

QUANTIFICATION OF AREA FUGITIVE EMISSIONS AT OIL SANDS MINES

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1. Purpose

This directive provides a standard minimum procedure for flux chamber measurements to quantify area fugitive greenhouse gas emissions from mine faces and tailings ponds at oil sands mines. This directive is to be applied for reporting under the Specified Gas Emitters Regulation and Specified Gas Reporting Regulation.

2. Summary

Estimations of fugitive emissions from large area sources such as tailings ponds and mine faces carry a large amount of uncertainty. The uncertainty is amplified at the sector level when different methods, area delineations and procedures are applied. This directive provides a consistent, minimum procedure for flux chamber measurements that requires sampling on a coarse grid and then focuses on areas requiring greater sampling to reduce uncertainty.

The minimum requirements for area fugitive sampling are as follows:

Tailings Ponds:

- Conduct sampling in each zone at three locations or at one location per 400,000 m² (40 hectares), whichever is greater;
- Compute standard error on average fluxes in carbon dioxide equivalent (CO₂e) for each zone, based on current or prior year results;
- Compute expected additional number of samples required based on standard error; and
- As required, conduct additional samples on new grid to reach the target standard error (up to maximum total sample requirement of 1 sample location per 40,000 m² (4 hectares)).

Mine Faces:

- Divide into zones based on time of exposure, and if applicable, other physical characteristics;
- Conduct sampling in freshly exposed areas (<1 week) where safely possible - 1 sample location per 500,000 m² (50 hectares);
- Conduct sampling on zones that have been exposed for greater than 1 week and less than 6 months, with 1 sample location per 1,000,000 m² (100 hectares); and
- Conduct sampling on zones that have been exposed for greater than 6 months, with a minimum of 3 sample locations per zone.

3. Scope

This directive is to be used at all oil sands mining facilities regulated under the Specified Gas Emitters Regulation and Specified Gas Reporting Regulation in the quantification of area fugitive emissions, specifically those from mine faces and tailings ponds. Unless otherwise specified, all portions of this directive apply to both mine faces and tailings ponds. Both carbon dioxide (CO₂) and methane (CH₄) must be sampled in all area fugitive emissions sampling. Coordination of other air sampling requirements, such as those to measure Volatile Organic Compound (VOC) emissions, is strongly encouraged.

If other sources of area fugitive emissions (e.g., landfill sites, separators, alternative tailings treatment or deposition areas, overburden, reject ore and topsoil storage areas, etc.) exist at facilities, they must also be quantified and reported in the compliance submissions. This directive may assist in quantifying emissions from sources other than mine faces and tailings ponds, but using flux chamber methods may not be relevant for some sources and therefore this directive is not a requirement. Remote sensing or engineering calculation options may be more appropriate in the quantification of emissions when it is unsafe or impossible to apply a flux chamber method. If flux chambers are being used for other sources, this directive should be utilized to the extent applicable.

This directive has also been incorporated in the updated Specified Gas Reporting Standard.

4. Effective Date

This directive is to be implemented starting in the 2014 calendar year (with compliance reports due March 31, 2015). New facilities are required to implement this directive starting in 2014, or the first full year of commercial operation, whichever comes later.

This document reflects the first phase of improving the accuracy and consistency of quantification practices. Discussions of the results of implementing this directive, and any changes to be made in future phases of this directive, will continue with stakeholders with a goal of implementing more substantial revisions for the 2015 compliance year (reported in 2016). Facilities are expected to develop contracts and sampling plans as prior to June 1, 2014.

Facilities must contact Alberta Environment and Sustainable Resource Development to discuss any requests for exceptions or adjustments needed in the directive or to obtain site-specific sampling plan approvals. The Director under the *Climate Change and Emissions Management Act* retains discretion to approve site-specific plans or accommodate deviations from the directive with due consideration to fair treatment and reasonable justification.

5. Definitions

Area Fugitive Emissions – greenhouse gas emissions from non-point sources related to industrial activity, including, but not limited to, exposure and disturbance of mine faces, product, by-product and waste handling, storage and disposal in non-enclosed spaces.

Standard Error (SE) – provides a measure of the standard deviation of the error between the mean. SE is estimated based on sampling a population and the true (unbiased) mean of the population. Reducing standard error in measuring flux rate for an area increases the accuracy of the estimate of the flux rate for that area in the time period measured. SE is estimated by the sample standard deviation divided by the square root of the sample size (assuming statistical independence of the values in the sample):

$$SE_{\bar{x}} = \frac{s}{\sqrt{n}}$$

Where: s is the sample standard deviation, that is the sample-based estimate of the standard deviation of the population as expressed in the following equation

$$s = \sqrt{\frac{1}{n-1} \sum (x_i - \bar{x})^2}$$

n is the size (number of observations) of the sample.

The above equations can be rewritten as:

$$SE_{\bar{x}} = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n \times (n-1)}}$$

Cumulative Standard Error – the total standard error for a survey, calculated as the sum of the standard errors for each sample zone, as shown in the example in Section 6.3.

Fermentable Substrate – all substances that can be reasonably expected to be fermented by microbial activity in tailings ponds or deposition areas including but not limited to lost diluents.

Source – an area fugitive emissions source is a distinct region with a clearly identifiable and relatively stable boundary, such as a single pond or mine face which may contain one or more emission zones.

Tailings Ponds – for the purposes of this directive, tailings ponds are tailings deposition areas with liquid surfaces. Other tailings-related emissions sources, such as alternative tailings deposition areas, sand dumps, etc., are expected to be quantified (or justified as negligible) to the best of a facility's ability and included in the emissions inventory. This directive may not be applicable to quantifying all of these related sources.

Uncertainty – for the purposes of this directive, uncertainty is a general term incorporating the accuracy and precision of an estimate including effects inherent in the measurement method as well as the effects of spatial and temporal variability of the area fugitive emissions. Actual uncertainty is not quantifiable with existing techniques. Standard error will be used to estimate the uncertainty of the quantification method.

Zones – for the purposes of this directive, a zone is a region of fugitive emissions that is assumed to have similar emissions flux and is sampled with the intent of determining average flux for that area at the time of sampling, such as a bubbling zone. Zones are delineated to allow sampling effort to be prioritized for zones with the greatest contribution to total emissions and emissions uncertainty. A single zone cannot span more than one source.

High Priority Zones for Mine Faces – regions that have been disturbed in the last 1 week. Priority zones have increased sampling requirements as outlined in Section 7.

Normal Priority Zone for Mine Faces – regions that were last disturbed between 1 week and 6 months ago.

Low Priority Zone for Mine Faces – regions that have not been disturbed in the in the last 6 months.

6. Measurement and Calculation Methods

6.1. General Description

A standardized point measurement technique (adapted from Kienbusch, M., Measurement of Gaseous Emissions Rates from Land Surfaces Using an Emission Isolation Flux Chamber, User's Guide, EPA Users Guide, Contract No. 68-02-03389-WA18 (EPA/600/8-86/008), 1986) has been used historically, which has reasonably well understood measurement uncertainty.

Total flux rate estimates are formed based on averaging point sampling of mass flux rates within the zones of different types over the time interval between sampling programs using the following equation.

$$\text{Emissions (E)} = \sum_{j=A_0}^{A_y} F_j \times A_j$$

Where: j is a type of emissions zone such as a bubbling zone on a tailings pond or the pit floor at the mine face;

F is equal to the average of the measured flux for a given emissions zone per emissions survey expressed in tonnes CO₂e/m²/year (see example 6.3.1); and

A is the surface area of the emissions zone.

6.2. Method Enhancements

Enhanced technology has recently become available which allows for real time concentration analysis and thus real time flux measurement for CO₂ and CH₄. This represents a significant improvement over the historic grab sample method in terms of speed and quantity of data collection, analysis costs and detection limits.

A methodology document including quality assurance and control provisions is under development that will provide the details of the new technology and its application. These technical details are beyond the scope of this directive and are left to professional expertise of the practitioner until this reference document is available.

Each data point collected with this equipment (after the initial chamber gas has been expelled) is equivalent to a replicate sample. Due to the small time interval between data points, 30 to 90 minutes of data should be collected to be considered equivalent to the triplicate sample requirement of this directive. The practitioner can observe variability in the flux during that period to determine the appropriate data collection period using the real time data.

6.3. Uncertainty Assessment

All estimates of emissions from area fugitive sources must be accompanied by quantification of standard error for each sample location as well as the cumulative standard error for each zone and source.

The standard error is first quantified for each zone by gas species and on a CO₂e basis and then is rolled up to a total for each area fugitive emission source. The standard error for each zone is used to inform future sampling requirements and may also help guide the appropriate selection of zones. Where a parameter is multiplied or divided by a scalar, the standard error should be

multiplied or divided equally. Where parameters are added or subtracted the standard error associated with the emissions should be added. Therefore, where parameters are averaged, the standard error values should also be averaged.

Example

Consider combining flux measurements from a source with two zones (i) [with area A and flux F] in which three locations were sampled in triplicate (j=9) [with each sample flux f (tonnes CO₂e/year)]. The area fugitive emissions are calculated as the average flux from each zone:

$$\text{zone flux } (\bar{F}) = \frac{\sum_{i=1}^{n=9} f_i}{(n)}$$

Where: i is a sample location within an emissions zone; and

f is a single flux measurement with the grab sample method, or the average of the measured flux for a given sample location if the continuous flux measurement method is being applied, in tonnes CO₂e/m²/year.

The total standard error would be calculated as the standard error from each zone multiplied by the area of the zone added together with the standard error from other zones:

$$\text{zone flux standard error } (SE_{flux}) = \sqrt{\frac{\sum_{i=1}^{n=9} (f_i - \bar{F})^2}{(n)(n-1)}}$$

$$\text{source emissions standard error } (SE_i) = \sum_{i=1}^{n=2} A_i \times SE_{flux,i}$$

Note that the standard error should be calculated for each gas species independently, scaled by the global warming potential (GWP) and summed to give the cumulative standard error for the zone. The GWP from the Specified Gas Emitters Regulation applies.

6.4. Outlier Treatment

Any direct measurement technique has the possibility of erroneous results or statistical outliers. Since the statistical methods for determining and dealing with outliers in small sample sizes are not robust, no data point will be considered an outlier on a numeric basis alone. There may be qualitative causes for considering a sample erroneous, such as if the sampling equipment has malfunctioned or a sample has been compromised in transport. Exclusion of samples on this basis is permissible and should be documented in the report or appendices, with any associated data still reported for information purposes.

6.5. Sample Dates and Frequency

Complete area fugitive emissions surveys will be conducted annually at minimum.

There are times where the surface flux may be low due to low surface temperature or ice formation, yet the temperature at depth in a tailings pond remains relatively constant and

therefore the biogenic gas formation continues. For mine faces the amount of methane and CO₂ present in the formation in situ does not vary with temperature, but the observed surface flux may vary with time of exposure or meteorological conditions. Therefore, to be conservative, measurements of surface flux will only be taken in the summer and fall (June to September) and the observed average flux will be extrapolated over the remaining months. No reduction factor will be used in extrapolating emissions over the winter months.

Area fugitive emissions sources that have had relatively constant flux over 3 years (cumulative standard error over time of less than 5 per cent of total area fugitives from most recent year) can be assumed to have the same flux as the maximum from the previous 3 years, for a period of up to two years (scale total emissions by change in area), and therefore excluded from the annual sampling requirement. The total emissions from sources assumed constant must not exceed 1 per cent of total annual emissions from the previous calendar year or 50,000 tonnes CO₂e, whichever is lower.

6.6. Combining Multiple Surveys

Multiple quantification surveys may be taken within the sampling window (June to September) to increase the accuracy of the emissions quantification for one or more sources or zones. The scope of repeat surveys can be limited to areas of high emissions and/or variability, if desired. Data from additional surveys shall be included on a straight averaging basis for a given zone, as shown in simplified form in the example described in Section 6.7.

6.7. Example of Average Flux and Standard Error with Constant Zones Calculation

	SURVEY 1 - June		SURVEY 2 - August		Formula
	Zone 1	Zone 2	Zone 1	Zone 2	
Sample Flux 1 (t/m ² /y)	6	10	6	10	
Sample Flux 2 (t/m ² /y)	5	12	5	12	
Sample Flux 3 (t/m ² /y)	5	15	5	15	
Sample Flux 4 (t/m ² /y)	9	14	4	-	
Sample Flux 5 (t/m ² /y)	3	-	3	-	
Sample Flux 6 (t/m ² /y)	8	-	2	-	
Sample Flux 7 (t/m ² /y)	7	-	-	-	
Sample Flux 8 (t/m ² /y)	4	-	-	-	
Sample Count (#)	8	4	6	3	=count()
Average Zone Flux (t/m ² /y)	5.88	12.75	4.17	12.33	=average()
Zone Flux Standard Error (t/m ² /y)	0.72	1.11	0.60	1.45	=stdev()/sqrt(sample count)
Zone Area (m ²)	100	10	95	10	
Zone % Area	91%	9%	90%	10%	= zone area / source area

COMBINED SURVEY ANALYSIS	Zone 1	Zone 2	Overall	Formula
Zone Average Flux (t/m ² /y)	5.14	12.57	-	=AVERAGE(all flux data for zone)
Zone Flux Standard Error(t/m ² /y)	0.52	0.81	-	=stdev(all data points for zone)/sqrt(num data points)
Average Zone % Area	0.91	0.09	-	=average(zone % area)
Source Average Annual Flux (t/m ² /y)	-	-	5.83	=sumproduct(zone flux, zone % area)
Source Annual Flux Standard Error (t/m ² /y)	-	-	0.55	=sumproduct(zone flux standard error, zone % area)

If zone definition has changed significantly between surveys (i.e., if more or fewer zones are identifiable or if the zones have significantly changed in size and location), then the average flux for the source will be calculated on a sample location weighted average basis. The provision of Section 6.10 for non-detect results is to be applied across all surveys if multiple surveys are conducted.

6.8. Surface Area Measurement and Calculation

All surface area measurements should be calculated as the average annual area based on interpolation between the best available surface area data, using at minimum, data near the beginning and end of year, and the date the survey was conducted. For tailings ponds, if the total water surface area is available but zone area data is not, the zones are assumed to scale equally with the total water surface area.

For mine pits, if detailed mine shovel/pit report outputs are used along with high resolution imaging, the surface areas may be calculated annually as an interpolation between year-end reports.

The area at January 1st of the calendar year is calculated as a linear interpolation between the previous and subsequent area measurement. The area at December 31st is calculated in the same way if two data points to interpolate between are available. If no surface area data after the end of the reporting year is available at the time of reporting (e.g., if reporting for 2013 and no measurement has been conducted in 2014 yet), then the surface area for the source at December 31st is assumed to be the greater of the last measurement or a linear extrapolation from the last two measurements.

When a new source is started (new pond activated or new mine pit opened) the area is taken as zero on the day prior to commissioning. Once the area at the start and end of the year has been calculated, the time weighted average area for the year can be calculated. The example in Section 6.9 shows the area calculation for a source measured multiple times in a year.

6.9. Simplified Example of Average Annual Source Surface Area Calculation

	A	B	C	D	
1	Area Survey Date (day/month/year)	Source Surface Area (Ha)	Days from Previous Data Point (days)	Contribution to Annual Average Area (Ha)	Formula
2	10/1/2012	0	-	-	
3	1/1/2013	12	92	-	$B3 = (B4-B2) * C3 / (C4 + C3)$
4	3/10/2013	20	68	3	
5	5/8/2013	50	59	6	$D_i = C_i * Average(B_i, B_{i-1}) / 365$
6	9/1/2013	80	116	21	
7	11/12/2013	90	72	17	
8	12/31/2013	97	49	13	$B8 = MAX(B7, (C8 + C7) / C7 * (B7 - B6) + B6)$
9	Annual Average Area (m2)	-	-	59	$D9 = SUM(D4: D8)$

6.10. Concentration Analysis

CO₂ can have a relatively high detection limit for the flux chamber method. In the area fugitive emissions surveys conducted to date it is common to see wide variations in CO₂ flux within a single location, even multiple zero or non-detection readings along with high fluxes. Therefore, for zones where one or more non-zero concentrations are measured, any readings with no detected concentration will be assumed to have a concentration equal to the detection limit. This limitation is expected to improve significantly with the real time concentration measurement technology now available.

7. Sample Locations and Emissions Zones

The determination of zone boundaries relies heavily on practitioner judgement. The advantage of defining distinct emissions zones is that increased sampling effort can then be used in quantification of zones that contribute more to the total emissions, or have more uncertainty, such as bubbling zones. In some past survey results, emissions flux has been reported for equal area zones which are not based on physical characteristics, but a rather the way sample locations and samples are distinguished and rolled up to calculate total emissions. This does not typically affect the total emissions or average flux but does affect the standard error. Where past results are reported in equal area zones not based on observed characteristics, the source emissions and standard error should be calculated on an aggregate basis for the source as a single zone.

7.1. Tailings Ponds

Historically, flux chamber sampling programs at tailings ponds have identified three types of zones: bubbling; hydrocarbon slicks; and quiescent zones (area with no visible bubbling or hydrocarbon slicks at time of sampling). If distinct, homogeneous zones cannot be identified, then at minimum each tailings pond will be considered a source with a single zone and sampled

as such. If the previously defined zones are no longer appropriate due to changing site conditions or new observations, facilities can adjust their zone definitions.

A minimum of 3 samples are required per sample location. More samples should be taken if outliers are likely. When using continuous flux measurement, 30 to 90 minutes of data must be collected for each sample location.

Zones that had standard error and total emissions less than 1 per cent of total area fugitive emissions (including all area fugitive sources) in the previous survey can be considered low priority zones. Low priority zones are required to have 3 sample locations per zone (3 samples per location), but do not have a sample area density requirement.

Sample locations should be distributed throughout a zone, such as through a grid type sampling plan. Any area of visible bubbling, hydrocarbon slicks and the area surrounding outfalls or other disturbances (barges, etc.) must be used as a preferential sample location within the sample grid. The sample location should be as close as safely possible to the outfall or disturbance.

7.1.1. Flux-based Sample Requirements

The goal of the sample campaign is to focus sampling effort in the areas of greatest uncertainty and emissions. As such a fully variable sample density is more optimal than a simple split into broad zone types.

A minimum of 3 sample locations or 1 sample location per 40 hectares (400,000 m²) are required per zone, whichever is greater. The recommended approach if real time data collection is available is:

- Sample the zone/source at the minimum sample density in grid pattern;
- Calculate average flux and standard error based on samples taken;
- Determine if additional samples, are required; and
- Conduct sampling in an additional overlaid grid pattern.

The maximum sampling requirement for ponds is one sample location per 40,000 m² (4 hectares) or 3 locations per zone, whichever is greater. Facilities can add additional sample locations at their discretion if desired.

If standard error data is available, the required number of samples for a zone is calculated as:

$$N = \frac{SE_{flux}}{1000} \times Area$$

Where: N is the number of sample locations;

SE_{flux} is the cumulative standard error for the flux from the zone (tonnes CO₂e/m²/year). SE can be calculated based on the previous survey or calculated in the field for the present survey after sampling the minimum grid to determine if sampling requirements have been reduced; and

Area is the area of the zone (m²).

The corresponding sample density can be calculated as:

$$\frac{\text{Area}}{\text{sample location}} = \frac{1000}{SE_{flux}}$$

If standard error data is not available from either the current or previous survey, the required number of samples for a zone is calculated as:

$$N = \frac{\text{Flux}}{4000} * \text{Area}$$

Where: N is the number of sample locations;

Flux is the flux for the zone (tonnes CO₂e/m²/year);

4000 is a calculation constant (samples/(tonne CO₂e/year)); and

Area is the area of the zone (m²).

7.2. Mine Faces

Historically mine face emissions zones have typically been determined by the grade of ore (e.g., overburden, high grade, low grade, etc.). Little correlation has been demonstrated between ore grade and total greenhouse gas emissions, but additional analysis is needed. Data on ore quality can be generated by taking actual ore samples for analysis, or by drawing on ore quality data used for other purposes at the facility. For this directive, zones are to be defined based on the length of time the face has been exposed or a combination of length of exposure and ore quality. Flux data should be accompanied by an estimate of duration of mine face exposure at the time of sampling. If stronger correlations are observed between emissions and ore grade or location than time of exposure, this data can be used to refine the total flux estimate.

A minimum of 3 flux measurements are required per sample location or where continuous concentration measurement is possible 30 to 90 minutes of data must be collected.

Zones that have been exposed for less than 1 week are to be considered high priority zones. Zones with visible bubbling shall also be considered high priority zones. High priority zones must have at least 1 sample location per 500,000 m² (50 hectares) or 3 locations per zone, whichever is greater. Samples should be taken preferentially on newly exposed materials, recognizing that there are safety limitations to what is possible. Additional technology such as plume based sampling may help identify priority zones for sampling, and this type of screening is encouraged and should be documented in as much detail as possible.

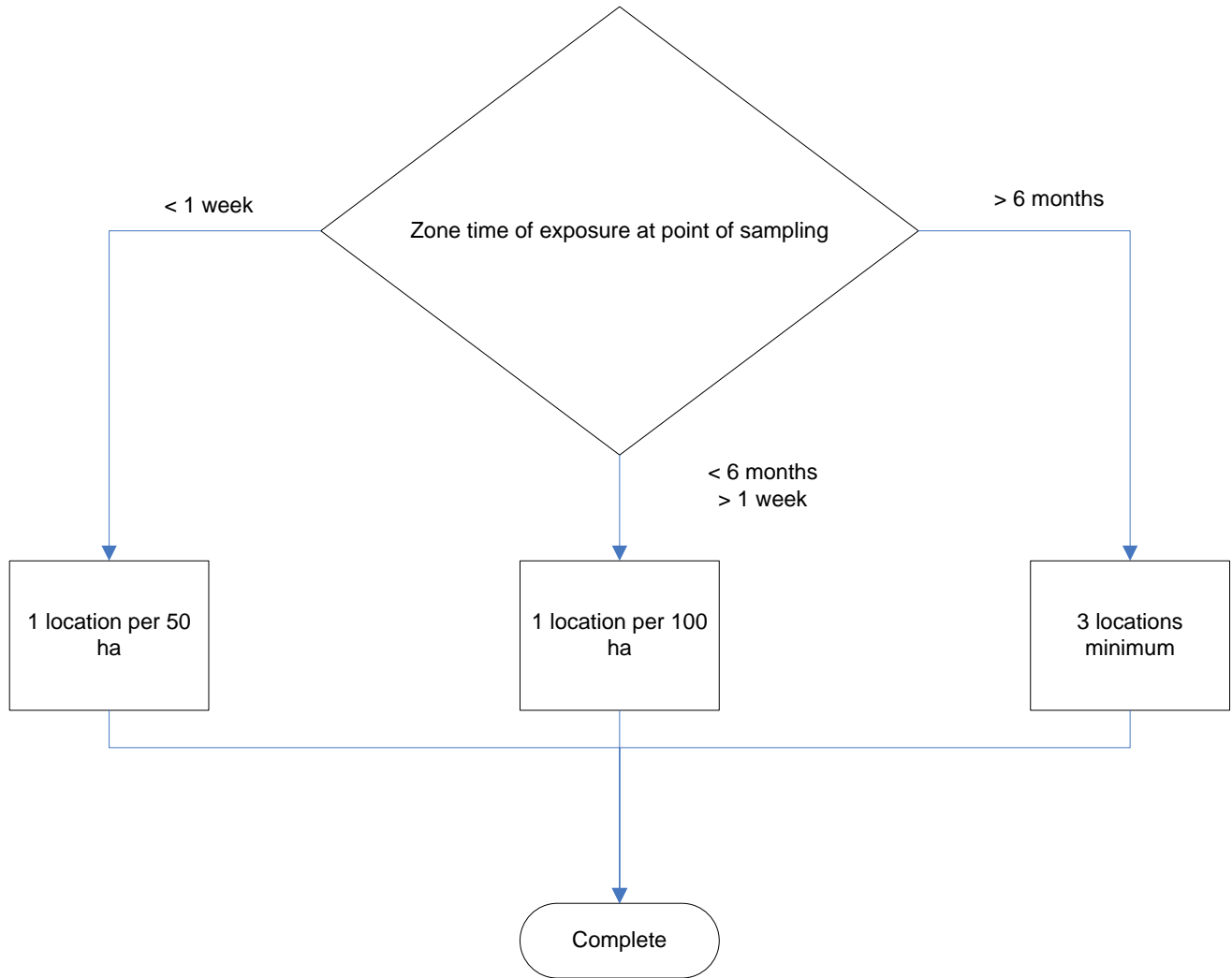
Zones that have been exposed and not disturbed for greater than 6 months can be considered low priority zones. Low priority zones are required to have 3 sample locations per zone (3 samples per location), but do not have an area requirement.

Zones that do not meet the definition of low or high priority zones must have at least 1 sample location per 1,000,000 m² (100 hectares) or 3 samples per zone, whichever is greater.

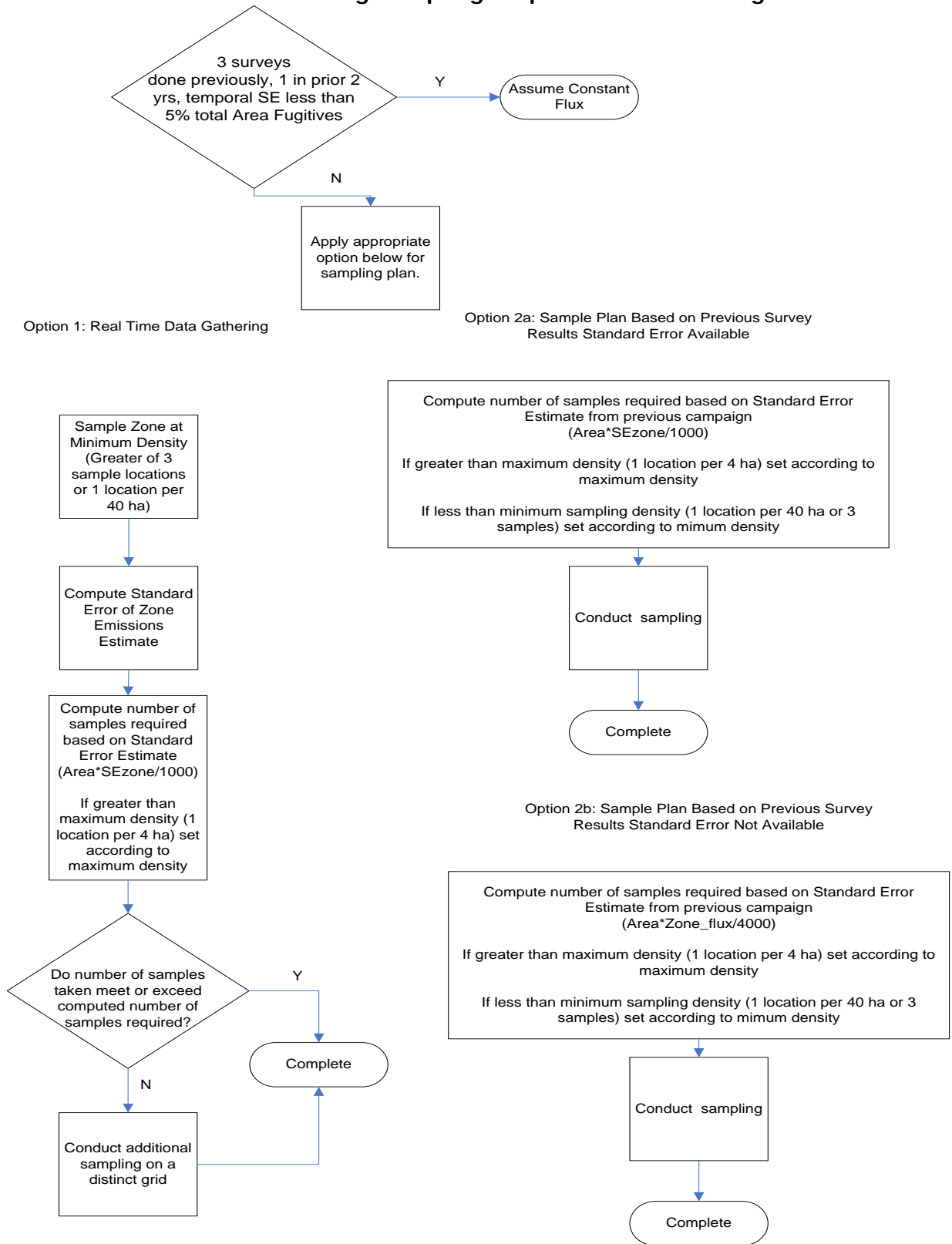
Sample locations should be distributed throughout a zone, such as through a grid type sampling plan. Bench tops are to be considered separate sources from bench toes and mine faces.

Plume-based or other alternative sampling techniques that can be demonstrated to have similar or more accuracy than the prescribed flux chamber sample number will be accepted by Alberta Environment and Sustainable Resource Development.

7.3. Flow Chart for Determining Sampling Requirement for Mine Faces



7.4. Flow Chart for Determining Sampling Requirement for Tailings Ponds



8. Reporting

All facilities must provide the following supporting information to support the review of their area fugitive emissions and evaluation of the directive:

- Consultant's report on area fugitive emissions surveys;
- All supporting raw survey data, including zone areas with any bad data or observations flagged;
- Full calculations of total area fugitive emissions estimate;
- Summary of tailings pond zone definitions and surface areas, tailings pond total water surface areas, including descriptions of large features within the area such as internal dykes, whether the pond is active, as well as if ponds have ever received froth treatment tails;
- Map from the time of the survey(s) identifying all zones, sampling locations and disturbances/outfalls in ponds;
- Summary of mine face areas and zone definitions and areas, as applicable;
- Details of any ore grade data available for sampling locations as well as time of exposure at when samples for each sample location;
- Full detailed calculations of standard error for each sample location, zone and source associated with area fugitive emissions; and
- A summary report of all fermentable substrates (such as diluent) lost into each tailings pond, and additives (citrate, glycol) used in extraction processes, expressed in total quantity and total carbon.

9. Alternative Methods

Alberta Environment and Sustainable Resource Development encourages the exploration of other methods of emissions quantification that can improve the accuracy and reduce the uncertainty of area fugitive emission quantification, including but not limited to input-based quantification tools for tailings ponds, inverse dispersion modelling approaches and other continuous measurement techniques, especially for high emission zones. Methods for the mine face emissions such as in situ gas analysis prior to disturbance should also be explored. The development of future Phases of this directive will include a more thorough review of emerging research and standards related to these alternative methods.

Alberta Environment and Sustainable Resource Development will work with facilities whenever possible to evaluate alternatives and to stay apprised of and promote the exploration of improved methods for estimating these emissions sources. Where alternative methods are being deployed, the alternative methods shall be demonstrably similarly or more accurate and conservative or conducted in conjunction with approved methods.

Original signed by
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Environment and Sustainable Resource Development
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Date: June 24, 2014