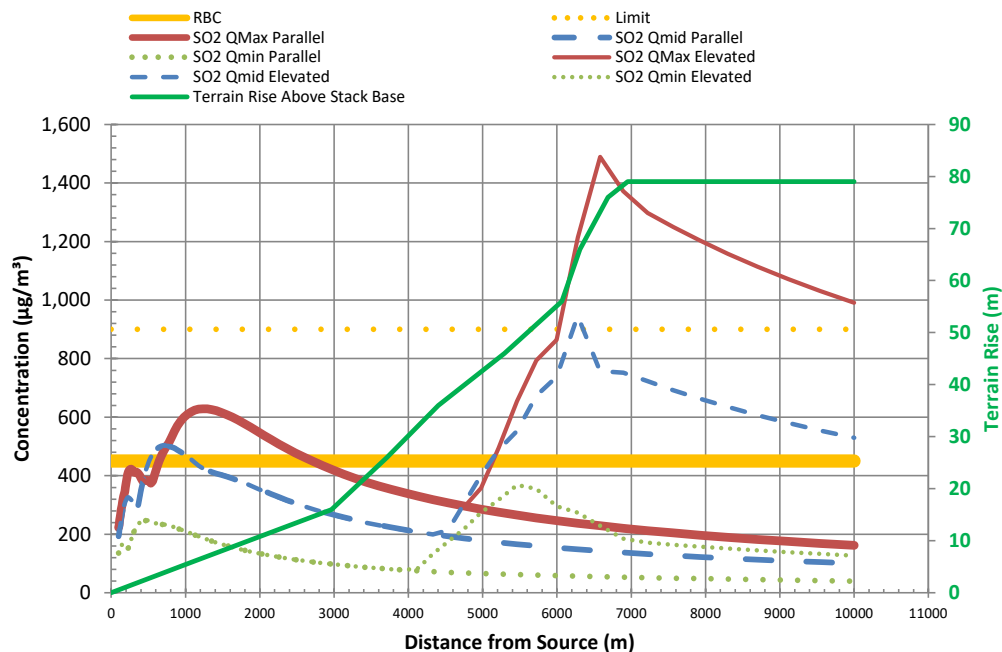


**Figure 12:** **Example oFIGURE 1 showing the Maximum Concentration at the Receptor Location in Comparison to the Terrain Elevation**
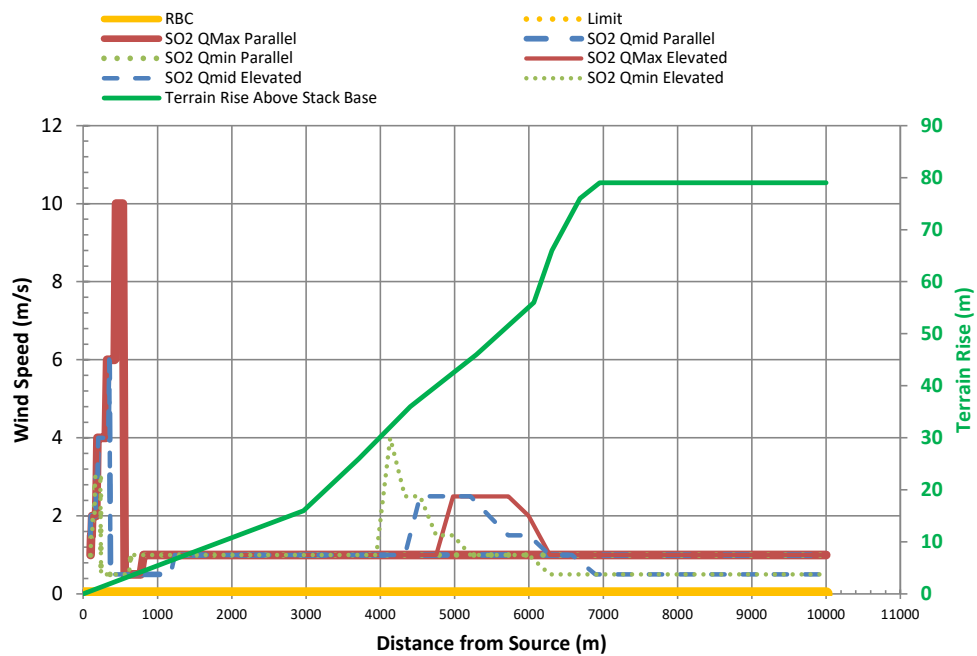
**Figure 13:** **Example oFIGURE 1 showing the Wind Speed that Causes the Maximum Concentration at the Receptor Location**

# Output Figure 2

The graphic provide on the **oFIGURE 2** page provides a useful summary of the hour-by-hour predicted $SO_2$ emissions and $H_2S$ emissions based upon the combustion efficiency and the hour-by-hour meteorology. Note that, the *AERflare* assessment for $SO_2$ requires the assessment based upon 100% conversion (i.e., constant emissions). The $SO_2$ emissions provided in **oFIGURE 2** are for reference only.

Figure 14 shows a probability plot for $SO_2$ emissions (left abscissa) and $H_2S$ emissions (right abscissa). The actual $SO_2$ emissions reflect the predicted efficiency for 99% of the time as shown in Figure 15. The $H_2S$ emissions are relatively low most of the time but are high for the 1% of the time, when the flare is inefficient.
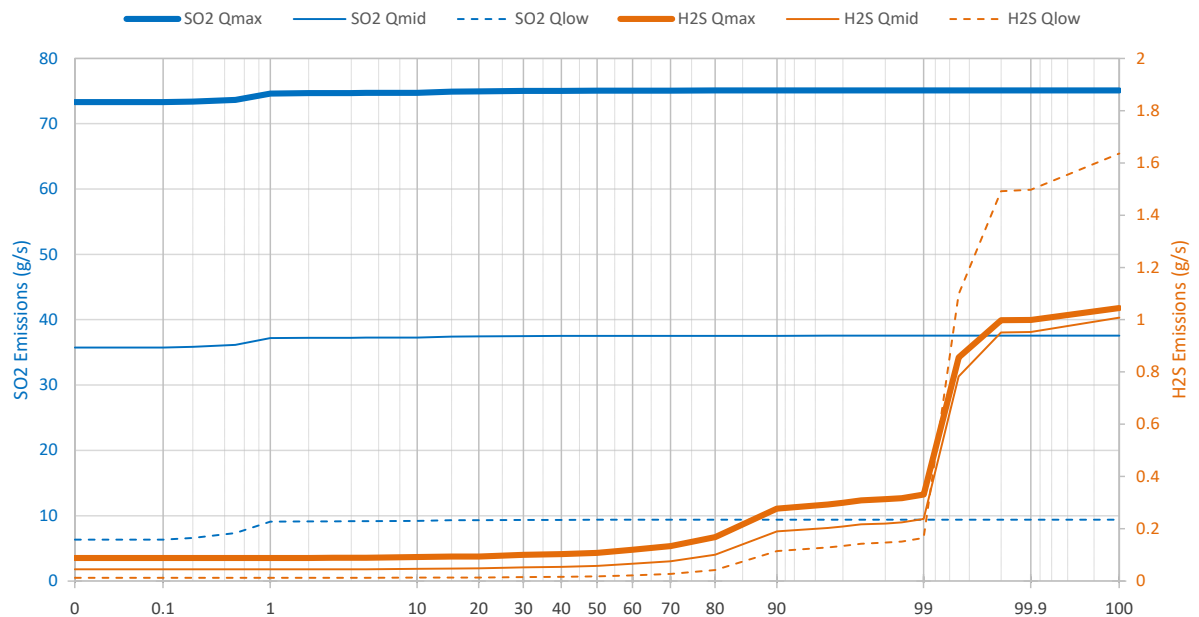


**Figure 14:    Example Emissions Chart from oFIGURE 2 for Hour-By-Hour Assessment**
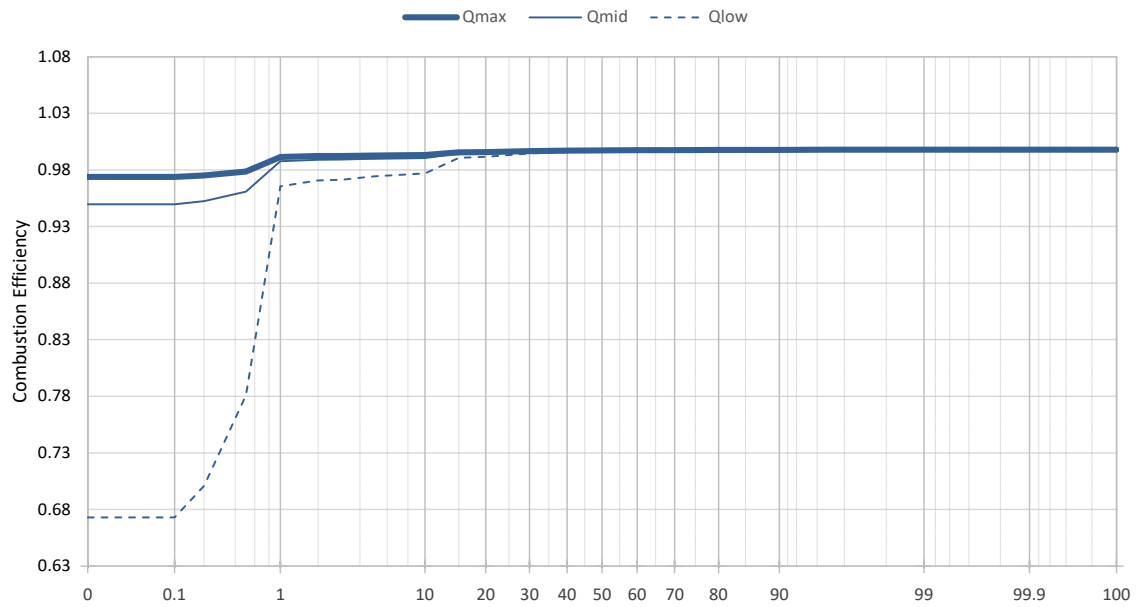
**Figure 15:** **Example Efficiency Chart from oFIGURE 2 for Hour-By-Hour Assessment**

# 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.

$$Q(t) = Q_{\max}(t) \exp\left(-t/\tau\right)$$

Where

$$\tau = V / Q_{\max}$$

And $V$ is the total volume of gas released (standard conditions) and $Q_{max}$ is the initial maximum release rate (volume per time, standard conditions). The time constant ($\tau$, 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. The default limit is 99% of volume.

Transient releases are more difficult to model because the dispersion model *AERMOD* is limited to a steady (constant) release rate. Casual use of the maximum release or average release rate to simplify the emissions for use in *AERMOD* can create strong bias in the air quality predictions.

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 **iSOURCE** 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, 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 | -- | ○ 1. Equal Duration  ◉ 2. Equal Mass |
| Raw Gas User Initial maximum flow rate, QMAX | $10^3$m³/d (15°C and 101.325 kPa) | |
| Raw Gas User Total volume within vessels/pipes, QTOTAL | $10^3$m³ (15°C and 101.325 kPa) | |
| User selected # of puffs, NPUFFS | -- | 3 |
| User selected puff duration, PUFDUR | 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, TEMP0

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 (chocked 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 16, Mannan 2005) provides a default value of 0.6 which allows for pipe friction from the orifice to the flare.
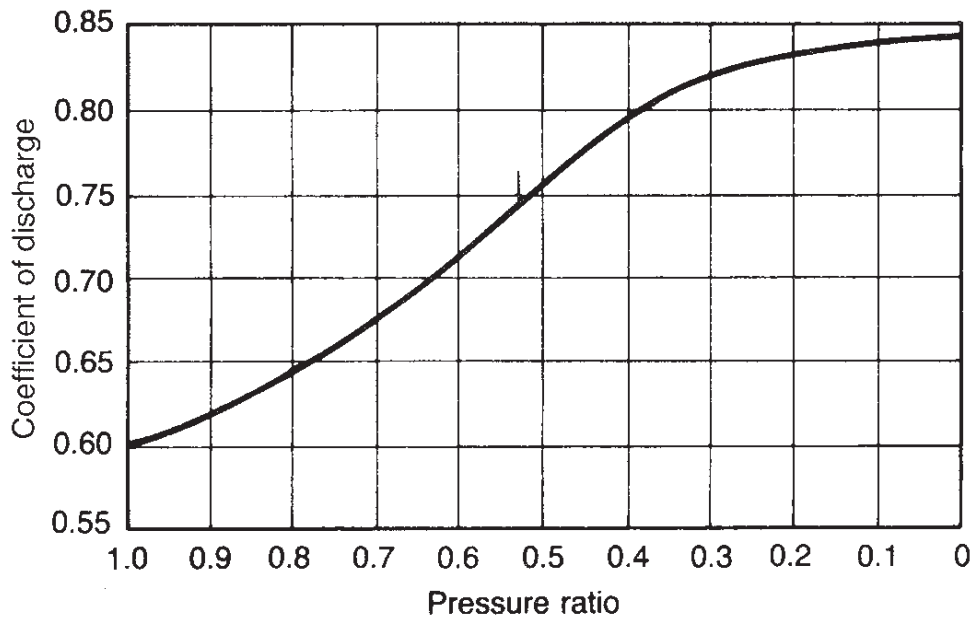


**Figure 16:    Coefficent of Discharge for Gas Flow Through an Orifice (Mannan 2005)**

# 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 17.)

# 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 **oAERMOD** 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 17) 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.
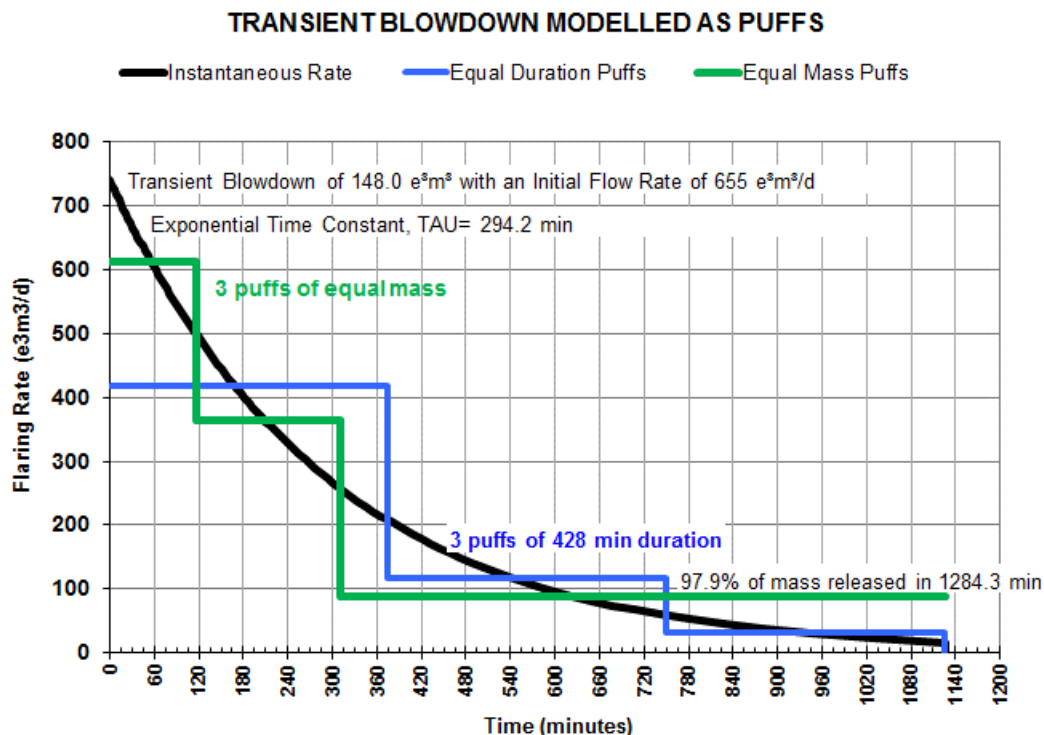


**Figure 17:** **Example Continuous Exponential Blowdown Curve shown *AERflare* modelled Discrete Stepped Sequence using Equal Mass Steps or Equal Duration Steps**

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 | 10³m³/d (15°C and 101.325 kPa) | 418.23 | 116.79 | 32.61 |
| Duration | min | 375.25 | 375.25 | 375.25 |
| Equal Mass | 10³m³/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 | 10³m³/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 **oAERMOD** 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.
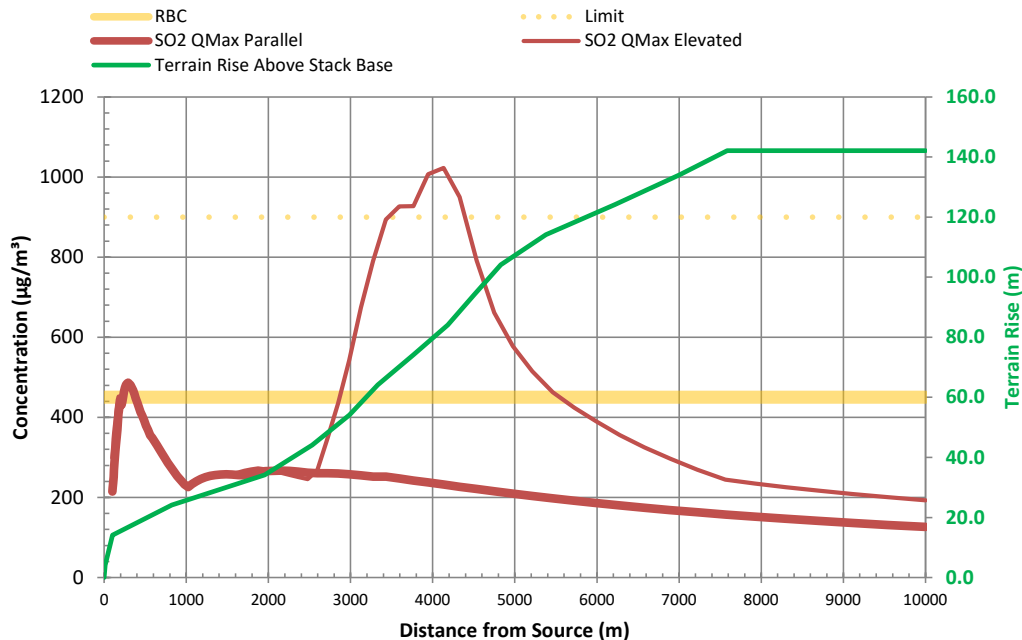


**Figure 18:    Blowdown Modelling Output from oAERMOD**

# 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 (iUSERMET)

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:

<div align="center">

http://www.albertamm5data.com/

</div>

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 one of the three levels of detail

| Step 2 | Get LCC Data | | |
|---|---|---|---|
| | | | Get Detailed LCC Data |
| | | | Get Screening LCC Data |
| | | ☐ Manual Entry | Use Single LCC Type |
| | 2.1 | Press 'Get LCC Data' to get LCC data from web and process it for the study area | |
| Land-Use Tiff | | P:\ERCBtools\libLCC\CanadaLandcover2015\CAN_LC_2015_CAL.tif Canada | ▼ |
| Map Sheets | 082o | | |

- the Get Detailed LCC Data button, processes the 'Land-Use Tiff' selected within the modelling domain. This is the most complex method and is suitable for an intermediate or refined modelling assessment. The data are summarized into the 'AERSURFACE Land-use Classification Codes' table and 'AERMET Site-Specific Site Characteristics' table. The detailed LCC data are used for creating meteorological data sets using MM5 extracted SAMSON and RAOBS files.

- the Get Screening LCC Data button, loads the pre-determined seasonal Albedo, Bowen Ratio and Roughness for the closest 10km x 10km grid cell within Alberta, British Columbia or Saskatchewan. These data are loaded into the 'AERMET Site-Specific Site Characteristics' table and are used to create a screening meteorological file using MAKEMET.

- the Use Single LCC Type button, displays a dialog window (see below) where the user can select a land-use type.  The selection used to fill the 'AERMET Site-Specific Site Characteristics' table and are used to create a screening meteorological file using MAKEMET

Create Reduced ScreeningMet

Landuse

- Coniferous Forest (10)
- Deciduous Forest (20)
- Mixed Forest
- Shrubland
- Cultivated Land (30)
- Grassland (40)
- Urban (50)
- Swamp/Wetland (60)
- Water (70)
- Quarries/Strip Mines/Gravel
- Barren/Rock/Earth Clay
- Perenial Snow Cover

CANCEL          OK
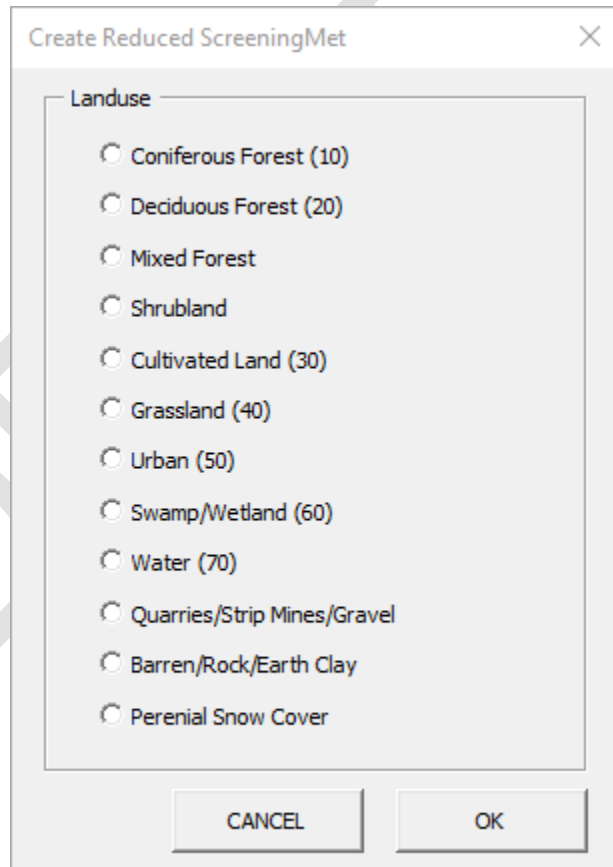
When the Get Detailed LCC Data button is pressed, *AERflare* determines the NTS map sheets required for the LCC assessment.  The map sheets are output to the Map Sheets field on the page.  *AERflare* then checks the LCCLIB local library if the LCC map sheet data has already been down loaded (see also 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* methodology.  Surface roughness is determined based upon the LCC within 3 km (variable rrough) of the flare location and Bowen ratio and albedo are determined based upon LCC data within 5 km (variable ralbbow) of the flare location.

The 'Get Detailed 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 (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 3 | Create Site Specific Screening+ User Met (OPTIONAL) | | Create ScreenMet |
|---|---|---|---|
| 3.1 | Enter the full path for MAKEMET output file X.sfc.  The x.pfl will be created in the same folder | | |
| 3.2 | Press 'Create ScreenMet' to create a site specific **SCREENING*** meteorological file | | |
| 3.3 | ScreenMet.sfc and ScreenMet.pfl will be created in the Screen Met Folder | | |

| BIN | FOLDER | BROWSE | COMMENTS |
|---|---|---|---|
| Screen Met filename | P:\ERCBtools\AERflare\dev\ScreeningMet_117.295W_55.157N.sfc | ... | |

## Step 4-Get MMEU Data

For intermediate and refined air dispersion modelling, a site-specific meteorological data file will be required. This requires a SAMSON (surface) and a RAOBS (upper air) data file. Within Alberta, these files are freely available based upon MM5 pre-processed data set. The process of extracting the data is listed below. Otherwise, the user can make use of files created or available from other means.

| Step 4 | Get MMEU Data |
|---|---|
| | This step extracts detail meteorology from Alberta MM5 data |
| 4.1 | Start the MMEU Multi-Model Extraction Utility |
| 4.2 | Select the 'AERMOD' output file type |
| 4.3 | Enter the UTM coordinates of your site and UTM zone, as listed in Step 1 |
| 4.4 | Selection 'Interpolate from 4 Closest Cells' Extraction Option |
| 4.5 | Ensure start date is January 1, 2002 and end date is December 31, 2006 (corresponding to dates below) |
| 4.6 | Press 'Check Inputs' button to ensure inputs are valid |
| 4.7 | Press 'Extract' button to start extraction process using MMEU |
| 4.8 | A dialog window will appear. Enter the location for SAMSON.dat and RAOBS.dat files. Record your entries for Step 5 (below). 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 4 is started well in advance of the air dispersion modelling analysis. |

| Dates Selected | |
|---|---|
| Start Date | January 1, 2002 |
| End Date | December 31, 2006 |

The Start Date and End Date are used for the relevant date range in the site-specific processing below.

## Step 5-Create Site-Specific 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 5 | Create Site Specific Refined User Met | | Create UserMet |
|---|---|---|---|
| 5.1 | Enter the time zone for the well location | | |
| 5.2 | Enter the full path for input files SAMSON.dat and RAOBS.dat. These are the output files from MMEU. | | |
| 5.3 | Enter the full path for AERMET output file X.sfc. The X.pfl will be created in the same folder. | | |
| 5.4 | Press 'Create UserMet' to create a site specific **REFINED** meteorological file | | |
| 5.5 | AERMOD.sfc and AERMOD.pfl will be created in the Refined Met folder | | |

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

| BIN | FULL PATH | BROWSE | COMMENTS |
|---|---|---|---|
| SAMSON.dat (input) | p:\2020\2001100–SpringBank\data\monitor\mm5\samson.dat | ... | |
| RAOBS.dat (input) | p:\2020\2001100–SpringBank\data\monitor\mm5\raobs.dat | ... | |
| REFINED Met (output filename) | P:\ERCBtools\AERflare\dev\test working folder\aermod.sfc | ... | |

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.

# Meteorological Summary (oMETSUM)

The **oMETSUM** (meteorology summary) page can be used to summarize an *AERMOD* meteorological data file (\*.SFC). The processing provides:

- wind rose – the wind rose provides a representation of the frequency of the wind speeds as a function of wind angle. The wind rose is presented in an area preserving format that does not distort the perception of frequency.
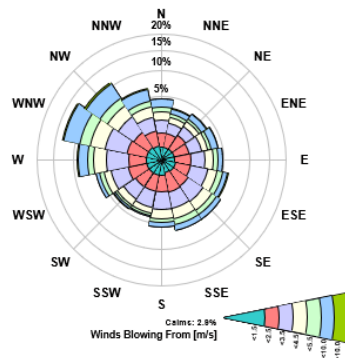


- The number of hours of meteorology for each year. The number of hours can be an important consideration for the application of risk based criteria.



- Stability Class Histogram – The stability class histogram shows the frequency of stability class as a function of time of day. Although AERMOD uses micro-meteorological processing for dispersion calculations, the Pasquill-Gifford (PG) stability classes remain an important representation of turbulence structure and is readily interpreted. Class A,B,C result from solar insolation and are only created during daylight hours.
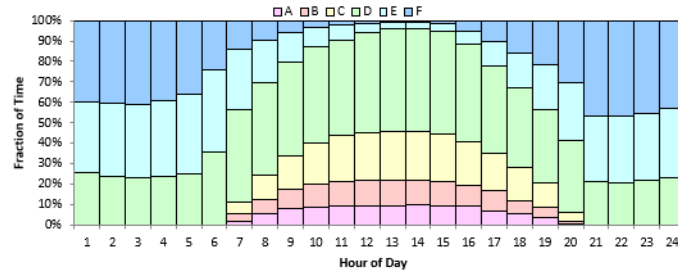
- Mixing Height –
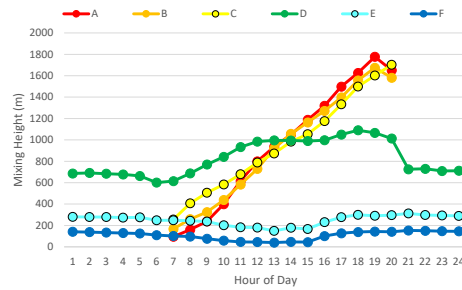


- Wind Speed –
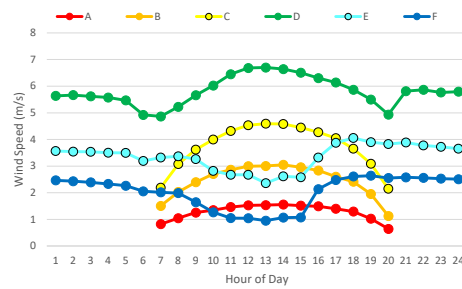


- Wind Speed Statistics –
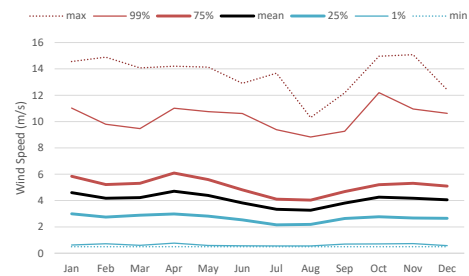


- Wind Speed Histogram – This chart is a histogram of the wind speeds. The bin sizes are shown in the table next to the chart on the spreadsheet.
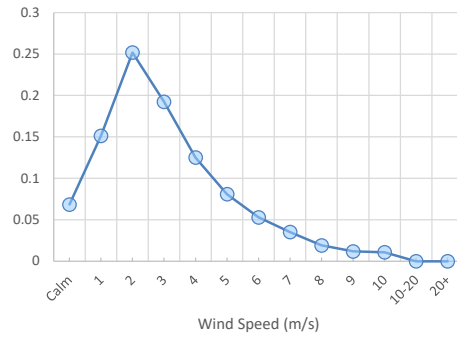
- Temperature – This chart shows the ranges of temperature statistics as a function of month for the data set.
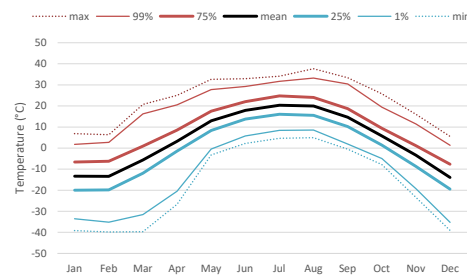


- Meteorological QA/QC – the AERMOD program source code includes internal QA/QC of the meteorological data provided in the SFC file. The QA/QC is duplicated in AERflare and a summary table is provided. Conditions for warnings of meteorological hours that outside of typical ranges are listed in the table

### Meteorology QA/QC

| Parameter | Conditions | Count |
|---|---|---|
| Calms | (Ua = 0) | 0 |
| Wind Speed | (Ua >= 90) Or (Ua < 0) | 0 |
| Wind Direction | (WD > 900) Or (WD <= -9) | 0 |
| Temperature | (Ta > 900) Or (Ta <= 0) | 0 |
| Obukov Length | (OBULEN < -99990) | 0 |
| Mechanical Mixing Height | (ZiMech > 90000) Or (ZiMech < 0) | 0 |
| Convective Mixing Height | (ZiConv > 90000) Or (ZiConv < 0) | 4 |
| Ustar | (Ustar < 0) Or (Ustar >= 9 | 0 |
| Wstar | (Wstar < 0) And (OBULEN < 0) | 0 |

- Summary Tables – The data for each of the summary charts are listed matrices at the bottom of the page.

# Site-specific Terrain (iUSERTER)

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

## *Step 1- Define Receptor Grid*

The iUSERTER page is used to create a user defined terrain and receptor grid using nested discrete receptor locations.

Step 1 in defining the grid is to set the center location. By default, the center location is the source location. Press the REFRESH button to copy the coordinates from the iFACILITY page. The UTM X,Y coordinate pair can be entered manually by typing the X,Y and UTM zone; then press the RECALC button to initialize the geographical latitude and longitude.



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.

Receptor spacing is defined by the table illustrated below. Each grid is defined by a resolution (spacing between points in X and Y) and the radius (distance from source). Within the radius the area is filled with receptors points with the prescribed resolution. The grid is series of nested grids beginning with the facility fenceline (ID=1). The resolution for ID=1 is the spacing of receptor points along the fence not within the fenceline. For ID=2 to 7, the resolution is spacing of grid points within each radius. The default values provide a resolution that meets the Alberta Air Modelling Guidelines. ID=3 and ID=7 are inserted to quickly add higher resolution as required. The total number receptor points are estimated. Duplicate receptor points are removed. The chart below the table visualizes the receptor spacing as a function of distance.

Reset to Default

**Receptor Grid Spacing**

| ID | Resolution (m) | Default (m) | Radius (m) | Default (m) | Receptors |
|----|----------------|-------------|------------|-------------|-----------|
| 1 | 20 | 20 | 100 | 100 | 161 |
| 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 | 1521 |

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



Copy Chart
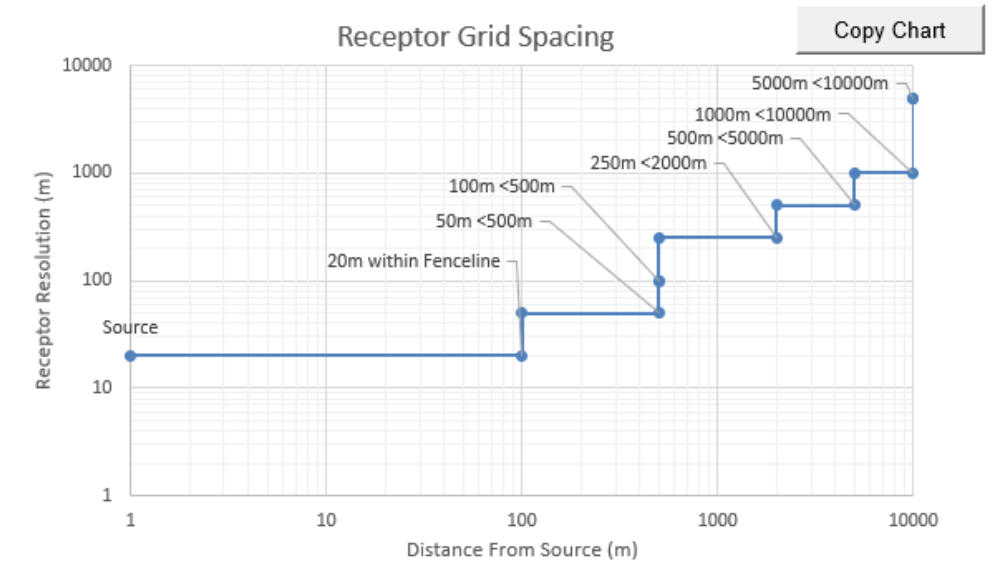
# Step 2-Create Receptors

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.

The receptor grid is created using the DEM data as defined on the IBIN page and the grid definition defined in the table above. Modifiers listed below can be used to adapt to different circumstances:

- Read User Receptor Grid – allows the user to define their own receptor spacing as defined by a file listing X,Y pairs in CSV format with no header

- Read Fenceline from *.CSV – by default AERflare assumes a well pad with 100m radius with the source at the center. A site-specific fenceline can be entered by providing a file listing of X,Y pairs in CSV format with no header.

- Fill Fenceline with receptors – on-site air quality can be assessed by including receptors within the fenceline. The resolution of the receptor spacing within the fence is entered in the prompt as shown below.

- Read sources list from *.CSV – a receptor grid should provide a minimum resolution of 50m receptor spacing within 500m of each source. The receptor grid can be created for use with multiple source by importing the source list as a list X,Y pairs in CSV format with no header.

- Read user DEM *.CSV – site-specific DEM information can be imported rather than using the DEM information from IBIN page.  This may be useful for developing input files from different countries which may use a DEM format that is not supported by AERflare.  In this case, the user can prepare an X,Y,Z file in CSV format that is large enough to cover the modelling domain and buffer outside of the domain for hill-height processing. The resolution of the user DEM file should be sufficient

so that receptor can use nearest neighbour processing for terrain elevations.

| 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 downloaded as required or loaded from DEMLIB.<br>☐ Read User Receptor Grid     ☐ Read User DEM *.CSV File<br>☐ Read fenceline from *.CSV file<br>☑ Fill fenceline with receptors<br>☐ Read sources list from *.csv file | | |
| 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 INPUT | BROWSE | COMMENTS |
|---|---|---|---|
| receptor.csv | | ... | |
| dem.csv | | ... | |
| fence.csv | | ... | |
| sources.csv | | ... | |
| fill resolution (m) | 20 | | |

| BIN | FULL PATH FOR OUTPUT | BROWSE | COMMENTS |
|---|---|---|---|
| receptors.ter | P:\2021\receptors.ter | ... | |

| Map Sheets | 083n |
|---|---|

Depending upon the modifiers selected, the user will be prompted for the full path of the associated files. The receptor grid is output to the file as specified in the **receptor.ter** prompt. Receptor grid is created by pressing the Create Receptors button.

# Step 3-Find the Maximum

AEP 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 example, 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 | 482000.0 |
| Y UTM | 6113000.0 |
| UTM Zone | 11 |
|  | Conversion to Geographic Coordinates |
| Longitude | -117.2825 |
| Latitude | 55.1633 |

RECALC

Reset to Default

**Receptor Grid Spacing**

| ID | Resolution (m) | Default (m) | Radius (m) | Default (m) | Receptors |
|---|---|---|---|---|---|
| 1 | 20 | 20 | 20 | 100 | 17 |
| 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 | 865 |

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

The receptor grid is illustrated in a chart RECEPTOR GRID and the fenceline is shown in relationship to the list of sources in the chart FENCELINE. At the bottom of the page, the fenceline, receptor grid, sources list and domain are listed.

RECEPTOR GRID

FENCELINE
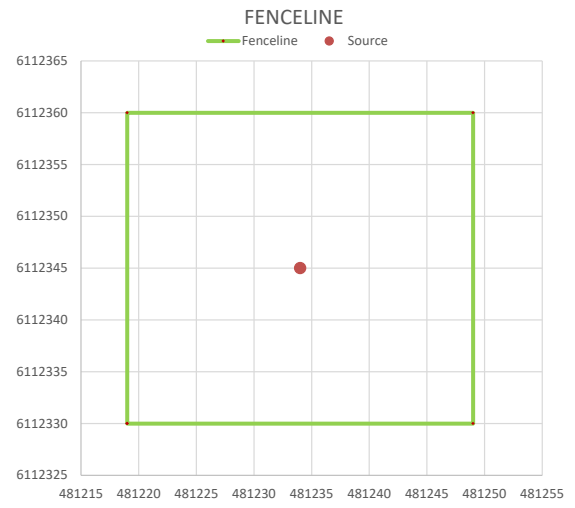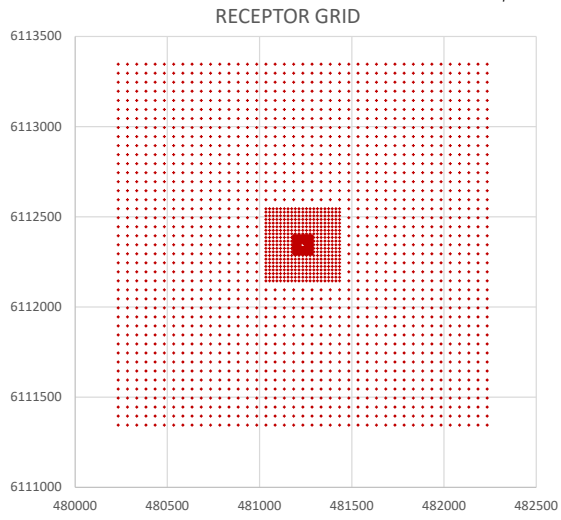
# Post-Processing External Refined Modelling Output (oPOSTPROCESS)

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 where used:

```
OU PLOTFILE 1 ALL FIRST myplot.dat
OU POSTFILE 1 ALL UNFORM 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 piles 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 | | ... | | ☐ 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/m² | 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 $SO_2$ or $H_2S$ 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, QMID 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/m³ | 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/m³ | 1292 | 8760 |
| | spring or yr 2 | µg/m³ | 1130 | 8760 |
| | summer or yr 3 | µg/m³ | 1149 | 8784 |
| | fall or yr 4 | µg/m³ | 1117 | 8760 |
| | month or yr 5 | µg/m³ | 1112 | 8759 |
| Concentration RBC (99.0th) | winter or yr 1 | µg/m³ | 236 | 8760 |
| | spring or yr 2 | µg/m³ | 299 | 8760 |
| | summer or yr 3 | µg/m³ | 311 | 8784 |
| | fall or yr 4 | µg/m³ | 328 | 8760 |
| | month or yr 5 | µg/m³ | 297 | 8759 |

This table is similar to what the user has already seen on the **oAERMOD** 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 | µg/m³ | VARIABLE | INPUT % | µg/m³ |
|---|---|---|---|---|---|
| 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.
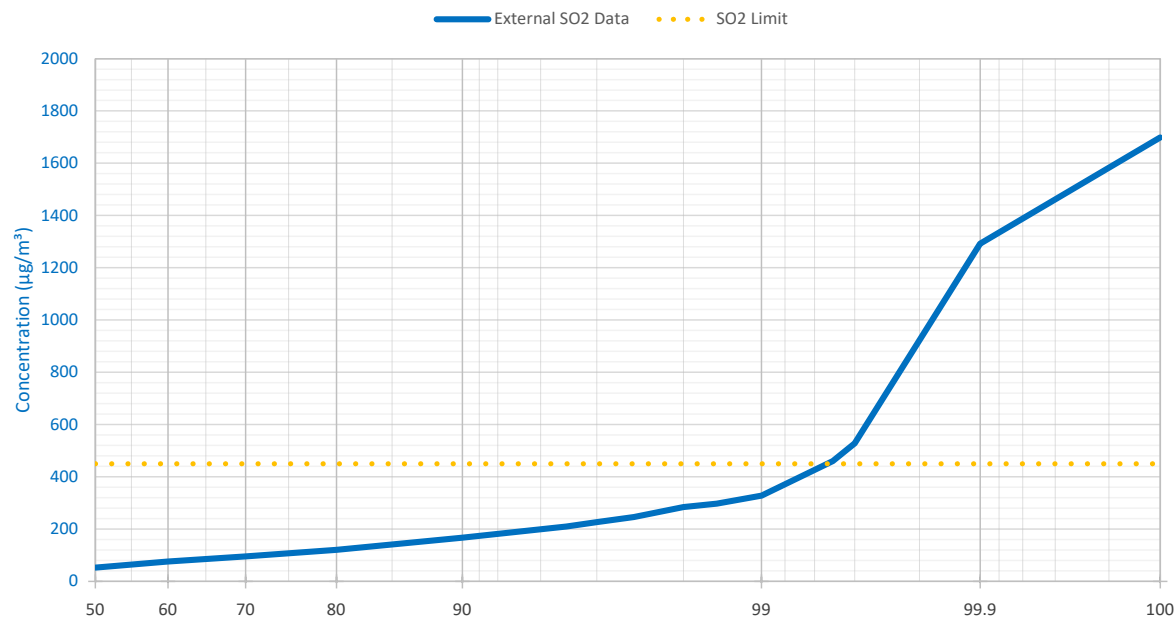
**Figure 19:** **Probability Density Function Curve Determined from the Maximum of Annual Statistics**

# 7.   BATCH OPERATIONS

The *AERflare* spreadsheet tool provides a rapid screening tool assessment for many types of flaring and incineration assessments with a user-interface principally intended for individual scenario assessment.  The batch page, included with *AERflare*, adds the ability to consecutively process a list of scenarios for sensitivity analysis, what-if analysis or to 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 $SO_2$ 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**, **iSOURCE**, **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.

    o All lines with a "1" in the run column will be loaded and processed during a batch mode operation.

    o 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.

    o 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. That said, a button was added to the **oBATCH** page to scan for differences between the **iBATCH** and **oBATCH**. The user is prompted when a difference is found and the processing will delete the **oBATCH** (ie, outputs only) without affecting the iBATCH inputs.

# 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**, **iSOURCE**, **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**, **iSOURCE**, **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**, **iSOURCE**, **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**, **iSOURCE**, **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 µg/m³. Since this concentration is greater than the $SO_2$ objective of 450 µg/m³, 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/m³ | 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/m³ | NA | NA | NA |
| RBC Maximum Concentration RBC (99.0th) | µg/m³ | 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 **iSOURCE** page, press ⸢Save to Batch Page⸥ 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 D: the selection of Permit vs Evaluation flaring option

   b. Column E: the selection of Continuous/Planned/Unplanned flaring option

   c. Column F,G,H: the selection of the calculation method to be used OPTION_USERMET, OPTION_USERTER, OPTION_NORUN

   d. Column E: the path to the meteorological data file has been entered correctly or leave blank to use a screening file determined by the location (western Canada only).

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; 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 BZ on the **oBATCH** page. The results for a 55 m stack are 486 µg/m³ and the results for a 60 m stack are 431 µg/m³.

# 8.    EXAMPLES

Four examples are included in this *AERflare* user guide

| Example 1 | Flare-Site A Screening | This is the example provided in the *ERCBflare* V1 user guide.  The terrain was based upon a specific location, but the coordinates were arbitrarily selected. |
| Example 2 | Flare-Site A Refined Assessment | 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 | Flare-Site B Blowdown | 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 | Incinerator-Site A | This is an example of an incinerator at Site-A. |

The locations of the sites used in the examples are shown on the left of Figure 20.
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 20
are plotted the worst-case terrain elevations as a function of distance from the
flare location.
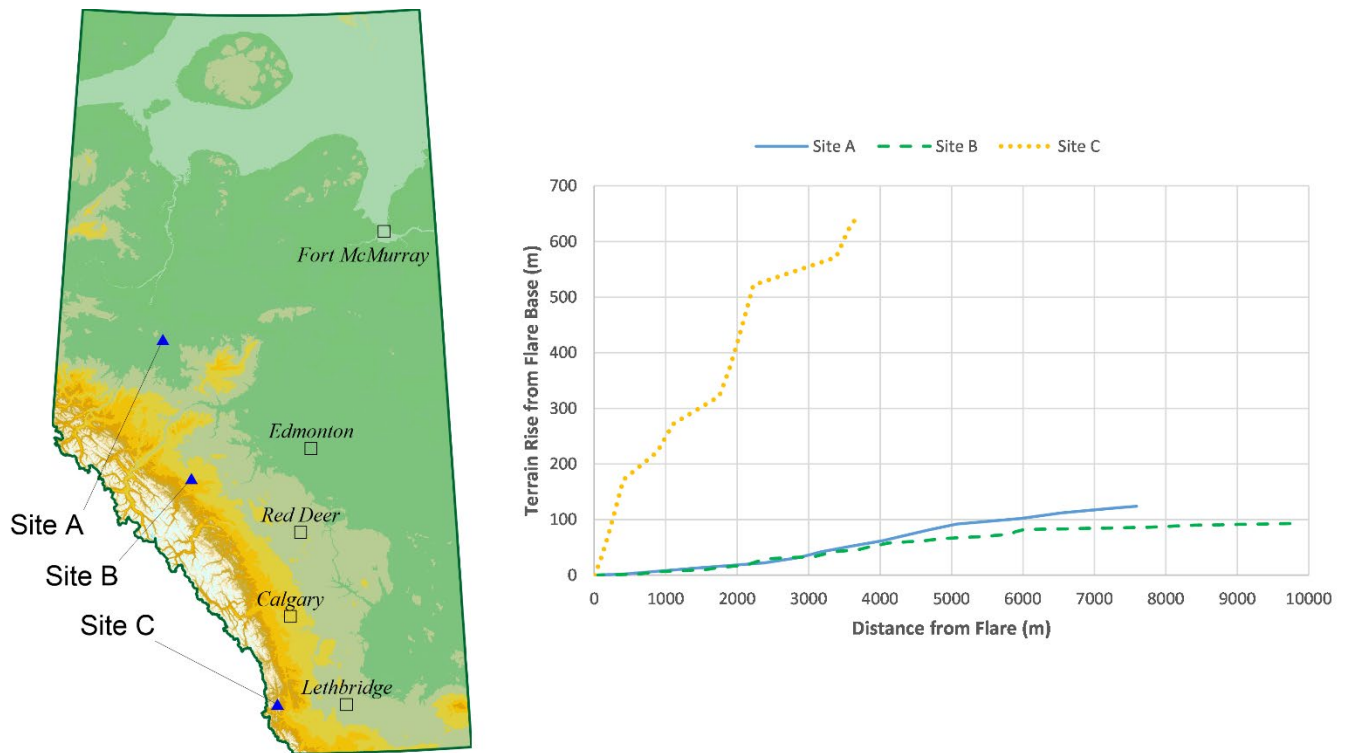
**Figure 20:** Locations and Worst-Case Terrain Rise around Sites used in the AERflare examples.

# Example 1 – Flare

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.

| Surface Location (LSD-SEC-TWP-RGE W?M) | | 01-02-003-04-W5M | |
|---|---|---|---|
| Mapping Datum | | NAR-B | NAR-B ▼ |
| Mapping Projection | | UTM | UTM ▼ |
| UTM Zone | | 11 | 11 (120W - 114W - Northern Hemispere) ▼ |
| **Surface Coordinates of Device** | X Coord (m Easting) | 481234 | |
| | Y Coord (m Northing) | 6112345 | |
| Device Base Elevation | m | 669.0926067 | |

On the **iSOURCE** page, the following entries define the scenario with a gas composition set to 100% $CH_4$ (methane).  Fuel gas is 100% $C_3H_8$ (propane).

| | | ERCBflarev1.05 Released | |
|---|---|---|---|
| Time of Year to Model the Event | -- | Annual ▼ | |
| **Pollutant** | | | |
| Modelled Pollutant Emission | -- | SO2 ▼ | |

| | | | |
|---|---|---|---|
| Requested Maximum Raw Gas $H_2S$ Concentration for **Subject** Zone or Source | % (for Permits round up to 0.5% increment) | 30.10000% | PERMITS ARE FOR INCREMENTS OF 0.5% |
| **Physical Source Parameters** | | | |
| Stack Tip Exit Height | m | 30.5 | |
| Stack Tip Diameter, $D_f$ | mm | 305 | |
| Unobstructed Flow Diameter, $D_{...}$ | mm | 305 | |
| | | | ☐ Individual Stream for Lift |
| | | | ☐ Individual Stream for Fuel |

A continuous flare scenario is described below with settings for Qmax and Qave.

---

| | | Flaring Type? | ◉ Continuous or Steady<br>○ Transient | |
|---|---|---|---|---|

| Continuous or Steady | UNITS | ENTRY | WARNINGS |
|---|---|---|---|
| Maximum Raw Gas Flow Rate<br>for Source of Sour Gas | 10³m³/d<br>(15°C and 101.325 kPa) | 250 | |
| MUST enter any 2 of the fields:<br>i) VOLUME of Raw Gas to be Flared<br>ii) AVERAGE FLOW RATE of Raw Gas<br>iii) DURATION of Flaring | i) Volume 10³m³<br>(15°C and 101.325 kPa) | 400 | -- |
| | ii) Average Flow Rate 10³m³/d<br>(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) | ◉ Yes ○ No | Adjust Fuel Gas to Raw Gas Ratio manually in Cell C93-E93, then check dispersion results |
| Is the fuel gas rate controlled<br>mfgr (1=Fixed, 2=Controlled, 3=Fixed Rate) | -- | ○ 1. Fixed for Qmax flow<br>◉ 2. Variable<br>○ 3. Fixed Rate | Enter the FGR for Qmax,Qave,Qmin flows |
| | Maximum<br>(QMAX) | Average<br>(QAVE) | Minimum<br>(QMIN) |
| Fuel Gas to Raw Gas Volume Rate Ratio<br>(default is zero) | 0 | 0.1 | 0.2 |
| Fuel Gas Rate<br>10³m³/d (15°C and 101.325 kPa) | 0 | 12.5 | 6.25 |
| | | | |
| Warnings | Acceptable NHV: 30.3 MJ/m³ | Acceptable NHV: 35.4 MJ/m³ | Acceptable NHV: 39.7 MJ/m³ |

On the **iLOCATION** page, press the REFRESH button to update the location of the flare coordinates on this page. The button also performs a coordinate conversion of the UTM coordinates to 10TM and geographic Lat/Long. The maps below the coordinates table show the location of the flare within Western Canada. A map of the world is also provided.

On the **iTERRAIN** page, press the Get DEM Data button to perform a worst-case terrain assessment for the flare location. The worst-case terrain profile is plotted along with plume rise criterion (now archaic, but representative) that may be used as a general guide for anticipating the possible plume impingement with terrain and higher ground level predictions. A map that shows the locations of the critical terrain elevations is also provided.

press the Get DEM Data button is REQUIRED. You must perform the worst-case terrain assessment in order to perform screening assessments.

Using Screening Mode, the user does not need to select any meteorology or receptor file. On the **oModelling** page, press the Set Mode Screening button. This will direct AERflare to use screening meteorology based upon the location, worst case screening terrain. Using the AERflare v.3.01 predictions using calculation HbH screening method, the updated land use data and update pre-determined land-use screening meteorological data characterization, are shown below.

A summary of the modelling run is provide as shown below:

| Continuous or Steady | Planned Non-Routine Flaring | |
|---|---|---|
| AERMOD Version Used | 19191 | Use the latest AERMOD release version https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models#aermod |
| Meteorological File Used | | P:\ERCBtools\AERflare\dev\ScreeningMet_117.295W_55.157N.sfc |
| Terrain Insert File Used | | <screening> |
| AERMOD Output File Base | | <temporary> |
| # Hours in Meteorological File | 3209 | |
| Source Type | 1 | 1: Steady  2: Transient |
| Dispersion Model Predictions These results account for the duration of the flaring event and 1h hour averaging time. | **Annual** | |
| Calculations terminated successfully | TRUE | blank=FALSE, TRUE=successful |

Which is followed by a summary of the modelling predictions.

| SO2 Predictions | Units | Maximum 1h (QMAX) | Average 1h (QAVE) | Minimum 1h (QMIN) |
|---|---|---|---|---|
| Averaging time is (minutes): 60 and total event duration is (minutes): 4608.0 | | Worst Case of Parallel or Elevated Terrain Results | | |
| Duration used for averaging time correction | min | 60.00 | 60.00 | 60.00 |
| Maximum Concentration (100th) | µg/m³ | 4271 | 2669 | 1424 |
| Distance to Maximum Concentration | m | 443 | 385 | 5634 |
| Wind Speed | m/s | 20.0 | 20.0 | 1.0 |
| PG Stability Class | PG | D | D | F |
| Distance Concentration drops below Obj#1 of 450 µg/m³ | m | 10000 | 10000 | 10000 |
| Distance Concentration drops below Obj#2 of 9923 µg/m³ | m | -1 | -1 | -1 |
| Distance Concentration drops below Obj#3 of 45 µg/m³ | m | 10000 | 10000 | 10000 |
| Climit Maximum Concentration CMAX (99.9th) | µg/m³ | NA | NA | NA |
| RBC Maximum Concentration RBC (99.0th) | µg/m³ | NA | NA | NA |
| Compliance with Ambient Objective | -- | NA | NA | NA |

The modelling predictions are summarized from the results displayed on the oAERMOD page. The oAERMOD page displays the raw results for the parallel and elevated terrain predictions. For screening meteorology, the results are provided for each season; and, if the meteorological data set was a multi-year dataset, the results would be summarized for each year of meteorology. In this case, the maximum concentration was predicted for parallel terrain.

| 1-HOUR AVERAGES - Parallel Airflow Terrain | Variable | Units | Maximum (QMAX) | Average (Qave) | Minimum (QMIN) | 1-HOUR AVERAGES - Elevated Terrain Maximum (QMAX) | Average (Qave) | Minimum (QMIN) |
|---|---|---|---|---|---|---|---|---|
| Maximum Concentration | cmax | µg/m³ | 4271 | 2669 | 1097 | 4098 | 2564 | 1424 |
| Distance to Maximum Concentration | xmax | m | 443 | 385 | 351 | 464 | 404 | 5634 |
| Wind Speed | ws | m/s | 20 | 20 | 15 | 20 | 20 | 1 |
| PG Stability Class | PG | PG | D | D | D | D | D | F |
| Distance Concentration drops below Obj#1 | xobj1 | m | 10000 | 10000 | 5266 | 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 (99.9th) | winter or yr 1 | µg/m³ | 3557 | 2345 | 960 | 3476 | 2129 | 1287 |
| | spring or yr 2 | µg/m³ | 3422 | 2361 | 911 | 3425 | 1635 | 1050 |
| | summer or yr 3 | µg/m³ | 3395 | 2337 | 921 | 3409 | 1886 | 1154 |
| | fall or yr 4 | µg/m³ | 3201 | 2133 | 892 | 3087 | 2356 | 1424 |
| | month or yr 5 | µg/m³ | | | | | | |
| Concentration RBC (99.0th) | winter or yr 1 | µg/m³ | 2690 | 1954 | 840 | 2568 | 1629 | 988 |
| | spring or yr 2 | µg/m³ | 3308 | 2243 | 880 | 3317 | 1303 | 708 |
| | summer or yr 3 | µg/m³ | 3308 | 2229 | 875 | 3271 | 1415 | 756 |
| | fall or yr 4 | µg/m³ | 1677 | 1350 | 864 | 1637 | 1873 | 1197 |
| | month or yr 5 | µg/m³ | | | | | | |
| Likelihood of Concentrations being less than Ambient Objective | winter or yr 1 | -- | 56.565% | 63.530% | 73.286% | 56.101% | 91.665% | 96.047% |
| | spring or yr 2 | -- | 55.116% | 59.719% | 68.629% | 54.828% | 95.085% | 96.720% |
| | summer or yr 3 | -- | 52.715% | 59.684% | 68.018% | 52.335% | 94.538% | 96.747% |
| | fall or yr 4 | -- | 63.812% | 71.033% | 83.437% | 63.287% | 88.342% | 95.565% |
| | month or yr 5 | -- | | | | | | |

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 6. 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 6:** **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 |
| AERflare v3.01 [b] | 625.6 | 29.6 |

[a] Used modified US EPA method similar to AENV spreadsheet mod_flrcalcs.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?** | ◉ Continuous or Steady<br>○ Transient | | |
| **Continuous or Steady** | **UNITS** | **ENTRY** | **WARNINGS** |
| **Maximum Raw Gas Flow Rate** for Source of Sour Gas | 10³m³/d (15°C and 101.325 kPa) | 15 | |
| MUST enter any 2 of the fields:<br>i) **VOLUME** of Raw Gas to be Flared<br>ii) **AVERAGE FLOW RATE** of Raw Gas | **i) Volume** 10³m³ (15°C and 101.325 kPa) | | 22.500 |
| | **ii) Average Flow Rate** 10³m³/d (15°C and 101.325 kPa) | 7.5 | -- |
| iii) **DURATION** of Flaring | **iii) Duration** hours | 72 | -- |

On the **iLOCATION** page, press the REFRESH button to update the location of the flare coordinates on this page. The button also performs a coordinate conversion of the UTM coordinates to 10TM and geographic Lat/Long. The maps below the coordinates table show the location of the flare within Western Canada. A map of the world is also provided.

On the **iTERRAIN** page, press the Get DEM Data button to perform a worst-case terrain assessment for the flare location. The worst-case terrain profile is plotted along with plume rise criterion (now archaic, but representative) that may be used as a general guide for anticipating the possible plume impingement with terrain and higher ground level predictions. A map that shows the locations of the critical terrain elevations is also provided.

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

---

| Calculation | Meteorology | Terrain | Statistic | Concentration (µg/m³) | Concentration Limits (µg/m³) |
|---|---|---|---|---|---|
| Screening | Screening: AERflare default grid cell | Worst Case | Maximum | 636 | 450 |
| Intermediate | Site-specific (Screening) | Worst Case | Maximum | 606 | 450 |
| Intermediate | Site-specific | Worst Case | Maximum | 584 | NA |
| | | | CMAX=99.9th | 579 | 900 |
| | | | RBC=99th | 562 | 450 |
| Refined | Site-specific | Site-specific | Maximum | 560 | NA |
| | | | CMAX=99.9th | 412 | 900 |
| | | | RBC=99th | 316 | 450 |

Using Screening Mode, the user does not need to select any meteorology or receptor file.  In Screening Mode, *AERflare* determines the location of the flare and finds the closest 10km x 10km grid cell from pre-processed land-use. The grid cell land use is used to create a screening meteorological dataset using MakeMet.exe. Receptors are created using parallel terrain (flat) from 100m to 10km, and the worst-case terrain elevations. In Screening Mode, 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 SO$_2$ 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 Intermediate Mode, a site-specific screening meteorological dataset or site-specific full meteorology assessment to this flaring scenario. You can create a site-specific screening meteorological dataset on the **iUSERMET** page. On the **iUSERMET** page, Select the land-use Tiff in the 'Step 2' input group, then press the REFRESH button at the top of the page to ensure the coordinates on **iUSERMET** are the same as the flare location on **iFACILITY**. Press the Get Detailed LCC Data button to perform a site-specific land-use assessment. Once completed, the land-use within the modelling domain will be summarized for each land-use type and the Albedo, Bowen Ratio and surface roughness will be summarized by month.  In input group 3, press Create ScreenMet button to create a site-specific screening meteorological file using MakeMet or continue with Step 4 and Step 5 to create a site-specific refined meteorological dataset. In the Intermediate Assessment mode, the screening worst

case terrain is still used, therefore *AERflare* calculates both a parallel air flow and an elevated terrain prediction. The concentration predictions for the Intermediate Mode modelling are less than conservative Screening Mode results, but are still above the ambient guidelines. Because the results are greater than the ambient objectives, the next course of action would be to model using Refined Mode modelling.

If we proceed with Refined Mode modelling, both site-specific meteorology and site-specific terrain are required. Site-specific refined meteorology can be created using the steps on the **iUSERMET** page. A site-specific receptor file can be created using the steps on the **iUSERTER** page. To create a receptor file, press the REFRESH button on the top of the **iUSERTER** page to ensure the coordinates for the flare are the same as the **iFACILITY** page. Press the Reset to Default button to reset the dimension of the receptor grid to the default spacing and distances, and then make any changes according to your preferences. In Step 2, enter the output file name and path, then press Create Receptors to generate the AERMOD receptor grid. Back on the **oMODELLING** page, In the Refined Mode modelling option, *AERflare* does not calculate parallel air flow predictions, since the site-specific terrain includes all possible terrain and wind directions, however, it is recommended that both the parallel and elevated terrain modelling be performed. 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.

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 µg/m³ at the 99.9th percentile. In this case, the 99.9th percentile prediction is less than the 450 µg/m³ objective.

To investigate options to reduce the concentration, the **iBATCH** page can be configured to increase fuel gas in steps. On the **iSOURCE** page, select 'YES' for Is Fuel Gas Added? Enter 0.1 in each of the entry locations. At the top of the **iSOURCE** 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= 100th Percentile [µg/m³] | Climit1=99.9th Percentile [µg/m³] | RBC=99th Percentile [µg/m³] |
|---|---|---|---|
| 0 | 592 | 416 | 326 |
| 0.1 | 553 | 371 | 286 |
| 0.2 | 498 | 332 | 256 |
| 0.3 | 467 | 304 | 231 |
| 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 **iSOURCE** 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 AEP ambient air quality guideline of 450 µg/m³ at a modelled 99.9th percentile.

| Stack Height (m) | Maximum Concentration= 100th Percentile [µg/m³] | Climit1=99.9th Percentile [µg/m³] | RBC=99th Percentile [µg/m³] |
|---|---|---|---|
| 27 | 592 | 416 | 326 |
| 35 | 576 | 317 | 247 |
| 40 | 554 | 273 | 217 |
| 45 | 550 | 272 | 188 |
| 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 **iSOURCE** 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 Refined Mode option on the
**oMODELLING** page. The results are compared below.

| Time of Year to Model | Maximum Concentration= 100th Percentile [µg/m³] | Climit1=99.9th Percentile [µg/m³] | RBC=99th Percentile [µg/m³] |
|---|---|---|---|
| Annual | 592 | 416 | 326 |
| November | 590 | 415 | 306 |
| 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 RBC=306 µg/m³ prediction will meet
the end point of 450 µg/m³. The RBC prediction is created from 11040 data
points (see **oSUMMARY** in the Minmum Number of Meterological Data
Points in a year cell C83) out of the total (annual) meteorological data set of
43824 (# Hours in Meteorological File on **oMODELLING**). 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=11040). 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.

| Requested Maximum Raw Gas H₂S Concentration for **Subject** Zone or Source | % (for Permits round up to 0.5% increment) | 42.00000% |
|---|---|---|
| **Physical Source Parameters** | | |
| Stack Tip Exit Height | m | 30.5 |
| Stack Tip Diameter, D$_f$ | mm | 609.6 |
| Unobstructed Flow Diameter, D$_{...}$ | mm | 609.6 |

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 **iSOURCE** page.

|  | Flaring Type? | ○ Continuous or Steady<br>⦿ Transient |
|---|---|---|

When `Transient` is selected, the Continuous or Steady section of the **iSOURCE** inputs is grayed out, and the Transient Source section of inputs is activated. The transient blowdown can be described in several different ways: pressure vessel description; initial (peak) flowrate and volume; initial flow rate and time duration to a percentage of initial pressure; or, average flowrate and time duration to a percentage of initial pressure. In most cases, for safety, a facility or plant will depressurize to 50% within 15min; and, therefore, the blow down can be described by either the initial flowrate or average flowrate. In the following example, a vessel is depressurized.

| **Transient Source** | **UNITS** | **ENTRY** |
|---|---|---|
| Define the transient in one three ways: description of initial equivalent vessel conditions, Qmax/Vol or Qave during the depressurization | -- | ⦿ 1. Vessel Description<br>○ 2. Qmax & Volume<br>○ 3. Qave (50% in 15min)<br>○ 4. Qmax (50% in 15min) |

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 | -- | ○ 1. Equal Duration  ◉ 2. Equal Mass |
| Raw Gas User Initial Maximum Flow Rate, QMAX | 10³m³/d (15°C and 101.325 kPa) | |
| Raw Gas User Total Volume within vessels/pipes, QTOTAL | 10³m³ (15°C and 101.325 kPa) | |
| User selected # of puffs, NPUFFS | -- | 3 |
| User selected puff duration, PUFDUR | 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 method 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
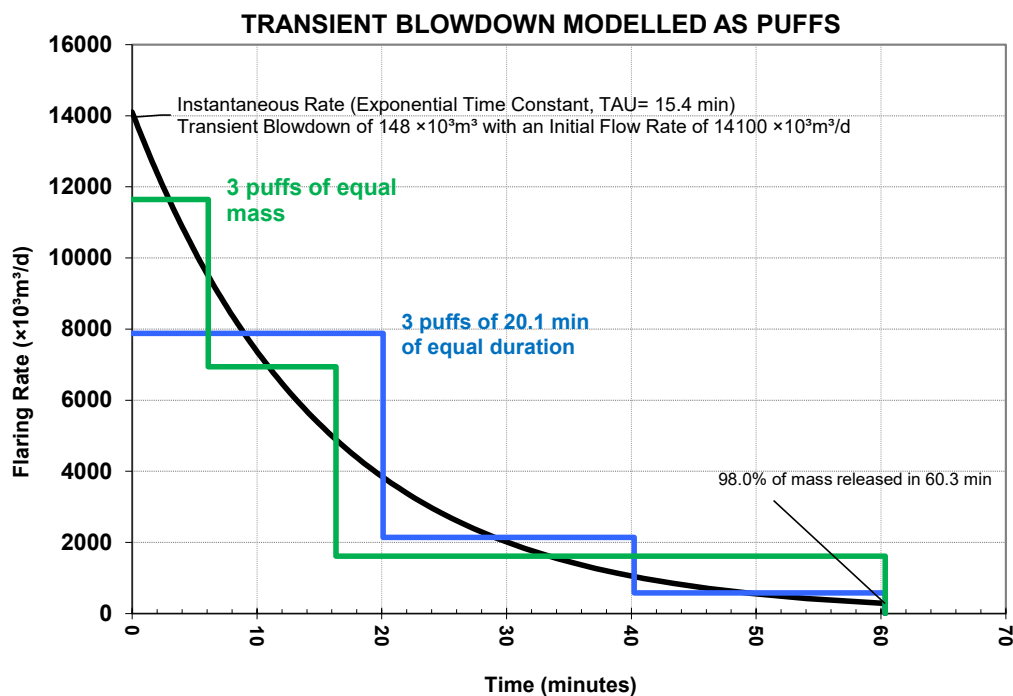


The table Flowrates Modelled summarizes the steps as Qhi, Qmed and Qlo.  In this case, the Qhi duration is 6.10 minutes, Qmed is 10.24 minutes and Qlo is 43.99 minutes.  The flowrate Qhi, Qmed and Qlo will be modelled in *AERflare* replacing the Qmax, Qave and Qmin flow rates for a steady flare, and then combined to account for the duration of each step.

Flowrates Modelled

| Description | Units | Qhi | Qmed | Qlo |
|---|---|---|---|---|
| Equal Duration | 10³m³/d (15°C and 101.325 kPa) | 7878 | 2138 | 580.4 |
| End of step | minutes | 20.11 | 40.22 | 60.33 |
| Duration | minutes | 20.11 | 20.11 | 20.11 |
| Equal Mass | 10³m³/d (15°C and 101.325 kPa) | 11650 | 6938 | 1615 |
| End of step | minutes | 6.10 | 16.34 | 60.33 |
| Duration | minutes | 6.10 | 10.24 | 43.99 |
| Volume Flowrate to Be Modelled | 10³m³/d (15°C and 101.325 kPa) | 11650.00 | 6938.00 | 1615.00 |
| Duration | minutes | 6.10 | 10.24 | 43.99 |

Using the Screening Mode method, the output of the air dispersion modelling for the transient blowdown is shown in the table below.  The individual outputs, Qmax, Qave and Qmin 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 (Qhi) produces a very high ground level concentration (18963 µg/m³) but is only present for 6.1 minutes,

---

therefore the hourly time average equivalent of this phase alone is 18292*6.1/60 = 1860 µg/m³ (see also the **oAERMOD** page output for intermediate results). The middle phase (Qmed), and the last phase (Qlo) produces a ground level concentration of 3310 µg/m³ and 13898 µg/m³ averaged over 10.4 min and 43.96 min, respectively.  In this case, the average concentration over the hour, is approximately the summation of the components (because the blowdown duration is approximately 1h), and equals 18963 µg/m³. This result exceeds the regulatory limit of 450 µg/m³ and additional modelling refinements are required.

| Calculation Option | Meteorology | Terrain | Individual Output | Concentration 1h Time Average (µg/m³) | Transient Blowdown 1h Time Average [µg/m³] | Concentration Limits (µg/m³) |
|---|---|---|---|---|---|---|
| Screening | Screening: AERflare Grid Cell | Worst Case | Qmax | 1860 | 18963 | 450 |
| | | | Qave | 3310 | | |
| | | | Qmin | 13898 | | |

*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 **oAERMOD** screening case or the more refined **oPOSTPROCESS**, both include approximations since *AERMOD* is not capable of the required complexity of dispersion modelling.

Using the Intermediate Mode and Refine Mode options, more refined predictions for the transient blowdown.  In both cases, the predictions do not meet the endpoints for RBC (99th) nor the allowable maximum (99.9[th]).  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 Option | Meteorology | Terrain | Statistic | Concentration (µg/m³) | Concentration Limits (µg/m³) |
|---|---|---|---|---|---|

| Screening | Screening: AERflare Grid Cell | Worst Case | Maximum | 18963 | 450 |
|---|---|---|---|---|---|
| Intermediate | Site-specific | Worst Case | Maximum | 12240 | NA |
| | | | CMAX=99.9th | 6344 | 900 |
| | | | RBC=99th | 2412 | 450 |
| Refined | Site-specific | Site-specific | Maximum | 12029 | NA |
| | | | CMAX=99.9th | 5580 | 900 |
| | | | RBC=99th | 1857 | 450 |

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# *Appendix A*

The *AERflare* spreadsheet was designed to use a platform that provided transparency for 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 calcmaxcr(…)

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.

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

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.

**TRANSIENT BLOWDOWN MODELLED AS PUFFS**

━━ Instantaneous Rate     ━━ Equal Duration Puffs     ━━ Equal Mass Puffs

Transient Blowdown of 148.0 e³m³ with an Initial Flow Rate of 655 e³m³/d

Exponential Time Constant, TAU= 36.0 min

**3 puffs of equal mass**

**3 puffs of 428 min duration**

97.9% of mass released in 1284.3 min

Flaring Rate (e3m3/d) — Time (minutes)
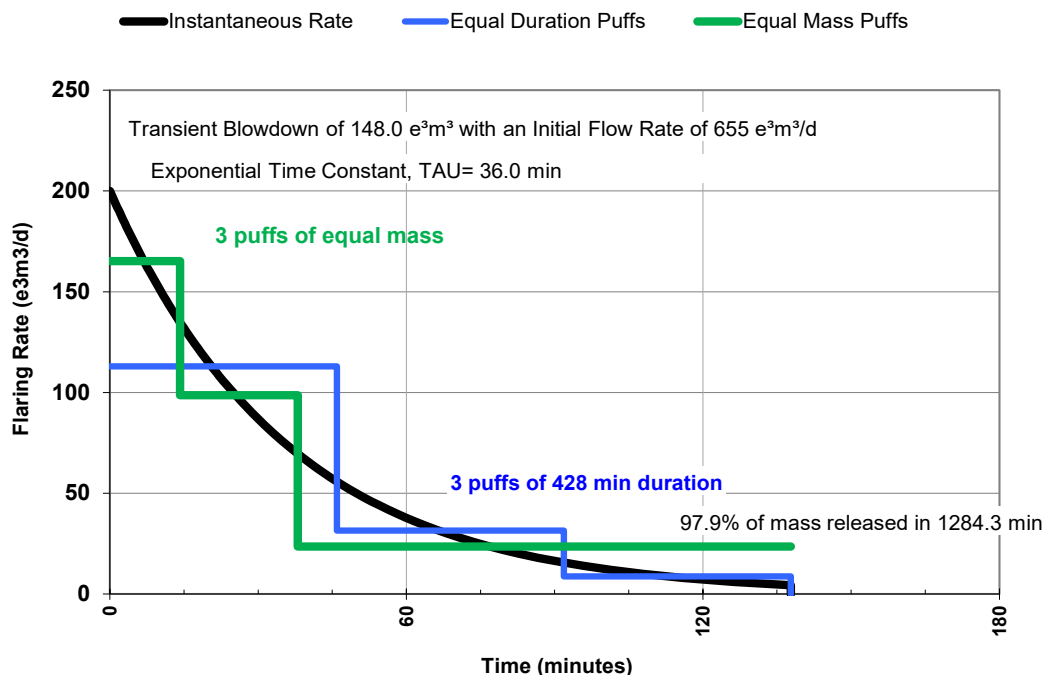
This function can also be used with inputs of consecutive predictions. For instance, for the blowdown sequence above, the green line represents the real durations (14 min, 24 min, and 100 min) for three modelling runs at rates (165 e3m³/d, 99 e3m³/d and 24 e3m³/d, respectively). Each rate is modelled 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 µg/m³; 25 µg/m³, respectively). Using the *CalcMaxCR(...)* function the real 1 hour average (worst case) concentration is calculated to be 62.5 µg/m³:

```
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 µg/m³, 24 min at 75 µg/m³ and 22 min (ie the fraction of the 1 hour period remaining) at 25 µg/m³. Alternatively, a 1 hour period could be composed of 24 min at 75 µg/m³ and 36 min at 25 µg/m³, or 60 min at 25 µg/m³.

In the above example, it doesn't appear necessary to examine all of the sequential combinations since the maximum concentration of 100 µg/m³ 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 calculations 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:

$$ws = ws_{ref} \left( \frac{\max(h_s, 10\,\mathrm{m})}{h_{ref}} \right)^{plx0}$$

(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:

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

<div align="right">(A.3)</div>

The constants are chemical specific and are listed on the **PROPERTIES** page (see section label Table D1).  The low temperature constants (a1, a2, a3, a4, and a5) are listed at a reference temperature of 25 °C along with a high temperature range (b1, b2, b3, b4 and b5).  Correction factor a1*, is used to make the low range values match at the GPSA reference temperature of 15 °C.  Correction factor b1*, 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 cpo (kJ/(kmol·K)) is the molar heat capacity, R (kPa·m$^3$/(kmol·K)) is the universal gas constant, $T$ is the temperature for molar heat capacity (Kelvin), RANGE (a_low) is a range variable pointing to the chemical specific molar heat capacity $a$ series low temperature parameters (see **PROPERTIES** page), 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:

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

(A.4)

Where the lead constants a1, a2, a3, a4, a5, a6 and a1* 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 (b1, b2, b3, b4, b5, b6, and b7 respectively) for chemical mixtures. There is a discontinuity between the two temperature ranges. To avoid this behaviour, a correction factor, *b7 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_rangeadjust(TRUE or FALSE))
```

Where $h_o$ (kJ/kmol) is the enthalpy, R (kPa·m$^3$/(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_rangeadjust* parameter is an optional parameter (default is TRUE) to include or not include the $a_6$ parmameter. The *use_rangeadjust* 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 at is used in the *AERpro* to determine to position and dimension of the flare flame.  The position parameter XL is a function is 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, Critcal_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 FORTRAN 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 Bochkanov 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/

# *Appendix B*

Values are listed for the following seasonal categories:
1. Midsummer with lush vegetation;
2. Autumn with unharvested cropland; (NOT USED)
3. Late autumn after frost and harvest; or winter with no snow;
4. Winter with continuous snow on ground;
5. Transitional spring with partial green coverage or short annuals

**ROUGHNESS FOOTNOTES**

1. Values are listed for the following seasonal categories: 1 - Midsummer with lush vegetation; 2 - Autumn with unharvested cropland; 3 - Late autumn after frost and harvest; or winter with no snow; 4 - Winter with continuous snow on ground; 5 - Transitional spring with partial green coverage or short annuals
2. Estimate based on Stull, Fig 9.6. We have specified a larger roughness than the AERMET "calm open sea" roughness value because we have assumed that most of the water is closer to land and will experience waves and be closer to the shoreline, increasing roughness.
3. Assume 50% "High Intensity Residential" (22), 25% "Mixed Forest" (43), and 25% "Urban/Recreational Grasses" (85), using a weighted geometric mean value.
4. Based on the AERMET User's Guide (EPA, 2004a), Table 4-3.
5. For airport sites, assume 90% of land cover is "Transportation" with roughness similar to Class 31 (Bare Rock/ Sand/ Clay) and 10% is "Commercial/Industrial" with roughness similar to Class 22 (High Intensity Residential). For non-airport, assume 10% of land cover is "Transportation" and 90% is "Commercial/Industrial". Weighted geometric mean values are used.
6. Estimate based on Slade, Table 3-1, assuming the surface is not completely level due to inclusion of some larger rocks.
7. Estimate reflecting "significant surface expression"
8. Estimate reflecting significant mix of different land cover classes. A warning will be issued to the user if this category appears in more than 10% of the land cover data.
9. Assume "Mixed Forest" is 50% "Deciduous Forest" and 50% "Evergreen Forest", using a weighted geometric mean value.
10. Assume arid region would have approximately 50% less vegetation than a non-arid region.
11. Estimate based on Garratt, Table A6.

12. Estimate based on Slade, Table 3-1

13. Based on class 31 ("Bare Rock/Sand/Clay") for seasonal categories 1 &2 and 81, 82, 83 ("Pasture/Hay", "Row Crops" & "Small Grains") for seasonal categories 3, 4, & 5, with seasonal category 5 having a more similar amount of vegetation to seasonal category 3 and, therefore, the same roughness.

14. Estimate based on Randerson, Table 5.4

15. Assume 50% Mixed Forest (43) and 50% Emergent Herb Wetlands (92), using a weighted geometric mean value.

## ALBEDO FOOTNOTES

1. Values are listed for the following seasonal categories: 1 - Midsummer with lush vegetation; 2 - Autumn with unharvested cropland; 3 - Late autumn after frost and harvest; or winter with no snow; 4 - Winter with continuous snow on ground; 5 - Transitional spring with partial green coverage or short annuals

2. Estimate based on AERMET User's Guide, Table 4-1.

3. We assume no freeze of the water and no seasonal changes in albedo.

4. Estimate based on Stull, Table C-7 and Garratt, Table A8. Assume fresher snow and more ice in seasonal categories 3 & 4 and older snow in seasonal categories 1, 2, & 5.

5. Assume an equal mix of three classes: "High Intensity Residential", "Mixed Forest", and "Urban/Recreational Grasses."

6. Estimate based on Stull, Table C-7.

7. Estimate based on AERMET User's Guide, Table 4-1 albedo value for winter with continuous snow cover.

8. Estimate based on Garratt, Table A8.

9. Assume "Transitional" is similar to Class 84: "Fallow". A warning will be issues to the user if this category appears in more than 10% of the land cover data.

10. Estimate based on the average of Classes 41 and 42.

11. Estimate based on the non-arid shrubland having more vegetation that the arid-region shrubland.

12. Estimate based Class 51: "Shrubland (non-arid region)" for seasonal categories 1, 2 & 4 and AERMET User's Guide ("Cultivated Land") for seasonal categories 3 & 5.

13. Estimate based on AERMET User's Guide; assume more vegetation in summer and soil being wetter in spring than in fall.

14. Estimate based on AERMET User's Guide ("Cultivated Land") for seasonal category 3 & 4, and Garratt, Table A8 for seasonal categories 1, 2 & 5.

## BOWEN RATIO FOOTNOTES

1. Values are listed for the following seasonal categories: 1 - Midsummer with lush vegetation; 2 - Autumn with unharvested cropland; 3 - Late autumn after frost and harvest; or winter with no snow; 4 - Winter with continuous snow on ground; 5 - Transitional spring with partial green coverage or short annuals.

2.  Values for seasonal category 4 are based on the AERMET User's Guide (EPA, 2004a) and Oke (1978), Tables 4-2a-c, Bowen ratio values for winter with continuous snow cover, except for class 11 with the assumption the water does not freeze.
3.  Values for seasonal categories 1, 2, 3 & 5 are based on AERMET User's Guide (EPA, 2004a), Tables 4-2a-c and Oke (1978).
4.  Estimate based on composition being an equal mix of three classes: "High Intensity Residential", "Mixed Forest", and "Urban/Recreational Grasses."
5.  Estimate based on the Bowen ratio of "Transitional" being between the Bowen ratio of Classes 31 and 71.
6.  Assume "Mixed Forest" is composed of equal parts of "Deciduous Forest" and "Evergreen Forest."
7.  Estimate based on comparison to Bowen ratio for other classes."

## Season Surface Roughness

| Class Number | Class Name | SUMMER | Not Used | FALL | WINTER | SPRING | Reference |
|---|---|---|---|---|---|---|---|
| | | Seasonal Surface Roughness1 (m) | | | | | |
| | | 1 | 2 | 3 | 4 | 5 | Reference |
| 11 | Open Water | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | Stull [2] |
| 12 | Perennial Ice/Snow | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | Stull [2] |
| 21 | Low Intensity Residential | 0.40 | 0.40 | 0.30 | 0.30 | 0.40 | 50% 22 + 25% 43+ 25% 85[3] |
| 22 | High Intensity Residential | 1 | 1 | 1 | 1 | 1 | AERMET [4] |
| 23 | Commercial/Industrial/Transp (Not at Airport) | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 90% 22 & 10% 31[5] |
| 31 | Bare Rock/Sand/Clay (Non-arid Region) | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | Slade [6] |
| 32 | Quarries/Strip Mines/Gravel | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | Estimate [7] |
| 33 | Transitional | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | Estimate[8] |
| 41 | Deciduous Forest | 1.3 | 1.3 | 0.6 | 0.5 | 1 | AERMET [4] |
| 42 | Evergreen Forest | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | AERMET [4] |
| 43 | Mixed Forest | 1.3 | 1.3 | 0.9 | 0.8 | 1.1 | 50% 41+ 50% 42 [9] |
| 51 | Shrubland (Non-arid Region) | 0.3 | 0.3 | 0.3 | 0.15 | 0.3 | AERMET [4] |
| 61 | Orchards/Vineyards/Other | 0.3 | 0.3 | 0.1 | 0.05 | 0.2 | Garratt[11] |
| 71 | Grasslands/Herbaceous | 0.1 | 0.1 | 0.01 | 0.005 | 0.05 | AERMET [4] |
| 81 | Pasture/Hay | 0.15 | 0.15 | 0.02 | 0.01 | 0.03 | Garratt [11] & Slade[12] |
| 82 | Row Crops | 0.2 | 0.2 | 0.02 | 0.01 | 0.03 | Garratt [11] & Slade[12] |
| 83 | Small Grains | 0.15 | 0.15 | 0.02 | 0.01 | 0.03 | Garratt [11] & Slade[12] |
| 84 | Fallow | 0.05 | 0.05 | 0.02 | 0.01 | 0.02 | 31 & 81,82,83[13] |
| 85 | Urban/Recreational Grasses | 0.02 | 0.015 | 0.01 | 0.005 | 0.015 | Randerson[14] |
| 91 | Woody Wetlands | 0.5 | 0.5 | 0.4 | 0.3 | 0.5 | 50%43 & 50%92 [15] |
| 92 | Emergent Herbaceous Wetlands | 0.2 | 0.2 | 0.2 | 0.1 | 0.2 | AERMET [4] |
| 23x | Commercial/Industrial/Transp (Site at Airport) | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 10% 22 & 90% 31[5] |
| 31x | Bare Rock/Sand/Clay (Arid Region) | 0.05 | 0.05 | 0.05 | NA | 0.05 | Slade [6] |
| 51x | Shrubland (Arid Region) | 0.15 | 0.15 | 0.15 | NA | 0.15 | 50% 51 (Non-Arid)[10] |

## Seasonal Albedo

| Class Number | Class Name | Seasonal Albedo Values | | | | | Reference |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 (not used) | 3 | 4 | 5 | |
| 11 | Open Water | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | AERMET[2,3] |
| 12 | Perennial Ice/Snow | 0.6 | 0.6 | 0.7 | 0.7 | 0.6 | Stull & Garratt[4] |
| 21 | Low Intensity Residential | 0.16 | 0.16 | 0.18 | 0.45 | 0.16 | (22+43+85)/35 |
| 22 | High Intensity Residential | 0.18 | 0.18 | 0.18 | 0.35 | 0.18 | Stull[6] & AERMET[7] |
| 23 | Commercial/Industrial/Transp (Not at Airport) | 0.2 | 0.2 | 0.2 | 0.4 | 0.2 | Stull[6] & AERMET[7] |
| 31 | Bare Rock/Sand/Clay (Non-arid Region) | 0.2 | 0.2 | 0.2 | 0.6 | 0.2 | Garratt[8] & AERMET[7] |
| 32 | Quarries/Strip Mines/Gravel | 0.2 | 0.2 | 0.2 | 0.6 | 0.2 | Garratt[8] & AERMET[7] |
| 33 | Transitional | 0.18 | 0.18 | 0.18 | 0.45 | 0.18 | same as 84[9] |
| 41 | Deciduous Forest | 0.16 | 0.16 | 0.17 | 0.5 | 0.16 | Stull[6] & AERMET[7] |
| 42 | Evergreen Forest | 0.12 | 0.12 | 0.12 | 0.35 | 0.12 | Stull[6] & AERMET[7] |
| 43 | Mixed Forest | 0.14 | 0.14 | 0.14 | 0.42 | 0.14 | (41+42)/2[10] |
| 51 | Shrubland (Non-arid Region) | 0.18 | 0.18 | 0.18 | 0.5 | 0.18 | Estimate[11]&AERMET[7] |
| 61 | Orchards/Vineyards/Other | 0.18 | 0.18 | 0.18 | 0.5 | 0.14 | Estimate[12] |
| 71 | Grasslands/Herbaceous | 0.18 | 0.18 | 0.2 | 0.6 | 0.18 | AERMET[2] |
| 81 | Pasture/Hay | 0.2 | 0.2 | 0.18 | 0.6 | 0.14 | AERMET[2,13] |
| 82 | Row Crops | 0.2 | 0.2 | 0.18 | 0.6 | 0.14 | AERMET[2,13] |
| 83 | Small Grains | 0.2 | 0.2 | 0.18 | 0.6 | 0.14 | AERMET[2,13] |
| 84 | Fallow | 0.18 | 0.18 | 0.18 | 0.6 | 0.18 | Garratt[8] |
| 85 | Urban/Recreational Grasses | 0.15 | 0.15 | 0.18 | 0.6 | 0.15 | Estimate[14] |
| 91 | Woody Wetlands | 0.14 | 0.14 | 0.14 | 0.3 | 0.14 | Stull[6] & AERMET[7] |
| 92 | Emergent Herbaceous Wetlands | 0.14 | 0.14 | 0.14 | 0.3 | 0.14 | Stull[6] & AERMET[7] |
| 23x | Commercial/Industrial/Transp (Site at Airport) | 0.18 | 0.18 | 0.18 | 0.35 | 0.18 | Stull[6] & AERMET[7] |
| 31x | Bare Rock/Sand/Clay (Arid Region) | 0.2 | 0.2 | 0.2 | NA | 0.2 | Garratt[8] |
| 51x | Shrubland (Arid Region) | 0.25 | 0.25 | 0.25 | NA | 0.25 | Stull[6] |

## Season Bowen Ratio

| Class Number | Class Name | Seasonal Average Bowen Ratio1 | | | | | Reference |
| --- | --- | --- | --- | --- | --- | --- | --- |
| | Class Name | 1 | 2 (Not Used) | 3 | 4 | 5 | |
| 11 | Open Water | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | AERMET & Oke[3] |
| 12 | Perennial Ice/Snow | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | AERMET & Oke[3] |
| 21 | Low Intensity Residential | 0.80 | 1.00 | 1.00 | 0.50 | 0.80 | Estimate[4] |
| 22 | High Intensity Residential | 1.5 | 1.5 | 1.5 | 0.5 | 1.5 | AERMET & Oke[3] |
| 23 | Commercial/Industrial/Transp (Not at Airport) | 1.5 | 1.5 | 1.5 | 0.5 | 1.5 | AERMET & Oke[3] |
| 31 | Bare Rock/Sand/Clay (Non-arid Region) | 1.5 | 1.5 | 1.5 | 0.5 | 1.5 | AERMET & Oke[3] |
| 32 | Quarries/Strip Mines/Gravel | 1.5 | 1.5 | 1.5 | 0.5 | 1.5 | AERMET & Oke[3] |
| 33 | Transitional | 1 | 1 | 1 | 0.5 | 1 | Estimate[5] |
| 41 | Deciduous Forest | 0.3 | 1 | 1 | 0.5 | 0.7 | AERMET & Oke[3] |
| 42 | Evergreen Forest | 0.3 | 0.8 | 0.8 | 0.5 | 0.7 | AERMET & Oke[3] |
| 43 | Mixed Forest | 0.3 | 0.9 | 0.9 | 0.5 | 0.7 | =(41+42)/2 [6] |
| 51 | Shrubland (Non-arid Region) | 1 | 1.5 | 1.5 | 0.5 | 1 | AERMET & Oke[3] |
| 61 | Orchards/Vineyards/Other | 0.5 | 0.7 | 0.7 | 0.5 | 0.3 | AERMET & Oke[3] |
| 71 | Grasslands/Herbaceous | 0.8 | 1 | 1 | 0.5 | 0.4 | AERMET & Oke[3] |
| 81 | Pasture/Hay | 0.5 | 0.7 | 0.7 | 0.5 | 0.3 | AERMET & Oke[3] |
| 82 | Row Crops | 0.5 | 0.7 | 0.7 | 0.5 | 0.3 | AERMET & Oke[3] |
| 83 | Small Grains | 0.5 | 0.7 | 0.7 | 0.5 | 0.3 | AERMET & Oke[3] |
| 84 | Fallow | 0.5 | 0.7 | 0.7 | 0.5 | 0.3 | AERMET & Oke[3] |
| 85 | Urban/Recreational Grasses | 0.5 | 0.7 | 0.7 | 0.5 | 0.3 | AERMET & Oke[3] |
| 91 | Woody Wetlands | 0.2 | 0.2 | 0.3 | 0.5 | 0.2 | Estimate[7] |
| 92 | Emergent Herbaceous Wetlands | 0.1 | 0.1 | 0.1 | 0.5 | 0.1 | AERMET & Oke[3] |
| 23x | Commercial/Industrial/Transp (Site at Airport) | 1.5 | 1.5 | 1.5 | 0.5 | 1.5 | AERMET & Oke[3] |
| 31x | Bare Rock/Sand/Clay (Arid Region) | 4 | 6 | 6 | NA | 3 | AERMET & Oke[3] |
| 51x | Shrubland (Arid Region) | 4 | 6 | 6 | NA | 3 | Estimate[7] |