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Evaluation of DEGADIS 2.1 Using Advisory Bulletin ADB-10-07

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EVALUATION OF DEGADIS 2.1
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ACRONYMS & ABBREVIATIONS

ABS	American Bureau of Shipping
Advisory Bulletin	Pipeline and Hazardous Materials Safety Administration Advisory Bulletin ADB-10-07
cm	centimeter
C.F.R.	Code of Federal Regulations
CSF	concentration safety factor
CSF_LFL	concentration safety factor at the lower flammability limit
DSF	distance safety factor
DSF_LFL	distance safety factor to the lower flammability limit
FAC2	factor of 2
FERC or Commission	Federal Energy Regulatory Commission
FPRF	Fire Protection Research Foundation
km	kilometer
LFL	lower flammability limit
LNG	liquefied natural gas
m	meter
m/s	meters per second
MDA	Modeler’s Data Archive
MEP	Model Evaluation Protocol
MER	Model Evaluation Report
MG	geometric mean bias
MRB	mean relative bias
MRSE	mean relative square error
NASFM	National Association of State Fire Marshals
NFPA	National Fire Protection Association
PHMSA	Pipelines and Hazardous Materials Safety Administration of the U.S. Department of Transportation
SPM	statistical performance measure
VG	geometric variance

1.0 INTRODUCTION

1.1 BACKGROUND

In the United States, Title 49, Code of Federal Regulations (C.F.R.), Part 193 prescribes the federal safety standards for liquefied natural gas (LNG) facilities. The siting requirements in Subpart B specify that each LNG container and LNG transfer system must have vapor-gas dispersion exclusion zones calculated in accordance with §193.2059. The regulation specifically approves the use of two models for performing these calculations, DEGADIS and FEM3A, but also allows the use of alternative models approved by the U.S. Department of Transportation.

The integral model DEGADIS was developed for the Gas Research Institute and the U.S. Coast Guard specifically to account for effects such as gravity spreading, negative or positive buoyancy effects on air entrainment, surface to cloud heat transfer, and phase change energy effects associated with air humidity in modeling dispersion of dense gases. The theoretical and experimental basis for the model was described in Gas Research Institute Report No. 89/0242, LNG Vapor Dispersion Prediction with the DEGADIS Dense Gas Dispersion Model. Extensive vapor dispersion experimental and analytical work, beginning in 1982, was also conducted prior to adoption of DEGADIS into the federal regulations in 1997 (RSPA, 1997).

1.1.1 Model Evaluation Protocol

In 2006, the Fire Protection Research Foundation (FPRF), at the request of the National Fire Protection Association (NFPA), began to develop guidance to be used in assessing vapor dispersion models in analyzing LNG facilities. The main focus of this effort was to develop a means to review dispersion models based on their scientific basis and through comparison with experimental data. The result of this study, released in 2007, was a Model Evaluation Protocol (MEP) that could be applied to determine the suitability of any dispersion model to simulate dispersion of LNG spills on land (Ivings et al., 2007). In 2009, the NFPA LNG Technical Committee revised the 2009 edition of NFPA 59A, Standard for the Production, Storage, and Handling of Liquefied Natural Gas, to remove the prescription of DEGADIS and require that a model be acceptable to the Authority Having Jurisdiction based on an evaluation using the MEP.

The MEP is based on the European Union Scientific Model Evaluation of Dense Gas Dispersion Models, known as the SMEDIS protocol, which is in turn based on criteria set by the Council of European Communities Model Evaluation Group on Heavy Gas Dispersion. The MEP consists of three stages: scientific assessment; verification; and validation. Initially, the physical, mathematical and numerical basis of the model is reviewed (i.e., scientific assessment). Then, the model developer provides evidence demonstrating that the model correctly implements the bases identified during scientific assessment (i.e. verification). Finally, various simulations are performed with the model and compared to a database of experimental results from wind tunnel and field trial tests (i.e. validation) (Ivings et al., 2007).

Results of the scientific assessment, model verification, and validation are contained in the Model Evaluation Report (MER). Ivings et al. (2007) specifies that the MER is composed of eight sections:

- Section 0. Evaluation information;
- Section 1. General model description;
- Section 2. Scientific basis of model;
- Section 3. User-orientated basis of model;
- Section 4. Verification performed;
- Section 5. Evaluation against MEP qualitative assessment criteria;
- Section 6. Validation performed and evaluation against MEP quantitative assessment criteria; and
- Section 7. Conclusions

The results of application of the MEP to a specific model, as summarized in these seven sections of the MER, can then be used as a basis for establishing the limitations and safety margins of the dispersion model.

As part of the protocol development, the MEP was partly applied to both DEGADIS and FEM3A. Based on the scientific assessment and model verification, the limits of applicability of both models were described and an assessment of previous validations were given. However, the lack of a standard validation database prevented application of the full MEP from being within the scope of that report (Ivings et al., 2007). In February 2009, the FPRF completed and released both the validation database and the "Guide to the LNG Model Validation Database," with subsequent revisions in September 2009 and May 2010 (Coldrick et al., 2010). Validation of DEGADIS or FEM3A against the database was not performed as application of the remaining portions of the MEP was not within the scope of that effort.

1.1.2 PHMSA Advisory Bulletin ADB-10-07

In 2009, the National Association of State Fire Marshals (NASFM) released an independent review of the MEP. The goal of NASFM's report, "Final Report: Review of the LNG Vapor Dispersion Model Evaluation Protocol," was to ensure that hazard models evaluated with the MEP process were suitable for the specific situations in which LNG facilities were being planned (AcuTech, 2009). The panelists for the NASFM effort suggested improvements to the MEP and also identified difficulties in using this approach in a regulatory setting.

After reviewing the MEP report and validation database issued by the FPRF in 2007 and 2010, as well as the NASFM study, the U.S. Department of Transportation's Pipelines and Hazardous Materials Safety Administration (PHMSA) issued Advisory Bulletin ADB-10-07 (Advisory Bulletin) to provide guidance on obtaining approval of alternative vapor-gas dispersion models under Subpart B of 49 C.F.R. Part 193 (PHMSA, 2010). The approach is based on the scientific assessment, verification, and validation of the MEP with adjustments to address the concerns raised by NASFM, as well as by staff of the Federal Energy Regulatory Commission (FERC or Commission).

1.2 PROJECT SCOPE

This document provides the complete MEP, as adjusted by modifications from the PHMSA Advisory Bulletin, to the DEGADIS dense gas vapor dispersion model specified in 49 C.F.R. § 193.2059. This serves two purposes: (1) completing the MEP for DEGADIS partially done by Ivings et al. (2007); and (2) illustrating the appropriate level of information requested by the Advisory Bulletin for obtaining PHMSA approval of an alternative vapor-gas dispersion model as allowed by §193.2059(a).

The document is intended for developers/evaluators who are going to submit a request to PHMSA for an alternative model approval under 49 C.F.R. § 193.2059(a). Sections 2.0 and 3.0, as well as the validation database, provide an example of the level of detail requested by ABD-10-7. Section 4.0 provides an example of the suitability and limitation descriptions which would be included in a public PHMSA approval.

Completion of the MEP and the DEGADIS validation work was performed by FERC staff. The validation work which accompanies this report is included in the Excel spreadsheet, entitled "DEGADIS Validation Database.xls," being issued concurrently with this document. Review of the MEP results and limitations for the suitable use of the DEGADIS model in exclusion zone calculations was done by staff of the PHMSA.

2.0 RESULTS OF THE 2007 PARTIAL DEGADIS EVALUATION

2.1 SCIENTIFIC ASSESSMENT AND VERIFICATION

Appendix B 10.2 of Ivings et al., (2007) addressed all of the sections of the MEP guidance, except for Section 6.2, "Evaluation against MEP quantitative assessment criteria." The conclusions of Appendix B are available upon request from the FPRF and are not repeated in this document. Certain sections of the scientific assessment that were addressed did not provide enough detail to thoroughly evaluate the limitations of the model. As discussed in the following sections, the Advisory Bulletin was used to address those areas.

2.2 APPLICATION OF THE VALIDATION DATABASE TO DEGADIS

Using the LNG Model Validation Database, the following sections of the MEP can now be completed for the DEGADIS model (Coldrick et al., 2010):

- 6.2.1 Validation cases modeled;
- 6.2.2 Model performance for key statistical evaluation parameters;
- 6.2.3 Evaluation against quantitative assessment criteria; and
- 6.2.4 Additional comments.

2.2.1 Validation Cases Modeled (MER Section 6.2.1)

The DEGADIS model is limited to dispersion over unobstructed level terrain with uniform roughness length specified by the user. Therefore, the current validation study is limited to the following field trials and wind tunnel trials conducted at full scale:

- Maplin Sands 27, 34, 35;
- Burro 3, 7, 8, 9;
- Coyote 3, 5, 6;
- Thorney Island 45, 47;
- CHRC A;
- BA-Hamburg DA0120 (Unobstructed), DAT223 (Unobstructed 2); and
- BA-TNO TUV01, FLS.

The DEGADIS model is also limited to providing the concentration and temperature along the vapor cloud centerline. Parameters are provided to determine the concentration at crosswise and vertical locations along the vapor cloud, but similar parameters are not provided for the temperature distribution. Therefore, values of temperatures are not provided for evaluation.

2.2.2 Model Performance for Key Statistical Evaluation Parameters (MER Section 6.2.2)

The model results are compared to the experimental measurements to develop the following statistical performance measure (SPM) values: mean relative bias (MRB); geometric mean bias (MG); mean relative square error (MRSE); geometric variance (VG); factor of 2 (FAC2); concentration safety factor (CSF); concentration safety factor at the lower flammability limit (CSF_LFL); distance safety factor (DSF); and distance safety factor at the lower flammability limit (DSF_LFL). The SPM values are shown in Table 2.2-1. Shaded cells indicated where the SPM were not within the MEP acceptance criteria.

Table 2.2-1:
SPM Evaluation against Quantitative Assessment Criteria: Overall Trial Average

Data Set	Quantitative Criteria								
	-0.4<MRB <0.4	**0.67< MG<1.5**	**MRSE<2.3**	**VG<3.3**	**FAC2 >50%**	**0.5<CSF<2**	**0.5< CSF_LFL<2**	**0.5<DSF<2**	**0.5< DSF_LFL<2**
Maximum Arc-wise Gas Concentration									
Field Trials (Short Time Avg.)	-0.47	0.60	0.49	1.80	58%	1.93	1.80	N/A	N/A
Field Trials (Long Time Avg.)	-0.77	0.41	0.92	3.76	36%	3.13	N/A	N/A	N/A
Wind-Tunnel Tests (Scaled)	0.79	2.43	0.80	2.84	36%	0.47	N/A	N/A	N/A
Maximum Gas Concentration Arc-wise Distance									
Field Trials (Short Time Avg.)	-0.32	0.72	0.21	1.25	89%	N/A	N/A	1.47	1.43
Field Trials (Long Time Avg.)	-0.29	0.74	0.19	1.23	89%	N/A	N/A	1.43	N/A
Wind-Tunnel Tests (Scaled)	0.50	1.68	0.32	1.42	68%	N/A	N/A	0.62	N/A

Table 2.2-1 (cont'd): SPM Evaluation against Quantitative Assessment Criteria: Overall Trial Average									
Data Set	Quantitative Criteria								
	-0.4<MRB <0.4	**0.67< MG<1.5**	**MRSE<2.3**	**VG<3.3**	**FAC2 >50%**	**0.5<CSF<2**	**0.5< CSF_LFL<2**	**0.5<DSF<2**	**0.5< DSF_LFL<2**
Maximum Point-wise Gas Concentration									
Field Trials (Short Time Avg.)	0.52	3.73	1.28	>1,000	46%	0.91	N/A	N/A	N/A
Field Trials (Long Time Avg.)	-0.12	1.28	1.26	>1,000	33%	2.70	N/A	N/A	N/A
Wind-Tunnel Tests (Scaled)	0.24	1.50	0.48	11.92	69%	1.07	N/A	N/A	N/A
Cloud Width									
Field Trials (Short Time Avg.)	0.46	1.61	0.28	1.35	84%	N/A	N/A	0.64	N/A
Field Trials (Long Time Avg.)	0.24	1.28	0.12	1.14	92%	N/A	N/A	0.81	N/A
Wind-Tunnel Tests (Scaled)	-0.09	0.91	0.03	1.03	100%	N/A	N/A	1.11	N/A

2.2.3 Evaluation Against Quantitative Assessment Criteria (MER Section 6.2.3)

With the exception of the maximum gas concentration arc-wise distance SPM values, DEGADIS does not meet the MEP quantitative assessment criteria. The SPM values for maximum arc-wise gas concentration indicate DEGADIS may over-predict maximum arc-wise concentrations by more than a factor of 2 with a moderate to large degree of scatter. The SPM values for the maximum point-wise gas concentration indicate DEGADIS may under-predict or over-predict maximum point-wise concentrations by more than a factor of 2 with an extremely high degree of scatter. The SPM values for plume width indicate DEGADIS may under-predict cloud widths by less than a factor of 2 with a low degree of scatter. The results also indicate that DEGADIS is more over-predictive and generally shows less scatter for long time averages than short time averages.

2.2.4 Additional Comments (MER Section 6.2.4)

As stated in the Advisory Bulletin, model predictions outside the quantitative assessment criteria do not necessarily mean that the model is unacceptable. However, such results may alternatively impact the safety factor associated with the model.

Based on the MEP groups, it would appear that DEGADIS is generally over-predictive by more than a factor of 2 and therefore additional safety margins may be seen as over-burdensome. However, upon examination of individual test and sensor data, SPM trends become clearer in the model predictions, as shown in Table 2.2-2. Results of the individual tests and sensor data trends are discussed below.

Table 2.2-2: SPM Evaluation against Quantitative Assessment Criteria: Individual Trial Average									
Data Set	Quantitative Criteria								
	-0.4<MRB <0.4	**0.67< MG<1.5**	**MRSE<2.3**	**VG<3.3**	**FAC2 >50%**	**0.5<CSF<2**	**0.5< CSF_LFL<2**	**0.5<DSF<2**	**0.5< DSF_LFL<2**
Maximum Arc-Wise Gas Concentration									
Maplin Sands 27 (short)	-0.08	0.93	0.37	1.55	75%	1.29	1.40	N/A	N/A
Maplin Sands 34 (short)	0.24	1.28	0.06	1.06	100%	0.78	0.74	N/A	N/A
Maplin Sands 35 (short)	-0.33	0.71	0.17	1.20	83%	1.45	1.28	N/A	N/A
Burro 3 (short)	-1.00	0.32	1.05	2.48	0%	3.31	3.37	N/A	N/A
Burro 3 (long)	-1.37	0.18	1.90	21.49	0%	5.92	N/A	N/A	N/A
Burro 7 (short)	-0.79	0.42	0.78	2.64	33%	2.62	1.86	N/A	N/A
Burro 7 (long)	-1.09	0.28	1.26	5.61	0%	3.75	N/A	N/A	N/A
Burro 8 (short)	0.08	1.09	0.21	1.25	75%	1.01	0.77	N/A	N/A
Burro 8 (long)	-0.09	0.90	0.36	1.50	50%	1.35	N/A	N/A	N/A
Burro 9 (short)	-0.64	0.51	0.46	1.70	67%	2.04	1.95	N/A	N/A
Burro 9 (long)	-0.80	0.41	0.80	2.89	33%	2.78	N/A	N/A	N/A
Coyote 3 (short)	-0.93	0.36	0.91	3.36	0%	2.88	2.78	N/A	N/A
Coyote 3 (long)	-1.42	0.17	2.02	25.27	0%	6.30	N/A	N/A	N/A
Coyote 5 (short)	-0.57	0.56	0.33	1.44	75%	1.80	1.77	N/A	N/A
Coyote 5 (long)	-1.17	0.26	1.40	9.10	0%	4.05	N/A	N/A	N/A
Coyote 6 (short)	-0.68	0.49	0.50	1.48	75%	2.10	2.06	N/A	N/A
Coyote 6 (long)	-1.03	0.32	1.08	3.69	0%	3.21	N/A	N/A	N/A
Thorney Island 45 (long)	-0.29	0.74	0.20	1.24	89%	1.42	N/A	N/A	N/A
Thorney Island 47 (long)	-0.28	0.75	0.18	1.21	83%	1.42	N/A	N/A	N/A
CHRC A (scaled)	0.31	1.36	0.10	1.11	100%	0.74	N/A	N/A	N/A
Hamburg DA0120 (scaled)	1.15	3.81	1.37	6.56	13%	0.28	N/A	N/A	N/A
Hamburg DAT 223 (scaled)	0.63	1.97	0.56	1.95	33%	0.56	N/A	N/A	N/A
TNO FLS (scaled)	0.81	2.42	0.75	2.46	17%	0.44	N/A	N/A	N/A

Table 2.2-2 (cont'd): SPM Evaluation against Quantitative Assessment Criteria: Individual Trial Average									
Data Set	Quantitative Criteria								
	-0.4<MRB <0.4	**0.67< MG<1.5**	**MRSE<2.3**	**VG<3.3**	**FAC2 >50%**	**0.5<CSF<2**	**0.5< CSF_LFL<2**	**0.5<DSF<2**	**0.5< DSF_LFL<2**
Maximum Gas Concentration Arc-Wise Distance									
Maplin Sands 27 (short)	-0.08	0.92	0.10	1.11	100%	N/A	N/A	1.13	1.20
Maplin Sands 34 (short)	0.16	1.18	0.03	1.03	100%	N/A	N/A	0.85	0.80
Maplin Sands 35 (short)	-0.26	0.77	0.11	1.12	100%	N/A	N/A	1.33	1.19
Burro 3 (short)	-0.63	0.52	0.43	1.60	50%	N/A	N/A	1.96	2.21
Burro 3 (long)	-0.55	0.56	0.35	1.47	75%	N/A	N/A	1.82	N/A
Burro 7 (short)	-0.65	0.50	0.56	1.93	33%	N/A	N/A	2.18	1.52
Burro 7 (long)	-0.64	0.50	0.56	1.93	33%	N/A	N/A	2.17	N/A
Burro 8 (short)	0.05	1.05	0.10	1.11	100%	N/A	N/A	1.00	0.87
Burro 8 (long)	0.04	1.04	0.11	1.11	100%	N/A	N/A	1.02	N/A
Burro 9 (short)	-0.41	0.66	0.22	1.27	67%	N/A	N/A	1.57	1.54
Burro 9 (long)	-0.36	0.69	0.21	1.25	67%	N/A	N/A	1.52	N/A
Coyote 3 (short)	-0.55	0.57	0.31	1.39	100%	N/A	N/A	1.77	1.78
Coyote 3 (long)	-0.48	0.61	0.24	1.29	100%	N/A	N/A	1.65	N/A
Coyote 5 (short)	-0.36	0.70	0.13	1.15	100%	N/A	N/A	1.44	1.48
Coyote 5 (long)	-0.14	0.87	0.05	1.05	100%	N/A	N/A	1.17	N/A
Coyote 6 (short)	-0.48	0.62	0.23	1.27	100%	N/A	N/A	1.63	1.67
Coyote 6 (long)	-0.45	0.63	0.20	1.23	100%	N/A	N/A	1.58	N/A
Thorney Island 45 (long)	-0.06	0.94	0.08	1.09	100%	N/A	N/A	1.10	N/A
Thorney Island 47 (long)	-0.28	0.74	0.18	1.23	83%	N/A	N/A	1.44	N/A
CHRC A (scaled)	0.24	1.27	0.07	1.07	100%	N/A	N/A	0.79	N/A
Hamburg DA0120 (scaled)	0.73	2.17	0.57	1.90	25%	N/A	N/A	0.47	N/A
Hamburg DAT 223 (scaled)	0.36	1.45	0.19	1.22	100%	N/A	N/A	0.71	N/A
TNO FLS (scaled)	0.46	1.61	0.26	1.31	83%	N/A	N/A	0.64	N/A

Table 2.2-2 (cont'd): SPM Evaluation against Quantitative Assessment Criteria: Individual Trial Average									
Data Set	Quantitative Criteria								
	-0.4<MRB <0.4	**0.67< MG<1.5**	**MRSE<2.3**	**VG<3.3**	**FAC2 >50%**	**0.5<CSF<2**	**0.5< CSF_LFL<2**	**0.5<DSF<2**	**0.5< DSF_LFL<2**
Maximum Point-Wise Gas Concentration									
Burro 3 (short)	1.04	16.28	1.95	>1000	45%	0.47	N/A	N/A	N/A
Burro 3 (long)	0.49	3.87	1.38	>1000	27%	0.97	N/A	N/A	N/A
Burro 7 (short)	0.42	2.78	1.20	>100	60%	0.96	N/A	N/A	N/A
Burro 7 (long)	-0.24	0.89	1.67	31.6	10%	3.05	N/A	N/A	N/A
Burro 8 (short)	0.41	4.05	1.10	>1000	52%	0.98	N/A	N/A	N/A
Burro 8 (long)	0.25	4.10	1.19	>1000	52%	1.25	N/A	N/A	N/A
Burro 9 (short)	0.38	3.02	1.01	>1000	60%	0.96	N/A	N/A	N/A
Burro 9 (long)	-0.03	1.34	0.91	33.6	40%	1.52	N/A	N/A	N/A
Coyote 3 (short)	0.80	4.05	1.58	>100	42%	0.65	N/A	N/A	N/A
Coyote 3 (long)	-0.77	0.30	1.73	42.9	25%	8.06	N/A	N/A	N/A
Coyote 5 (short)	0.60	2.93	1.31	>100	29%	0.92	N/A	N/A	N/A
Coyote 5 (long)	-0.24	0.77	0.93	5.21	43%	2.44	N/A	N/A	N/A
Coyote 6 (short)	0.13	1.66	0.98	59.0	38%	1.31	N/A	N/A	N/A
Coyote 6 (long)	-0.49	0.64	1.16	8.14	15%	2.51	N/A	N/A	N/A
CHRC A (scaled)	0.14	1.61	0.58	>100	78%	1.30	N/A	N/A	N/A
Hamburg DAT 223 (scaled)	0.51	1.72	0.37	1.53	63%	0.62	N/A	N/A	N/A
BA TNO TUV01 (scaled)	-0.08	0.92	0.21	1.25	100%	1.20	N/A	N/A	N/A
BA TNO FLS (scaled)	0.42	1.59	0.47	1.80	52%	0.76	N/A	N/A	N/A

Table 2.2-2 (cont'd): SPM Evaluation against Quantitative Assessment Criteria: Individual Trial Average									
Data Set	Quantitative Criteria								
	-0.4<MRB <0.4	**0.67< MG<1.5**	**MRSE<2.3**	**VG<3.3**	**FAC2 >50%**	**0.5<CSF<2**	**0.5< CSF_LFL<2**	**0.5<DSF<2**	**0.5< DSF_LFL<2**
Cloud Width									
Burro 3 (short)	0.78	2.30	0.65	2.11	33%	N/A	N/A	0.45	N/A
Burro 3 (long)	0.51	1.69	0.28	1.35	67%	N/A	N/A	0.60	N/A
Burro 7 (short)	0.43	1.55	0.20	1.24	100%	N/A	N/A	0.65	N/A
Burro 7 (long)	0.25	1.28	0.07	1.07	100%	N/A	N/A	0.78	N/A
Burro 8 (short)	0.34	1.42	0.21	1.25	75%	N/A	N/A	0.74	N/A
Burro 8 (long)	0.38	1.48	0.22	1.27	75%	N/A	N/A	0.71	N/A
Burro 9 (short)	0.49	1.65	0.25	1.31	100%	N/A	N/A	0.61	N/A
Burro 9 (long)	0.24	1.27	0.06	1.06	100%	N/A	N/A	0.79	N/A
Coyote 3 (short)	0.59	1.85	0.39	1.55	67%	N/A	N/A	0.56	N/A
Coyote 3 (long)	-0.18	0.83	0.08	1.08	100%	N/A	N/A	1.23	N/A
Coyote 5 (short)	0.49	1.65	0.22	1.29	100%	N/A	N/A	0.61	N/A
Coyote 5 (long)	0.34	1.41	0.11	1.13	100%	N/A	N/A	0.71	N/A
Coyote 6 (short)	0.22	1.25	0.09	1.10	100%	N/A	N/A	0.81	N/A
Coyote 6 (long)	0.11	1.12	0.02	1.02	100%	N/A	N/A	0.90	N/A
CHRC A (scaled)	-0.04	0.96	0.04	1.04	100%	N/A	N/A	1.06	N/A
BA TNO FLS (scaled)	-0.13	0.88	0.02	1.02	100%	N/A	N/A	1.14	N/A

DEGADIS generally over-predicts maximum arc-wise concentrations for field trials by approximately a factor of 2. Approximately 69% of the data were over-predicted (CSF>1) with approximately 40% being over-predicted by more than a factor of 2 contributing to the reason DEGADIS did not meet the MEP quantitative acceptance criteria for MRB, MG, and FAC2. The over-prediction is more severe for field trials with long time averages compared to field trials with short time averages. The higher over-prediction for longer time averages can be attributed to the little sensitivity the model shows to longer time averages compared to the sensitivity the experimental data exhibits.

DEGADIS generally under-predicts concentrations for wind tunnel tests by approximately a factor of 2. All of the scaled data were under-predicted (CSF<1) with approximately 64% of the scaled data being under-predicted by more than a factor of 2 (CSF<0.5). The longer time averages associated with the wind-tunnel tests are not as likely to affect the concentrations, since the wind-tunnel tests had near steady state releases.

All the data sets met the quantitative acceptance criteria for MRSE, since generally the field trials and wind-tunnel tests showed similar trends resulting in less scatter about the mean (i.e., over-predictive of field tests and under-predictive of wind tunnel tests). Since the field trials and wind-tunnel trials had opposite trends, the VG for the trial average was higher than the MEP acceptance criteria. The larger VG attributed to field trials with long time averages is a result of some sensors being more sensitive to the longer time averages than others, resulting in some data points being over-predicted by significant margins compared to others.

DEGADIS tends to over-predict concentrations in the near field where concentrations are still high and under-predict concentrations in the far field where concentrations become low, as shown in Figure 2.2-1 and Figure 2.2-2, which compare the measured and predicted concentrations (with ideal solid line and factor of 2 dotted lines). The transition from over-predictive to under-predictive happens near the lower flammability limit (LFL) concentration (5%).

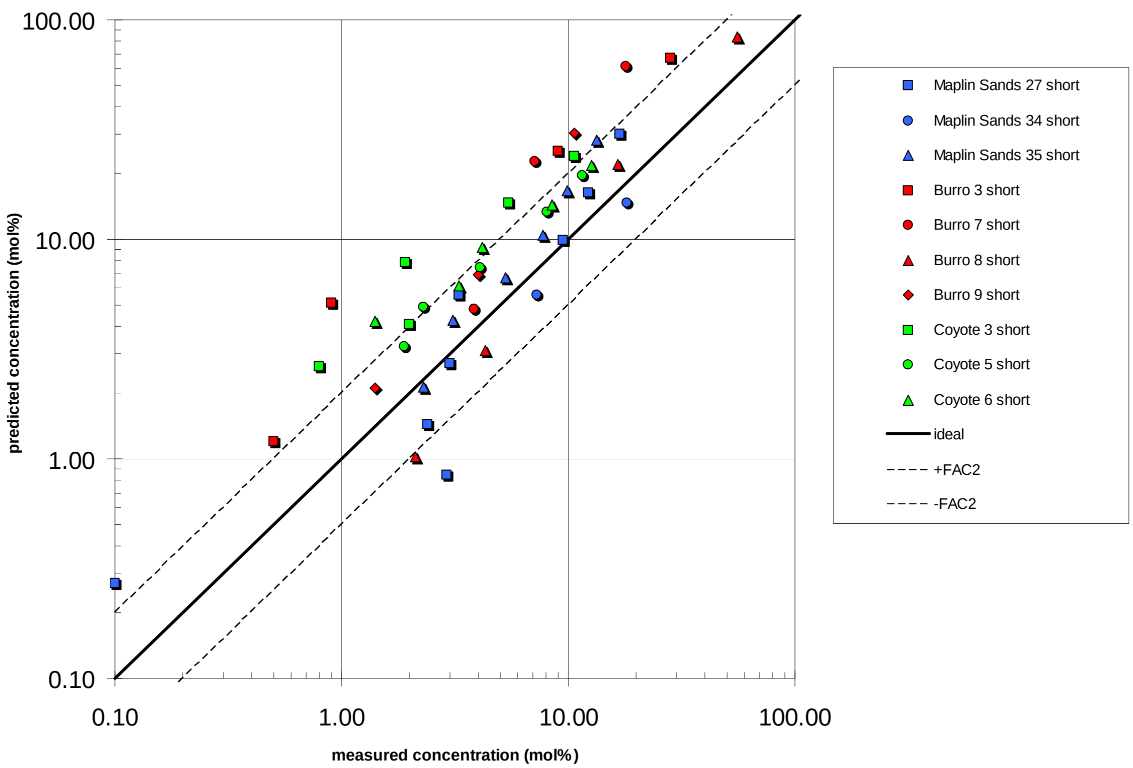


Figure 2.2-1: Short Time Average Measured and Predicted Concentrations

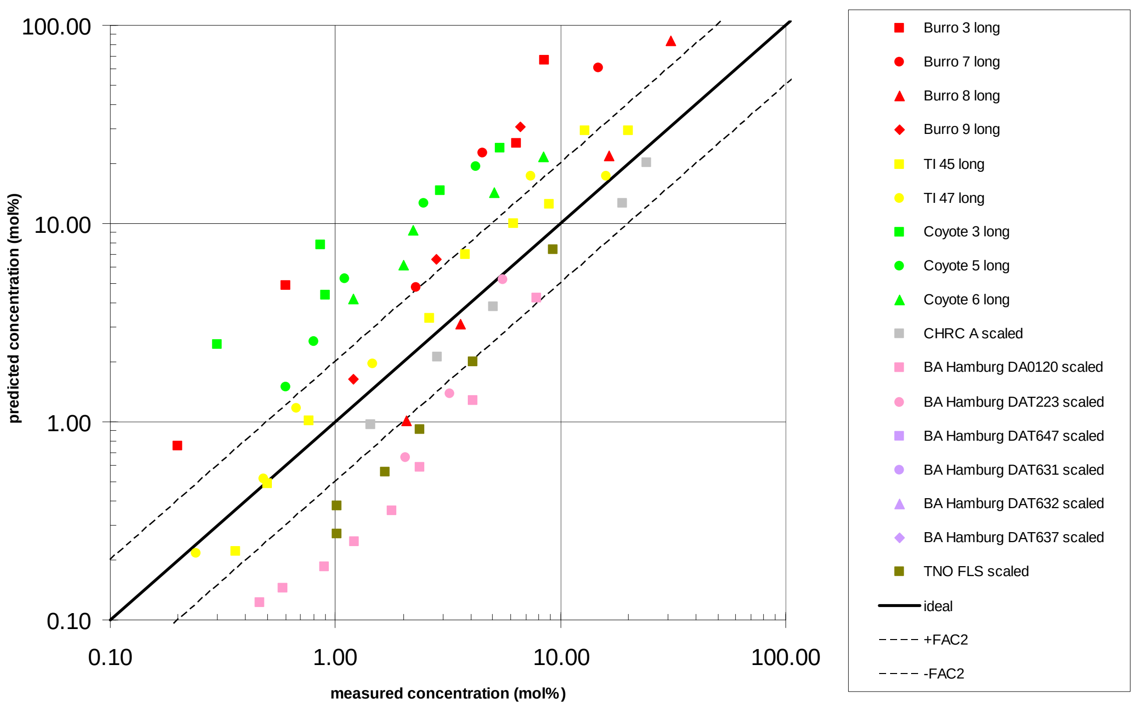


Figure 2.2-2: Long Time Average Measured and Predicted Concentrations

DEGADIS generally meets all the MEP quantitative acceptance criteria for the maximum gas concentration arc-wise distance with the exception of the wind-tunnel tests. The reason for the better results compared to the maximum arc-wise gas concentrations is two-fold. The large over-prediction of gas concentration in the near field is mitigated by the large drop off in concentration in the near field, and the large over-prediction of gas concentration in the far field is mitigated by the smaller change in concentration in the far field. For these reasons, the distance safety factor may not be affected by seemingly large concentration discrepancies that are actually small differences in distance.

DEGADIS generally over-predicts the distance to a given concentration for field trials by approximately a factor of 1.5. Approximately 89% of the field data is predicted with a factor of 2. The over-prediction is similar for short time averages and large time averages. This can be explained by the experimental gas concentration data in the near field being affected more by longer time averaging compared to the distances to the gas concentration in the near field. DEGADIS under-predicts the distance to a given concentration for wind-tunnel tests by a factor of 1.5. Approximately 68% of the wind-tunnel data is within a factor of 2.

DEGADIS predicts the maximum point-wise gas concentrations with a wide degree of scatter. DEGADIS generally seems to over-predict point-wise gas concentrations that are located closer to the cloud centerline where the maximum arc-wise concentration often occurred, and under-predict point-wise gas concentrations that are located farther from the cloud centerline. In addition, DEGADIS generally seems to under-predict short time averages and over-predict long time averages with a difference of a factor of 2 or more between them. The wide degree of scatter and inability of the DEGADIS crosswind gas concentration similarity profile to model bifurcation of clouds may make it unreliable to model point-wise gas concentrations.

DEGADIS generally meets all the MEP quantitative acceptance criteria for cloud width. DEGADIS generally over-predicts the distance to a given concentration for field trials by approximately a factor of 1.5. Approximately 84-92% of the field data is predicted with a factor of 2. DEGADIS shows better agreement with scaled wind-tunnel tests with all data within a factor of 2.

Anomalies

As shown in Figure 2.2-3, DEGADIS under-predicts the distance to the LFL for Burro 8 and Maplin Sands 34, but is well within a factor of 2.

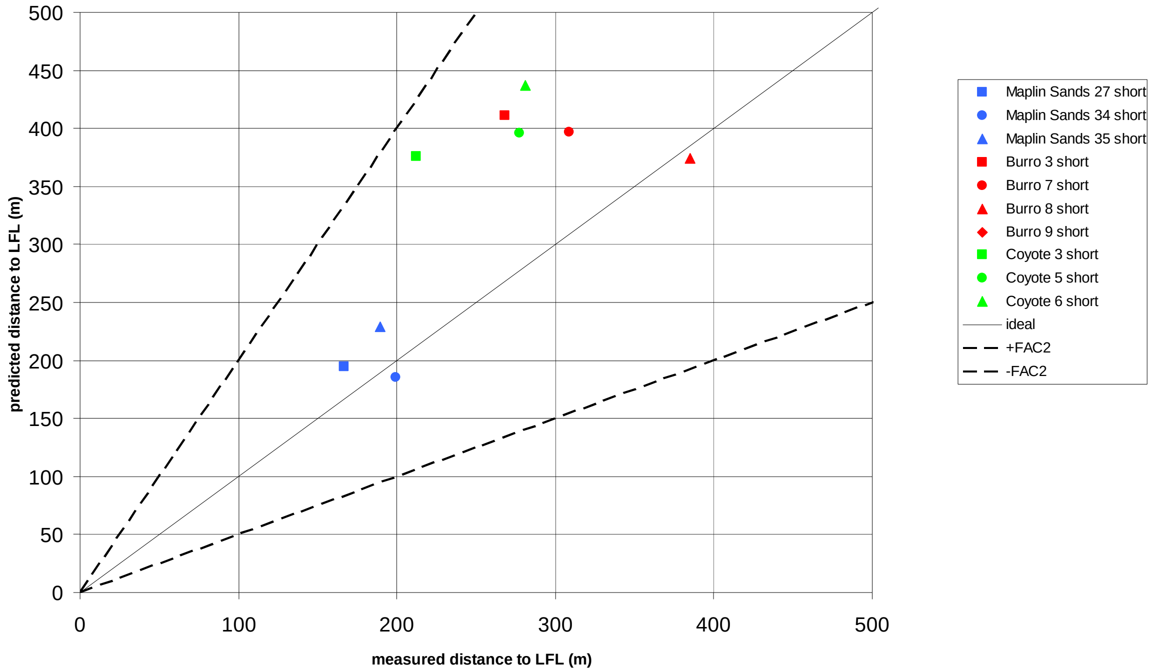


Figure 2.2-3 Short Time Average Measured and Predicted Distance to LFL

As shown in Figure 2.2-4, Maplin Sands data comparisons indicate that the model may be less conservative for dispersion over water. The inclusion of the water transfer sub-model had negligible effect on the gas concentration, raising some question as to the validity of the water transfer sub-model. The Maplin Sands 34 is the only other LNG field trial to show under-prediction, but this is partly due to the larger amount of data points taken in the far-field, in which the model tends to be more under-predictive.

As shown in Figure 2.2-4, Burro 8 data comparisons indicate that the model may be under-predictive for low wind speed with high atmospheric stabilities, which is a larger concern due to its applicability to the 49 C.F.R. § 193.2059 requirements (2 meters per second [m/s], F stability). Comparison against longer time averages will tend to reduce the concentration of the experiment (but not the model) and make it appear conservative.

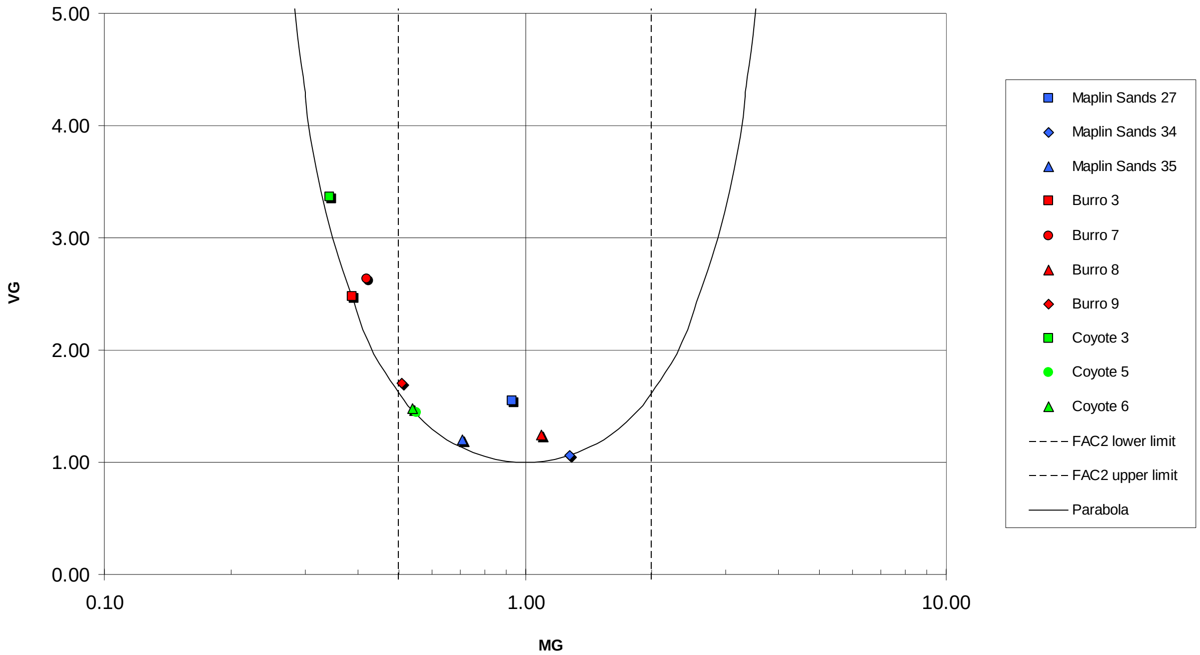


Figure 2.2-4 Short Time Average MG and VG

As shown in Figure 2.2-5, the only other low wind speed, high stability data (Thorney Island 45 and 47) indicated over-prediction. However, it was compiled using long time averages and matched closely with the Burro 8 long time average, which makes it difficult to comment as to whether under-prediction of low wind speed is a trend or not.

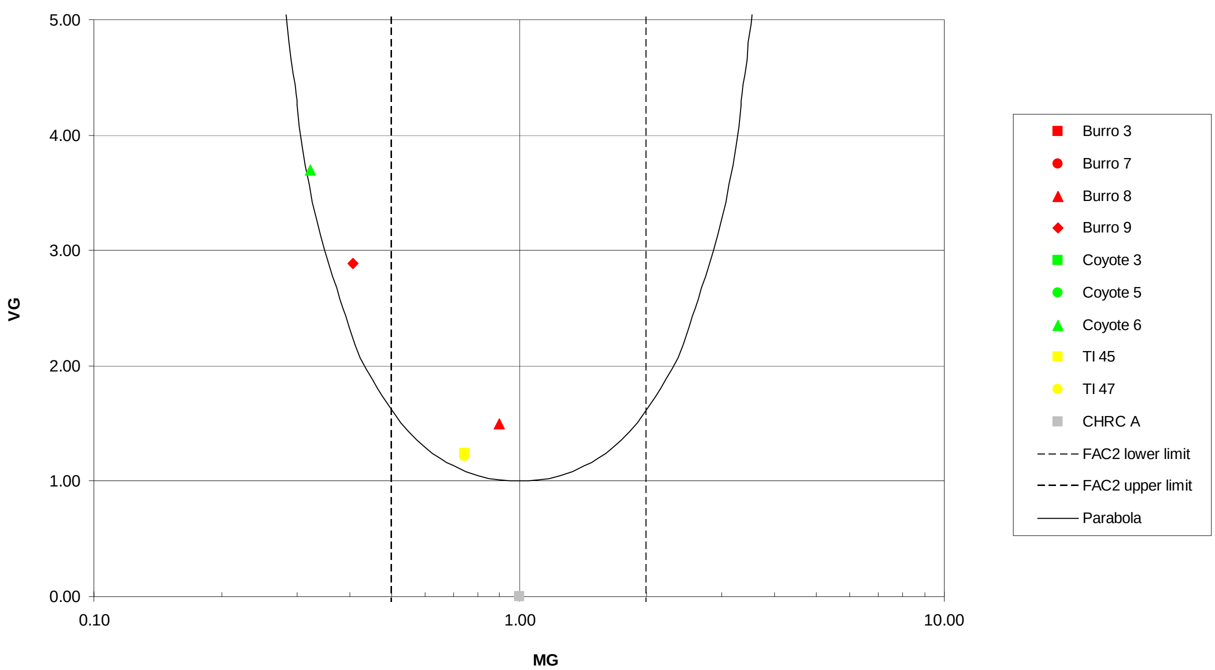


Figure 2.2-5 Long Time Average MG and VG

3.0 APPLICATION OF PHMSA ADVISORY BULLETIN ADB-10-07

This section provides a review of the DEGADIS model in accordance with the Advisory Bulletin and required supplementary documentation for obtaining approval of alternative vapor-gas dispersion models under Subpart B of 49 C.F.R. Part 193 (PHMSA, 2010) (Coldrick et al., 2010). In each of the following sections, the additional material requested by the Advisory Bulletin is reviewed and discussed.

3.1 SOURCE GEOMETRY HANDLED BY THE DISPERSION MODEL (MER SECTION 2.1.1.2; ADB-10-07 SECTION 1.A-D)

The DEGADIS model is able to simulate the dispersion of vapors emanating from ground level with zero momentum (i.e., a vaporizing liquid pool spreading axi-symmetrically). The model requires specification of a source radius and vaporization rate as a function of time. Source terms of regular geometries (e.g., circles, squares and low aspect ratio geometries) may be simplified to a circular area source term of equivalent cross-sectional area. Sources with high aspect ratios (e.g., long trenches) or irregular geometries cannot be directly inputted and may not be appropriately represented as a circular area. Therefore the model is not valid for those scenarios. Multiple source locations cannot be modeled.

DEGADIS is also able to simulate the dispersion of vapors from an elevated, vertically oriented gaseous jet source term with vertical momentum for plumes that become neutrally buoyant before reaching grade (e.g., vent stack releases and vertical pressure relief releases that do not reach grade). Horizontally oriented gaseous source terms, gaseous source terms with horizontal momentum, and gaseous source terms that may reach grade level where dense gas cloud effects may be applicable may not be accurately simulated by this model.

3.2 WIND FIELD (MER SECTION 2.2.2.1; ADB-10-07 SECTION 2)

The DEGADIS model is able to simulate steady state wind profiles. The model is not able to simulate transient wind speed or direction. Low wind speeds (less than 2 m/s) can be modeled, but may not be handled well by the model and may result in under-prediction of the hazard distance.

3.3 STRATIFICATION (MER SECTION 2.2.2.3; ADB-10-07 SECTION 3)

In the DEGADIS model, the Monin-Obukhov length is calculated automatically based on the Pasquill-Gifford category specified (A, B, C, D, E, or F). Specifying a different Monin-Obukhov length is also possible and will supersede any calculated value. Temperature and/or turbulence profiles cannot be inputted by the user. High atmospheric stability (F stability) can be modeled, but may not be handled well by the model and may result in under-prediction of the hazard distance.

3.4 TERRAIN TYPES AVAILABLE (MER SECTION 2.2.3.1; ADB-10-07 SECTION 4) & COMPLEX EFFECTS (MER SECTION 2.3.1.2; ADB-10-07 SECTION 4)

The DEGADIS model is limited to dispersion over unobstructed level terrain with uniform roughness length specified by the user. Sloped or varying terrain will affect the gravity spreading of a dense gas release. For dense gas releases, such as LNG vapor, the cloud will be stretched out as the dense gas plume flows along downward slopes. Therefore, for downward slopes, the centerline concentrations may be over-predicted in the near field, but under-predicted in the far field. Correspondingly, cross-wise concentrations and cloud widths may be over-predicted in the near field, but under-predicted in the far field. In contrast, upward slopes will oppose the movement of the dense gas, causing the vapor to accumulate and spread perpendicular to the upward slope. Therefore, for upward slopes, the centerline concentrations may be under-predicted in the near field, but over-predicted in the far field. Correspondingly, cross-wise concentrations and cloud widths may be under-predicted in the near field, but over-predicted in the far field. DEGADIS was not validated against sloped terrain tests, since it is not designed to simulate those scenarios.

3.5 OBSTACLE TYPES AVAILABLE (MER SECTION 2.2.4.1; ADB-10-07 SECTION 5) & COMPLEX EFFECTS (MER SECTION 2.4.3.1; ADB-10-07 SECTION 5)

The model is limited to dispersion over unobstructed level terrain with uniform roughness length specified by the user. For most instances, downwind concentrations assuming unobstructed terrain will be over-predictive. However, there are instances where downwind concentrations could be under-predictive due to wind channeling effects (Melton & Cornwell, 2009). Wind channeling may occur between adjacent LNG storage tanks, buildings, or large structures, which may result in the model being under-predictive for LNG vapor concentrations.

3.6 TURBULENCE MODELING (MER SECTION 2.3.1.5; ADB-10-07 SECTION 6)

The DEGADIS model parameterizes turbulence based on empirical turbulence coefficients formed from the user-specified atmospheric parameters (horizontal turbulent diffusivity) and Richardson number (vertical turbulent diffusivity).

The parameterization for horizontal turbulence is based on functions of the Pasquill stability category and averaging time. As averaging time increases, different empirical coefficients are used.

For Richardson numbers greater than zero, the parameterization for vertical turbulence is based on laboratory scale data for vertical mixing in stable density stratified fluid flows reported by Kantha et al (1977), Lofquist (1960), and McQuaid (1976) (Havens, Spicer 1990). For Richardson numbers less than zero, the function is taken from Colenbrander and Puttock (1983) and modified so the passive limits of the two functions agree (Havens, Spicer, 1990). When heat transfer from the surface is present, vertical mixing is enhanced by convection turbulence and is parameterized based on work by Zeman and Tennekes (1977) (Havens, Spicer, 1990).

The plume model has separate parameterizations for turbulence caused by jet effects. For area source terms, the parameterization of turbulence is a simplification based on unobstructed stably stratified flows. Therefore, it would not be appropriate for use in situations where obstructions are to be considered or where source terms with high momentum (i.e., jet releases) that may result in additional turbulence exist. For jet source terms, the parameterization of turbulence is based on jet effects and does not account for turbulence associated with impingement of a jet or with a dense vapor cloud reaching grade, and therefore would not be appropriate for releases that impinge on surfaces or reach grade.

3.7 BOUNDARY CONDITIONS (MER SECTION 2.3.1.7; ADB-10-07 SECTION 7)

The model requires the user to specify: the source term as a radius and vaporization rate at different time intervals; the wind profile in terms of the Pasquill-Gifford category (or Monin-Obukhov length); and the surface roughness. Zero velocity is imposed at the ground boundary condition. No other boundary conditions are able to be specified by the user.

3.8 COMPLEX EFFECTS: AEROSOLS (MER SECTION 2.3.1.1; ADB-10-07 SECTION 8)

Using DEGADIS, flashed vapors may be treated as gaseous jet source terms. However, for jet source terms, DEGADIS assumes a vertically oriented release with vertical momentum. DEGADIS also does not account for turbulence generated from plumes that reach grade or releases that impinge onto surfaces. Therefore, jet source terms, horizontally oriented gaseous source terms, gaseous source terms with horizontal momentum, and gaseous source terms that may reach grade level may not be accurately simulated by this model.

The model is not able to explicitly simulate the formation, vaporization, rainout, or subsequent dispersion of aerosol droplets. Hanna, et al. (1993) has attempted to simulate the dispersion of evaporated aerosol by specifying a source term based on the density of the vapor-aerosol-air mixture and the mole fraction of vapor-aerosol in the cloud (based on the corresponding mass concentration of the vapor-aerosol) obtained by assuming complete adiabatic mixing.

3.9 COMPUTATIONAL MESH (MER SECTION 2.4.3.1; ADB-10-07 SECTION 9)

As use of a computational mesh is not related to integral models such as DEGADIS, this section is not applicable.

3.10 DISCRETIZATION METHODS (MER SECTION 2.4.2.3; ADB-10-07 SECTION 10)

DEGADIS solves ordinary differential equations using the Runge-Kutta method with a variable step that is 4th order accurate. This is one of the oldest and probably the most commonly used numerical method for integral type models. More accurate numerical solution methodologies now exist, but are not expected to have a great effect on the results.

3.11 SOURCES OF MODEL UNCERTAINTY (MER SECTION 2.6; ADB-10-07, SECTION 11)

All models contain simplifications to minimize the computational time, which causes a certain degree of uncertainty and limits the applicability of the model. The areas of uncertainty for the DEGADIS model would be the numerical solver used to discretize the space, the source term simplification, the steady state wind profile simplification, and the turbulence parameterization.

3.12 SENSITIVITY TO INPUT (MER SECTION 2.6.4; ADB-10-07 SECTION 12)

A sensitivity analysis of the DEGADIS model was conducted based on the various inputs that could be specified, including source term, wind speed, surface roughness, atmospheric stability (and/or Monin-Obukhov Length), ambient temperature, ambient pressure, ambient relative humidity, and molecular weight. The sensitivity of the model was determined based on respective uncertainties for those values. Each sensitivity case is denoted by a corresponding letter and number. The letter corresponds to a different source term and the number designates the inputted variables as shown in Table 3.12-1.

The base case assumes values provided in the MEP, which were verified with the original data series reports available (Goldwire et al 1983a), (Goldwire, et al 1983b), (Koopman et al 1982a), (Koopman et al 1982b), (Colenbrander et al 1984a), (Colenbrander et al 1984b), (Colenbrander et al 1984c), (Johnson, 1985). Notes have been provided in the validation database for instances where there were conflicts between the MEP and original data series reports. The original data series reports were utilized to generate the sensitivity bounds for the inputs into DEGADIS. The lower and upper sensitivity bounds were based upon the lower and upper quartiles of the data. Where the lower and upper quartiles did not vary by more than 10% from the mean, no sensitivity analysis was conducted (e.g., a_10 and a_13). Since the wind tunnel tests were conducted under controlled atmospheric conditions, the wind tunnel test data were not subject to any sensitivity analyses related to atmospheric conditions. Values for the base case and sensitivity analyses are justified in the validation database.

Table 3.12-1: Sensitivity Case Designations	
Case Designation	**Description**
a	Base case
b_*	Alternative source term
c_*	Alternative source term
a_1	Averaging time sensitivity
a_2	Lower wind speed sensitivity
a_3	Higher wind speed sensitivity
a_4	Alternative wind speed sensitivity
a_5	Lower surface roughness sensitivity
a_6	Higher surface roughness sensitivity
a_7	Monin-Obukhov Length sensitivity
a_8	Lower atmospheric stability sensitivity
a_9	Higher atmospheric stability sensitivity
a_10	Ambient temperature sensitivity
a_11	Ambient pressure sensitivity
a_12	Ambient relative humidity sensitivity
a_13	Surface temperature sensitivity
a_14	Water Transfer Submodel sensitivity
a_15	Molecular weight sensitivity

The sensitivity cases and results are shown in Appendix A. Highlighted values indicate the upper and lower bounds of the calculated concentrations and distance to the LFL.

The ranges in concentrations are also shown in Appendix A with graphical depictions (vertical error bars) for each experiment followed by input/output summaries for each sensitivity run. The largest uncertainties are due to the specification of the surface roughness, wind speed, and molecular weight. As expected, specifying a lower surface roughness will generally result in higher concentrations downwind and subsequently longer distances to the LFL and vice versa. As expected, specifying a lower wind speed will generally result in higher concentrations downwind and subsequently longer distances to the LFL and vice versa. Specifying a lighter molecular weight of LNG (i.e., as methane) generally will result in higher concentrations downwind and subsequently longer distances to the LFL and vice versa. Overall, the concentrations may differ by more than a factor of four and downwind dispersion distances to the LFL may differ by up to a factor of two, dependant on the uncertainty in the user input and sensitivity to that input.

3.13 LIMITS OF APPLICABILITY (MER SECTION 2.7; ADB-10-07 SECTION 13)

The DEGADIS model is limited to dispersion over unobstructed level terrain with uniform roughness length specified by the user. The model cannot accurately simulate obstructed, sloped or varying terrain or terrain with varying surface roughness length.

The model does not have a built-in source term model and requires user-input to describe the source term. The source terms that can be defined are: (1) a single regularly shaped area source term with no momentum with specified equivalent radius and vaporization rate with respect to time (i.e., a single steady state or spreading vaporizing pool); or (2) an elevated vertically oriented gaseous jet source term with vertical momentum for plumes that become neutrally buoyant before reaching grade with specified diameter, elevation, release rate, and duration of release (i.e., a single time-limited elevated gaseous jet from a vent stack, pressure relief valve). Flashed vapors may be treated as gaseous source terms, where appropriate. Aerosol formation, vaporization, rainout, or subsequent dispersion of aerosol droplets cannot be modeled explicitly by the model, but alternative approaches may be suitable subject to further evaluation. The model cannot model multiple source terms that may occur simultaneously, nor can it accurately simulate a single source term with a highly irregular geometry or high aspect ratio (e.g., trenches). The model is not able to simulate horizontally oriented gaseous source terms, gaseous source terms with horizontal momentum, or gaseous source terms that may reach grade level where dense gas cloud effects may be applicable.

3.14 EVALUATION AGAINST THE MEP QUANTITATIVE ASSESSMENT CRITERIA (MER SECTION 6.2.4; ADB-10-07 SECTION 14)

3.14.1 Uncertainty Analysis of Model Input

This series of uncertainty analyses accounts for model uncertainty due to uncertainty in the assumption of input parameters specified by the user. This subtopic is further broken down into seven areas.

i. Analysis of source term(s)

The DEGADIS model does not have a built-in source term model and requires the specification of the source diameter and vaporization rate as a function of time.

For experiments involving LNG spills over water, this model validation study used the ABS (American Bureau of Shipping)/FERC LNG pool spread source term model to determine pool diameter and vaporization rates as a function of time (FERC, 2004a) (FERC, 2004b). The ABS/FERC LNG pool spread model assumes a 0.167 $kg/m^2/sec$ vaporization rate based on empirical data for spills over water. For all other experiments the specified pool diameters and rates were used and no sensitivity analysis was performed.

For the Thorney Island and wind tunnel trials, the gas was released through a well defined opening at ground level that was designed to give a release with negligible vertical momentum. The source term was defined based on this information without any need for additional sensitivity analyses. This approach is similar to previous validation studies (Hanna, et al 1993).

For experiments involving LNG spills over water, a sensitivity analysis was conducted to examine the effect of pool spread velocity. The ABS/FERC model, which models the pool spread and specifies a vaporization of 0.167$kg/m^2/sec$ was compared to an instantaneously formed steady-state pool (i.e. spreads instantaneously) using the same vaporization rate.

A sensitivity analysis was also conducted to examine the effect of the vaporization rate. A source term based on an instantaneously formed steady-state pool using a vaporization rate of 0.167 $kg/m^2/sec$ was compared to an instantaneously formed steady-state pool using a vaporization rate of 0.085 $kg/m^2/sec$. The 0.085 $kg/m^2/sec$ vaporization rate has been commonly used in previous validation studies, and is based on visual observations of the steady-state pool size and spill rate during the Maplin Sands experiments (Puttock, 1987). The resultant pool diameters are shown in Table 3.14-1.

Table 3.14-1: Pool Diameters as a Function of Vaporization Rate			
Test	**Maximum Pool Diameter based on ABS/FERC with 0.167 $kg/m^2/sec$**	**Steady-State Diameter based on 0.167 $kg/m^2/sec$**	**Steady-State Diameter based on 0.085 $kg/m^2/sec$**
Maplin Sands 27	14 m	13 m	19 m
Maplin Sands 34	14 m	13 m	18 m
Maplin Sands 35	15 m	14 m	20 m
Burro 3	26 m	26 m	36 m
Burro 7	28 m	28 m	39 m
Burro 8	32 m	30 m	42 m
Burro 9[a]	35 m	32 m	45 m
Coyote 3	30 m	28 m	39 m
Coyote 5	34 m	31 m	44 m
Coyote 6	33 m	31 m	43 m

a. It is noted that the pool diameters (and corresponding vaporization rate) may have greater uncertainties than those evaluated. For example, the diameter reported for the Burro 9 experiment by an airborne infrared imager was about 10 m in diameter (Koopman et al., 1981). However, this should not be considered representative of other experiments since rapid phase transitions destroyed the spill plate early in the test, drastically changing the nature of the LNG pool on the water surface.

The concentrations predicted indicate little sensitivity to the pool spread velocity and sensitivity to the vaporization rate and resultant steady pool diameter, as shown in Appendix A. As shown in Table 3.14-2, the distance to the LFL differs by less than 5%-10% from the base case, which is well within the overall uncertainty of the experimental or modeling results.

Table 3.14-2: Distance to LFL Uncertainty Due to Pool Spread Velocity and Vaporization Rate			
Test Arc	**ABS/FERC Pool Spread Model with 0.167 $kg/m^2/sec$**	**Steady-State Diameter based on 0.167 $kg/m^2/sec$**	**Steady-State Diameter based on 0.085 $kg/m^2/sec$**
Maplin Sands 27	204 m to LFL	206 m to LFL	216 m to LFL
Maplin Sands 34	191 m to LFL	191 m to LFL	191 m to LFL
Maplin Sands 35	223 m to LFL	222 m to LFL	202 m to LFL
Burro 3	405 m to LFL	402 m to LFL	394 m to LFL
Burro 7	388 m to LFL	387 m to LFL	368 m to LFL
Burro 8	289 m to LFL	291 m to LFL	308 m to LFL
Burro 9	492 m to LFL	482 m to LFL	465 m to LFL
Coyote 3	392 m to LFL	392 m to LFL	385 m to LFL
Coyote 5	396 to LFL	387 to LFL	358 to LFL
Coyote 6	457 m to LFL	455 m to LFL	451 m to LFL

ii. Analysis of boundary conditions

The DEGADIS model requires the user to specify the following items: the inlet boundary as a source term radius and vaporization rate at different time intervals (i.e. source term); the wind profile based on the Pasquill-Gifford (or Monin-Obukhov length) ; and the surface roughness. Zero velocity is imposed at the ground boundary condition. No other boundary conditions are specified by the user. The source term and wind profile boundary sensitivities are discussed in sections i and iii, respectively.

iii. Analysis of wind profile.

The DEGADIS model is only able to simulate steady state wind profiles and direction. For all trials, the wind speed used for the base case was defined as the domain average wind speeds from the MEP, which were verified to match the domain average wind sensor data during the dispersion periods found in the original data series reports, where available (Goldwire et al 1983a), (Goldwire, et al 1983b), (Koopman et al 1982a), (Koopman et al 1982b), (Colenbrander et al 1984a), (Colenbrander et al 1984b), (Colenbrander et al 1984c), (Johnson, 1985). Similarly, the upper and lower bounds for the wind speed were based on the upper and lower quartiles of the domain average wind sensor data during the dispersion periods found in the original data series reports, where available (Goldwire et al 1983a), (Goldwire, et al 1983b), (Koopman et al 1982a), (Koopman et al 1982b), (Colenbrander et al 1984a), (Colenbrander et al 1984b), (Colenbrander et al 1984c), (Johnson, 1985). Given the little fluctuation and/or uncertainty (<10% of mean) in some of the data, certain sensitivity cases were not simulated. In Maplin Sands 27, the original data series report (Colenbrander et al 1984a) claims that the wind speed sensor at 250 m, -90 deg, 10 m,, which recorded a 6.1 m/s mean (270-430 sec), probably represents the environmental conditions best, since the plume was blown in the direction of this pontoon. Accordingly, a number of reports list 6.1 m/s as the mean wind speed, while other reports list 5.5-5.6 m/s as the mean (190-350 sec) wind speed. Coincidentally, the upper quartile of the domain average wind sensor data provided in the original data series reports is 6.2 m/s. For consistency, the base case was taken as the 5.6 m/s domain averaged sensor data provided in the original data series reports and listed in the MEP. In addition, where the domain average wind sensor data reported in the MEP differed from the wind speed provided in the MEP, an additional case was simulated (a_4).

The upper and lower bounds for the stability class were based upon the atmospheric conditions (e.g. wind speed, cloud cover, insolation, time of day, etc). Wind speed data and atmospheric conditions were used in conjunction with various guidance documents, including the DEGADIS 2.1 documentation (Havens, Spicer, 1990), to determine the wind stability.

The surface roughness values for the base case were taken from the MEP (Coldrick et al., 2010) (Ivings et al., 2007). For field trials, surface roughness is rarely known to better than an order of magnitude (Johnson, 1985)). Where uncertainty or disagreement of the surface roughness existed, a sensitivity analysis to surface roughness was carried out. This effort was based on the bounds generated from the DEGADIS 2.1 documentation (Havens et al 1990) and recommended and generally accepted good engineering practices, which in certain circumstances varied greatly from that specified in the MEP (Coldrick et al., 2010). Previous validation studies conducted for the experiments were also examined (Hanna et al., 1993) (Ermak et al., 1989) (Puttock et al., 1984).

Maplin Sands

The MEP reports a surface roughness of 0.0003 meter (m) for Maplin Sands, which was conducted over waters protected by a bund (during periods of low tide) (Coldricket al., 2010). The Modeler's Data Archive (MDA) reports a value of 0.0003 m (Hanna et al., 1993). Ermak et al. (1989) reports a surface roughness of 0.000058 m. The Maplin Sands Reports provides a surface roughness estimate of 0.00002 m based on a 1:20 scale wind tunnel experiment to determine the effect on the surface roughness from the pontoons that were fitted with the sensor arrays (Puttock et al., 1984) (Colenbrander et al., 1984a), (Colenbrander et al., 1984b), (Colenbrander et al., 1984c). Based on photographic observations of the test site, most users could reasonably assume the surface roughness to correspond to open calm water or sea in coastal areas. The DEGADIS reports surface roughness of 0.0001 m for calm open seas and 0.001 m for sea in coastal areas (Spicer, Havens, 1982), (Havens, Spicer, 1990). Brutsaert reports 0.0001 m to 0.0006 m for large water surfaces (Brutstaert, 1982). The base case used the value of 0.0003 m reported in the MEP; a sensitivity analysis was conducted using 0.0001 m and 0.001 m. A third simulation was ran specifying the Monin-Obukhov lengths provided in the MEP. It should also be noted that all the Maplin Sands tests were conducted at low tide, where the 300 m low-lying bund may have affected the surface roughness and dispersion. The pontoons equipped with the sensor arrays would also have an influence on the dispersion.

Given the uncertainty in the surface roughness length that could be reasonably chosen, there was a moderate difference in downwind concentrations, as shown in Appendix A. As shown in Table 3.14-3, the distance to the LFL differs approximately 5-15% from the base case, which is within the overall uncertainty of the experimental or modeling results. As expected, specifying a higher surface roughness generally results in lower concentrations and shorter distances to the LFL.

Table 3.14-3: Distance to LFL Uncertainty Due To Surface Roughness Length: Maplin Sands			
Test	**Base Case 0.0003 m**	**Lower Bound 0.0001 m**	**Upper Bound 0.001 m**
Maplin Sands 27	204 m to LFL	214 m to LFL	175 m to LFL
Maplin Sands 34	191 m to LFL	184 m to LFL	176 m to LFL
Maplin Sands 35	223 m to LFL	246 m to LFL	200 m to LFL

Burro and Coyote

The MEP reports a surface roughness of 0.0002 m for Burro and Coyote, which were conducted over a spill pond surrounded by desert terrain. The spill pond was 58 m in diameter and 1.5 m below the surrounding terrain. The surrounding terrain had a slight upward slope rising 7 m above the water level at a downwind distance of about 80 m before leveling out thereafter (Coldrick et al., 2010). The MDA reports a value of 0.0002 m (Hanna et al., 1993). Ermak et al (1989) also reports a surface roughness of 0.0002 m. The Burro and Coyote Series Reports reports a value of 0.000205 m (Koopman et al., 1982a) (Koopman et al., 1982b) (Goldwire et al., 1983a) (Goldwire et al., 1983b) Based on photographic observations of the test site, users could reasonably assume the surface roughness to correspond to a desert or an area with sparse vegetation (Koopman et al., 1982c). The DEGADIS documentation reports surface roughness of 0.0005 m for desert and 0.01 m for few trees, winter time (Spicer, Havens 1990). Pielke (2002) reports 0.0003m for smooth deserts and 0.01m surface roughness value for the upper range of soils and short grass. Brutsaert (1982) reports 0.04 m for grass with some bushes and trees. The base case used the value of 0.0002 m reported in the MEP (Coldrick et al., 2010); a sensitivity analysis was conducted using 0.01 m. Simulations were also run specifying the Monin-Obukhov lengths provided in the MEP.

Given the great uncertainty in the surface roughness length that could be reasonably chosen, there was a noticeable difference in downwind concentrations, as shown in Appendix A. As shown in Table 3.14-4, the distance to the LFL differs by up to 40% from the base case, which is a source of significant uncertainty for the modeling results. With the exception of Burro 8, which was the only low-wind speed F stability test, the larger surface roughness resulted in lesser concentrations and a shorter distance to the LFL.

Table 3.14-4: Distance to LFL Uncertainty Due To Surface Roughness Length: Burro & Coyote		
Test	**Base Case 0.0002 m**	**Upper Bound 0.01 m**
Burro 3	405 m to LFL	257 m to LFL
Burro 7	388 m to LFL	242 m to LFL
Burro 8	289 m to LFL	302 m to LFL
Burro 9	492 m to LFL	307 m to LFL
Coyote 3	392 m to LFL	254 m to LFL
Coyote 5	396 to LFL	253 m to LFL
Coyote 6	457 m to LFL	292 m to LFL

Thorney Island

The MEP reports a surface roughness of 0.01 m for Thorney Island, which was conducted at an abandoned airfield on an island with 3 kilometers (km) of sheltered water downwind and 1 km of runway and grass periodically cut to 20 centimeters (cm) upwind of the prevailing wind direction (Johnson, 1985). The MDA reports a value of 0.01 m (Hanna et al., 1993). Ermak et al. (1989) reports a surface roughness of 0.005 m. Based on photographic observations of the test site, users could reasonably assume the surface roughness to correspond to a tarmac or an area with sparse vegetation (Goldwire et al., 1983b). The DEGADIS documentation reports surface roughness of 0.007 m for 3 cm cut grass, 0.01 m for few trees during winter time, and 0.03 m for the runway area of airports (Spicer, Havens 1990). Pielke (2002) reports a 0.01 m surface roughness value for the upper range of soils and short grass and 0.04 m to 0.1 m for long grass cut to 25 cm to 1 m. Brutsaert (1982) reports 0.00002 m for a smooth tarmac and 0.0045 m for grass (airport). The base case used the value of 0.01 m reported in the MEP; a sensitivity analysis was conducted using 0.00002 m and 0.03 m. A third simulation was run specifying the Monin-Obukhov lengths provided in the MEP.

Given the great uncertainty in the surface roughness length that could be reasonably chosen, there was a noticeable difference in downwind concentrations, as shown in Table 3.14-5. The concentration differs by up to a factor of almost 8 from the base case, which is a source of significant uncertainty for the modeling results.

Table 3.14-5: Concentration Uncertainty Due To Surface Roughness Length: Thorney Island			
Test	**Base Case 0.01 m**	**Lower Bound 0.00002 m**	**Upper Bound 0.03 m**
Thorney Island 45			
40 m	29.5%	12.8%	32.4%
53 m	29.5%	12.8%	16.0%
72 m	12.5%	12.8%	11.5%
90 m	10.0%	12.8%	7.9%
112 m	7.0%	12.8%	4.6%
158 m	3.3%	12.8%	1.9%
250 m	1.0%	3.3%	0.6%
335 m	0.5%	1.7%	0.3%
472 m	0.2%	0.8%	0.1%
Thorney Island 47			
50 m	17.4%	11.0%	20.4%
90 m	17.4%	9.2%	20.4%
212 m	2.0%	7.7%	1.3%
250 m	1.2%	6.9%	0.8%
335 m	0.5%	0.6%	0.3%
472 m	0.2%	0.5%	0.1%

The ambient temperature values for the base case were taken from the MEP, which were verified to match the sensor data during the dispersion periods found in the original data series reports, where available (Goldwire et al 1983a), (Goldwire, et al 1983b), (Koopman et al 1982a), (Koopman et al 1982b), (Colenbrander et al 1984a), (Colenbrander et al 1984b), (Colenbrander et al 1984c), (Johnson, 1985). If the MEP and original data series reports did not provide or record values, the values were assumed to take common values (e.g. 1 atmosphere). Given the little fluctuation and/or uncertainty (<10%) in all of the data, none warranted sensitivity cases.

The ambient pressure values for the base case were taken from the MEP, which were verified to match the sensor data during the dispersion periods found in the original data series reports, where available (Goldwire et al 1983a), (Goldwire, et al 1983b), (Koopman et al 1982a), (Koopman et al 1982b), (Colenbrander et al 1984a), (Colenbrander et al 1984b), (Colenbrander et al 1984c), (Johnson, 1985). In some cases, the MEP and original data series reports did not provide or record values. For these cases, the values were assumed to take atmospheric pressure (i.e. 1 atmosphere). For cases that did provide or record ambient pressure, the fluctuation was insignificant (<10%), and most cases would not warrant sensitivity cases. However, typically site specific values for ambient pressure are not available and atmospheric (i.e. 1 atmosphere) is assumed. To gauge this common assumption and determine the sensitivity of the model to this parameter, sensitivity cases were run where the ambient pressure differed from 1 atmosphere.

The ambient relative humidity values for the base case were taken from the MEP, which were verified to match the sensor data during the dispersion periods found in the original data series reports, where available (Goldwire et al 1983a), (Goldwire, et al 1983b), (Koopman et al 1982a), (Koopman et al 1982b), (Colenbrander et al 1984a), (Colenbrander et al 1984b), (Colenbrander et al 1984c), (Johnson, 1985). In some cases, the ambient relative humidity data listed in the MEP differed from the relative humidity sensor data provided in the original data series reports. In Maplin Sands 34, it is noted that the original data series report (Colenbrander et al 1984a) provides values of 72% at Maplin Sands test site and 74% at Foulness Met. Station (corrected to Maplin Sands site temp), which was located 5 km away in SW direction and about 1 km inland. The relative humidity sensor data showed a range from 70 to 77%. It is unclear where the 90% value listed in the MEP originated. For that reason, the base case was taken as the 72% average value provided in the original data series, and a sensitivity case to 90% relative humidity was provided. There was little fluctuation and/or uncertainty (<10%) in most of data, hence most cases did not warrant sensitivity cases, denoted N/A. However, typically site specific values for weather data are not available and nearby weather stations are relied upon. For this reason, sensitivity cases were also run where nearby weather station data was provided in the original data series report, such as the Maplin Sands trials.

The surface/ground temperature values for the base case were taken from the MEP, which were verified to match the sensor data during the dispersion periods found in the original data series reports, where available (Goldwire et al 1983a), (Goldwire, et al 1983b), (Koopman et al 1982a), (Koopman et al 1982b), (Colenbrander et al 1984a), (Colenbrander et al 1984b), (Colenbrander et al 1984c), (Johnson, 1985). If the MEP and original data series reports did not provide or record values, the values were assumed to take the temperature of the ambient temperature. Given the little fluctuation and/or uncertainty (<10%) in all of the data, none warranted sensitivity cases. In addition, the water transfer submodel within DEGADIS was used in the Maplin Sands trials. A sensitivity to the inclusion of this submodel was included for Maplin Sands.

The molecular weight values for the base case were taken from the MEP, which were verified to match the sensor data during the dispersion periods found in the original data series reports, where available (Goldwire et al 1983a), (Goldwire, et al 1983b), (Koopman et al 1982a), (Koopman et al 1982b), (Colenbrander et al 1984a), (Colenbrander et al 1984b), (Colenbrander et al 1984c), (Johnson, 1985). For the LNG field trials, the lower bound for the molecular weight was based on the molecular weight of methane assuming preferential boiloff; no upper bound was provided, as heavier molecular weights would not be expected than those listed in the MEP. Given the little fluctuation and/or uncertainty (<10%) in some of these values, some cases did not warrant sensitivity cases, denoted N/A.

The inputs for each sensitivity case utilized are summarized in Table 3.14-6. The inputs and outputs for each trial are shown in Appendix A.

Table 3.14-6: Sensitivity Case Inputs

	Maplin Sands 27	Maplin Sands 34	Maplin Sands 35	Burro 3	Burro 7	Burro 8	Burro 9	Coyote 3	Coyote 5	Coyote 6	Thorney Island 45	Thorney Island 47
Source Term												
Base Case	0.167kg/m^2/sec ABS/FERC	0.167kg/m^2/sec ABS/FERC	0.167kg/m^2/sec ABS/FERC	0.167kg/m^2/sec ABS/FERC	0.167kg/m^2/sec ABS/FERC	0.167kg/m^2/sec ABS/FERC	0.167kg/m^2/sec ABS/FERC	0.167kg/m^2/sec ABS/FERC	0.167kg/m^2/sec ABS/FERC	0.167kg/m^2/sec ABS/FERC	MEP	MEP
Alternative 1	0.167kg/m^2/sec steady state	0.167kg/m^2/sec steady state	0.167kg/m^2/sec steady state	0.167kg/m^2/sec steady state	0.167kg/m^2/sec steady state	0.167kg/m^2/sec steady state	0.167kg/m^2/sec steady state	0.167kg/m^2/sec steady state	0.167kg/m^2/sec steady state	0.167kg/m^2/sec steady state	N/A	N/A
Alternative 2	0.085kg/m^2/sec steady state	0.085kg/m^2/sec steady state	0.085kg/m^2/sec steady state	0.085kg/m^2/sec steady state	0.085kg/m^2/sec steady state	0.085kg/m^2/sec steady state	0.085kg/m^2/sec steady state	0.085kg/m^2/sec steady state	0.085kg/m^2/sec steady state	0.085kg/m^2/sec steady state	N/A	N/A
Wind Speed												
Base Case	5.6 (MEP)	8.5 (MEP)	9.6 (MEP)	5.4 (MEP)	8.4 (MEP)	1.8 (MEP)	5.7 (MEP)	6 (MEP)	9.7 (MEP)	4.6 (MEP)	2.3 (MEP)	1.5 (MEP)
Lower Bound	4.4 (25% quart.)	7.6 (25% quart.)	7.9 (25% quart.)	5.1 (25% quart.)	N/A	1.5 (25% quart.)	N/A	N/A	N/A	N/A	N/A	N/A
Upper Bound	6.1 (75% quart.)	9.5 (75% quart.)	11 (75% quart.)	5.8 (75% quart.)	N/A	2 (75% quart.)	N/A	N/A	N/A	N/A	N/A	N/A
Atmospheric Stability												
Base Case	C-D (MEP)	D (MEP)	D (MEP)	C (MEP)	D (MEP)	E (MEP)	D (MEP)	C (MEP)	C (MEP)	D (MEP)	E-F (MEP)	F (MEP)
Lower Bound	D (assumed)	N/A	N/A	N/A	N/A	F (assumed)	N/A	N/A	D (assumed)	E (assumed)	F (assumed)	N/A
Upper Bound	C (assumed)	C (assumed)	C (assumed)	N/A	C (assumed)	N/A	C (assumed)	N/A	N/A	N/A	E (assumed)	E (assumed)
Surface/Ground Roughness												
Base Case	3e-4 (MEP)	3e-4 (MEP)	3e-4 (MEP)	2e-4 (MEP)	2e-4 (MEP)	2e-4 (MEP)	2e-4 (MEP)	2e-4 (MEP)	2e-4 (MEP)	2e-4 (MEP)	1e-2 (MEP)	1e-2 (MEP)
Lower Bound	1e-4 (assumed)	1e-4 (assumed)	1e-4 (assumed)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2e-5 (assumed)	2e-5 (assumed)
Upper Bound	1e-3 (assumed)	1e-3 (assumed)	1e-3 (assumed)	1e-2 (assumed)	1e-2 (assumed)	1e-2 (assumed)	1e-2 (assumed)	1e-2 (assumed)	1e-2 (assumed)	1e-2 (assumed)	3e-2 (assumed)	3e-2 (assumed)
Ambient Temperature												
Base Case	288.1K (MEP)	288.4K (MEP)	289.3K (MEP)	307.75K (MEP)	306.96 (MEP)	306.02 (MEP)	308.52K (MEP)	311.45K (MEP)	301.49K (MEP)	297.26K (MEP)	286.25K (MEP)	287.45K (MEP)
Lower Bound	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Upper Bound	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ambient Pressure												
Base Case	1 (assumed)	1 (assumed)	1 (assumed)	0.936 (MEP)	0.928 (MEP)	0.929 (MEP)	0.928 (MEP)	0.924 (MEP)	0.927 (MEP)	0.930 (MEP)	1 (MEP)	1 (MEP)
Lower Bound	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Upper Bound	N/A	N/A	N/A	N/A	1 (assumed)	1 (assumed)	1 (assumed)	1 (assumed)	1 (assumed)	1 (assumed)	N/A	
Ambient Relative Humidity												
Base Case	53 (MEP)	72 (avg. data)	63 (avg. data)	5.2 (MEP)	7.4 (MEP)	4.5 (MEP)	14.4 (MEP)	11.3 (MEP)	22.1 (MEP)	22.8 (MEP)	100 (MEP)	97.4 (MEP)
Lower Bound	N/A	N/A	N/A	N/A	5	N/A	6.5	3.5	7.2	4.5	N/A	N/A
Upper Bound	63 (avg. Foulness)	90 (MEP)	77 (MEP)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Molecular Weight												
Base Case	17.23 (MEP)	16.66 (MEP)	16.39 (MEP)	17.26 (MEP)	18.22 (MEP)	18.12 (MEP)	18.82 (MEP)	19.51 (MEP)	20.19 (MEP)	19.09 (MEP)	57.8 (MEP)	57.8 (MEP)
Lower Bound	16.04 (methane)	16.04 (methane)	16.04 (methane)	16.04 (methane)	16.04 (methane)	16.04 (methane)	16.04 (methane)	16.04 (methane)	16.04 (methane)	16.04 (methane)	N/A	N/A
Upper Bound	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

iv. Analysis of sub-models.

The user is able to specify whether water transfer should be included in the analysis. If selected, a sub-model is utilized to calculate the effect of this phenomenon. Although all the LNG field trials were spilled over water, much of the dispersion was over land. Therefore, the water transfer sub-model was primarily applicable to the Maplin Sand trials, which were dispersed entirely over water. A sensitivity analysis of the water transfer sub-model was investigated. Negligible differences from the base case in the predicted concentrations and distance to LFL were found, as shown in Table 3.14-7.

Table 3.14-7: Effect of Water Transfer Sub-Model

Test	With Water Transfer	Without Water Transfer
Maplin Sands 27		
58 m	30.9%	30.9%
89 m	16.3%	16.3%
131 m	10.1%	10.1%
181 m	6.3%	6.4%
248 m	3.3%	3.3%
322 m	1.7%	1.7%
399 m	1.0%	1.0%
650 m	0.3%	0.3%
Maplin Sands 34		
87 m	14.6%	12.6%
179 m	5.6%	4.9%
Maplin Sands 35		
58 m	28.4%	28.4%
89 m	16.6%	16.6%
129 m	10.4%	10.4%
180 m	6.7%	6.7%
250 m	4.3%	4.3%
400 m	2.1%	2.1%

No other sub-models (e.g., turbulence models) would be applicable or are able to be specified by the user.

v. Analysis of temporal discretization averaging.

The DEGADIS model allows for specification of different time-averages. The time-averages specified in the validation study reflect the time-averaged data of the experimental measurements. For flammable gases, typically the short time averages are of most interest. Long time averages will reduce the maximum concentration as time progresses, which can result in concentrations predicted below that of interest (i.e., LFL) and potential under-prediction of the hazard. Longer time averages may provide insight into the duration of the hazard and/or the peak to mean ratio that may be a result of cloud meander or turbulence, which may be of importance in more detailed risk analyses. This is shown in Table 3.14-8.

Table 3.14-8:
Effect of Time-Average on the Maximum Arc-Wise Concentration

Test	Short	Long
Burro 3	1 second	100 seconds
57 m	66.7%	66.7%
140 m	25.3%	25.3%
400 m	5.1%	4.9%
800 m	1.2%	0.8%
Burro 7	1 second	140 seconds
57 m	61.2%	61.2%
140 m	22.7%	22.7%
400 m	4.8%	4.8%
Burro 8	1 second	80 seconds
57 m	83.8%	83.8%
140 m	22.0%	22.0%
400 m	3.1%	3.1%
800 m	1.0%	1.0%
Burro 9	1 second	50 seconds
140 m	30.6%	30.6%
400 m	6.9%	6.6%
800 m	2.1%	1.6%

Table 3.14-8 (cont'd): Effect of Time-Average on the Maximum Arc-Wise Concentration		
Test	**Short**	**Long**
Coyote 3	1 second	50 seconds
140 m	23.9%	23.9%
200 m	14.6%	14.6%
300 m	7.9%	7.8%
400 m	4.9%	4.3%
500 m	3.0%	2.4%
Coyote 5	1 second	90 seconds
140 m	19.6%	19.5%
200 m	13.4%	12.7%
300 m	7.5%	5.3%
400 m	4.9%	2.5%
500 m	3.3%	1.5%
Coyote 6	1 second	70 seconds
140 m	21.6%	21.6%
200 m	14.3%	14.3%
300 m	9.2%	9.2%
400 m	6.1%	6.1%

The maximum arc-wise concentrations are not greatly affected by time averaging, but will generally reduce the concentration. Longer time averages with respect to spill duration, higher turbulence, and higher wind speeds exhibit a greater reduction in concentrations (especially in the far field). The lower concentration may be a result of a lesser hazard duration and/or higher peak to mean ratio from turbulence and/or cloud meander. This reduction in concentration between time averaging can be seen in Coyote 5 where high wind speeds (>10 m/s) and neutral atmospheric stability were present.

The time-averaging in DEGADIS is primarily to take into account cloud meander and will increase gas concentrations farther from the centerline (via the parameterization of horizontal turbulence), while the time-averaging in experimental data will primarily reduce gas concentrations. Therefore, time-averaging has a relatively larger impact on cloud widths than centerline concentration, as shown in Table 3.14-9.

Table 3.14-9: Effect of Time-Average on the Plume Width		
Test	**Short**	**Long**
Burro 3	1 second	100 seconds
57 m	16.4%	17.0%
140 m	9.3%	12.4%
800 m	17.3%	27.5%
Burro 7	1 second	140 seconds
57 m	11.2%	11.1%
140 m	15.5%	16.7%
400 m	14.7%	17.4%
Burro 8	1 second	80 seconds
57 m	29.0%	28.9%
140 m	40.3%	39.2%
400 m	44.1%	42.8%
800 m	40.5%	39.4%
Burro 9	1 second	50 seconds
140 m	19.5%	27.7%
400 m	35.1%	36.2%
800 m	39.7%	47.6%
Coyote 3	1 second	140 seconds
140 m	19.7%	36.8%
200 m	16.2%	32.7%
400 m	25.7%	57.3%
Coyote 5	1 second	80 seconds
140 m	13.6%	13.7%
200 m	20.1%	20.9%
300 m	25.1%	27.7%
400 m	28.9%	34.4%
500 m	44.2%	57.5%
Coyote 6	1 second	50 seconds
140 m	22.7%	24.2%
200 m	23.6%	24.8%
300 m	23.6%	23.5%
400 m	26.6%	26.8%

vi. Analysis of spatial discretization averaging and grid resolution.

As use of a computational mesh is not related to DEGADIS, this section is not applicable.

vii. Analysis of geometrical representation for sloped and obstructed cases.

Sloped terrain and obstructions cannot be modeled with DEGADIS. Therefore, this analysis is not applicable.

3.14.2 Uncertainty Analysis of Model Output

This series of uncertainty analyses addresses model uncertainty due to uncertainty in the output used for evaluation.

i. Analysis of spatial output.

The DEGADIS model outputs concentrations at specific downwind distance intervals that do not always coincide with the experimental sensor locations. Therefore, interpolation of concentrations between downwind distances is often required to determine the concentration at the reflective experimental sensor location. The error associated with the interpolation is dependant on the model's output with respect to the sensor location. Most often there are not large differences between the interpolation points from a model's output with respect to the sensor locations and therefore this uncertainty is regarded as being inconsequential.

The determination of the distance to the LFL (taken as 5% for methane) requires interpolation or extrapolation of the experimental data and the model output. The experimental uncertainty associated with the interpolation and extrapolation is dependant on the distance between sensor locations relative to the distance to the LFL concentration. Since there is the potential for large gaps when interpolating and extrapolating the distance to the LFL from the experiments, there is the potential for a greater amount of uncertainty when determining the distance to the LFL for the experiments.

Linear, logarithmic-logarithmic (log-log) and power growth interpolation and extrapolation methodologies have been evaluated to determine the effect on the predicted results. Log-log interpolation of concentration and distance is generally more accepted for unobstructed dispersion compared to other methodologies, but it will generally provide less conservative results (i.e., shorter distances to LFL) and has the potential to under-predict the distances to the LFL. Linear interpolation will generally over-predict concentrations and was used in the Burro Series Report, but linear extrapolation will generally under-predict concentrations (Koopman et al., 1982a) (Koopman et al., 1982b). Linear interpolation and extrapolation also has the potential for higher uncertainties compared to the other methodologies. Power-growth interpolation tends to produce results in between linear and log-log interpolation.

In an attempt to "match" the uncertainty between the interpolation and extrapolation of the experimental data with the interpolation and extrapolation of the model output data, the distance to the LFL is interpolated and extrapolated using the sensor locations only. A more refined distance to the LFL from linear interpolation of the more detailed model spatial output is also evaluated to provide a better prediction of the distance to the LFL and an indication of the potential uncertainty from the interpolation and extrapolation methodologies using the experimental sensor locations.

For comparative reasons, the results among the three interpolation and extrapolation methodologies is provided in Table 3.14-10.

Table 3.14-10:

Comparison of Interpolation / Extrapolation Methodologies: Experiment Results

Test	Linearly interpolated/ extrapolated distance to the LFL	Power growth interpolated/ extrapolated distance to the LFL	Log-log interpolated/ extrapolated distance to the LFL
Maplin Sands 27	167m	165 m	158 m
Maplin Sands 34	199 m	209 m	241 m
Maplin Sands 35	190 m	188 m	187 m
Burro 3	268 m	235 m	183 m
Burro 7	309 m	276 m	256 m
Burro 8	385 m	377 m	356 m
Burro 9	361 m	341 m	315 m
Coyote 3	212 m	210 m	207 m
Coyote 5	277 m	274 m	267 m
Coyote 6	281 m	278 m	271 m
Falcon 1	293 m	312 m	371 m
Falcon 3	280 m	292 m	315 m
Falcon 4	6 m	31 m	34 m

As expected for the unobstructed experiments, the linear interpolation provided the most conservative (i.e., farthest distances to the LFL) followed by the power growth interpolation and then the log-log interpolation. Note that the Falcon tests, which contain obstructions in the flow field and had to be extrapolated, follow the opposite trend, as shown in Table 3.14-10.

Table 3.14-11: Comparison of Interpolation / Extrapolation Methodologies: Model Results				
Test	**Linearly interpolated/ extrapolated distance to the LFL**	**Power growth interpolated/ extrapolated distance to the LFL**	**Log-log interpolated/ extrapolated distance to the LFL**	**Refined linearly interpolated/ extrapolated distance to the LFL**
Maplin Sands 27	195 m	193 m	190 m	204 m
Maplin Sands 34	186 m	189 m	194 m	191 m
Maplin Sands 35	229 m	226 m	223 m	223 m
Burro 3	411 m	408 m	404 m	405 m
Burro 7	397 m	395 m	389 m	388 m
Burro 8	374 m	360 m	310 m	289 m
Burro 9	560 m	528 m	484 m	492 m
Coyote 3	376 m	373 m	367 m	392 m
Coyote 5	396 m	396 m	395 m	396 m
Coyote 6	437 m	445 m	463 m	457 m

The model results show a general convergence toward the refined linearly interpolated/ extrapolated results in the order of: linear, power growth, and then log-log interpolation/ extrapolation.[1] As expected, log-log interpolation appears to best predict the distance to the LFL (+7%, -7%) when evaluated against the more refined linear interpolated distances to the LFL from the model output. Also, as expected, linear interpolation generally resulted in more conservative distances to the LFL (up to +30%) when interpolating (Burro 8) and less conservative distances to the LFL (up to -5%) when extrapolating (Maplin Sands 34 and Coyote 6).[2] Power growth interpolation resulted in similar trends as linear (+25%, -3%), but less severe.

[1] The refined linearly interpolated/extrapolated results should have negligible uncertainty from interpolation/extrapolation given the model's spatial and concentration output being within close proximity to the LFL concentration.

[2] With the exception of Coyote 3, linear interpolation over-predicted the refined linear interpolated/extrapolated results.

The log-log interpolated experimental and model results using the sensor locations have been used (in lieu of more accurate model results) for evaluating the quantitative acceptance criteria for the concentration safety factor at the lower flammability limit (CSF_LFL) and the distance safety factor to the lower flammability limit (DSF_LFL) in order to "match" the uncertainty associated with the sensor location. However, as long as similar interpolation and extrapolation methodologies are compared, the values do not differ by much. Values are shown in Table 3.14-12. The log-log interpolation and extrapolation of the experimental and model results are compared in Table 3.14-13 with the more refined linear interpolated model results.

Table 3.14-12:
Experimental and Model Results for Lower Flammability Limits

Factor	Log-Log	Linear	Power Growth
CSF_LFL	1.80	1.81	1.75
DSF_LFL	1.43	1.34	1.38

Table 3.14-13:
Interpolation and Extrapolation of the Experimental and Model Results

Test	Log-log interpolated/ extrapolated distance to the LFL (Experi-ment)	Log-log interpolated/ extrapolated distance to the LFL (model)	Refined linearly interpolated/ extrapolated distance to the LFL (model)
Maplin Sands 27	158 m	190 m	204 m
Maplin Sands 34	241 m	194 m	191 m
Maplin Sands 35	187 m	223 m	223 m
Burro 3	183 m	404 m	405 m
Burro 7	256 m	389 m	388 m
Burro 8	356 m	310 m	289 m
Burro 9	315 m	484 m	492 m
Coyote 3	207 m	367 m	392 m
Coyote 5	267 m	395 m	396 m
Coyote 6	271 m	463 m	457 m

In addition, the model assumes a top-hat and Gaussian concentration profile in the cross-wise direction. Maximum concentrations are based upon the maximum concentration predicted by the model, which corresponds to the centerline concentration predicted in the integral model. However, the maximum concentration may not always be captured by the experiment or occur along the centerline. This will cause the model to generally over-predict experimental data where the actual maximum concentration was not captured by the sensors in the experiment. Cloud meandering during the experiments may reduce this over-prediction, but for many experiments the wind direction was fairly steady and meandering may not be significant.

The effect of this has been analyzed to some extent by evaluating the point-wise data that accounts for the offset between the vapor cloud centerline and the sensor that received the maximum concentration for the test. However, experimental data shows that maximum concentrations may not always exist along the centerline, which makes quantifying this effect more complex.

ii. Analysis of temporal output.

The DEGADIS model outputs concentrations at specific time intervals. The maximum concentration produced over the outputted time periods were utilized, and therefore no interpolation or extrapolations were utilized. This is not considered to be a large source of uncertainty.

3.14.3 Uncertainty Analysis of Experimental Data

This uncertainty analysis addresses experimental uncertainty due to uncertainty in the sensor measurement of gas concentration. The experimental uncertainty due to uncertainty in the sensor measurement was taken into account based upon the 90% confidence levels and uncertainties provided in the respective data series reports (Koopmanet al., 1982a) (Koopman et al., 1982b) (Goldwire et al., 1983a) (Goldwire et al., 1983b). This is shown in Table 3.14-14.

Table 3.14-14:
Uncertainty in the Sensor Measurement of Gas Concentration

Test	Measured (vol%)	- (vol%)	+ (%vol)
Maplin Sands 27	Short Time Avg.		
58 m	16.9	5.3	5.2
89 m	12.3	4.0	3.8
129 m	9.5	3.2	3.1
181 m	3.3	1.4	1.5
248 m	3.0	1.3	1.4
322 m	2.4	1.1	1.2
399 m	2.9	1.3	1.4
525 m	-	-	-
650 m	0.1	0.1	0.6
Maplin Sands 34	Short Time Avg.		
89 m	18.1	5.6	5.6
180 m	7.3	2.6	2.5
Maplin Sands 35	Short Time Avg.		
58 m	13.3	4.3	4.1
89 m	9.9	3.4	3.2
129 m	7.9	2.8	2.7
180 m	5.3	2.0	2.0
250 m	3.4	1.4	1.5
400 m	2.2	1.1	1.2

Table 3.14-14 (cont'd): Uncertainty in the Sensor Measurement of Gas Concentration						
Test	**Measured (vol%)**	**- (vol%)**	**+ (%vol)**	**Measured (vol%)**	**- (vol%)**	**+ (%vol)**
Burro 3	Short Time Avg.			Long Time Avg.		
57 m	28.2	1.6	1.6	8.5	0.5	0.5
140 m	9.0	0.5	0.5	6.4	0.4	0.4
400 m	1.2	0.4	0.4	0.7	0.2	0.2
800 m	0.9	0.3	0.3	0.9	0.3	0.3
Burro 7	Short Time Avg.			Long Time Avg.		
57 m	17.9	9.0	9.0	14.8	7.4	7.4
140 m	7.3	3.7	3.7	4.5	2.3	2.3
400 m	3.9	1.2	1.2	2.3	0.7	0.7
Burro 8	Short Time Avg.			Long Time Avg.		
57 m	55.9	3.1	3.1	31.0	1.7	1.7
140 m	18.1	9.1	9.1	16.4	8.2	8.2
400 m	6.1	1.8	1.8	5.4	1.6	1.6
800 m	2.1	0.6	0.6	2.1	0.6	0.6
Burro 9	Short Time Avg.			Long Time Avg.		
140 m	10.6	0.6	0.6	6.6	0.4	0.4
400 m	5.1	2.6	2.6	2.9	1.5	1.5
800 m	2.2	0.7	0.7	1.4	0.4	0.4

Table 3.14-14 (cont'd): Uncertainty in the Sensor Measurement of Gas Concentration						
Test	**Measured (vol%)**	**- (vol%)**	**+ (%vol)**	**Measured (vol%)**	**- (vol%)**	**+ (%vol)**
Coyote 3	Short Time Avg.			Long Time Avg.		
140m	10.7	0.6	0.6	5.4	0.3	0.3
200m	5.4	0.3	0.3	2.9	0.2	0.2
300m	1.9	0.2	0.2	0.9	0.1	0.1
400m	2.0	0.2	0.2	0.9	0.1	0.1
500m	0.4	0.1	0.1	0.1	0.0	0.0
Coyote 5	Short Time Avg.			Long Time Avg.		
140m	11.5	0.6	0.6	4.2	0.2	0.2
200m	8.1	0.4	0.4	2.5	0.1	0.1
300m	4.1	0.4	0.4	1.1	0.1	0.1
400m	2.3	0.1	0.1	0.8	0.0	0.0
500m	1.8	0.5	0.5	0.5	0.2	0.2
Coyote 6	Short Time Avg.			Long Time Avg.		
140m	12.7	0.7	0.7	8.4	0.5	0.5
200m	8.5	0.5	0.5	5.1	0.3	0.3
300m	4.2	0.4	0.4	2.2	0.2	0.2
400m	3.3	0.2	0.2	2.0	0.1	0.1
500m	2.6	0.8	0.8	1.9	0.6	0.6

Experimental uncertainty due to the sampling time, time averaging, spatial/volumetric averaging, cloud meander, and other errors or uncertainties associated with the experiment were not required to be quantified by the Advisory Bulletin; however, examination of all sensor data provided additional insight into uncertainty associated with the maximum concentrations recorded in the MEP. These uncertainties were noted in the validation database for each sensor and quantified, where possible. Where it was possible to estimate the uncertainty, it was included as part of the experimental uncertainty. Several qualitative examples are provided for the Burro series:

- In some tests the IST sensors became saturated with high concentrations (~18%) and became “pegged” out. Burro 3 data indicates that the 57 m arc may not be a good indication of the maximum concentration because there was no sensor that coincided with the “centerline” of cloud for this test and there was minimal fluctuation in wind direction. Therefore, the maximum concentration is based on sensors 14 m from the vapor cloud “centerline.”

- Burro 7 data indicates that early in the test the wind direction may have prevented the vapor cloud from dispersing over the sensor array at the 57 m arc. This may have prevented the sensors from capturing the actual maximum concentration.

- Burro 8 data indicates bifurcation of the vapor cloud.

- Burro 9 data indicates that a large rapid phase transition occurred during the experiments that may have affected the accuracy of the sensor array at the 57 m arc. In addition, the lowest positioned sensor at the 57 m arc was not operable and would have likely experienced the maximum concentration due to its low elevation.

3.14.4 Uncertainty Analysis Results

Graphical depictions of the predicted and measured gas concentration values for each experiment, with indication of the experimental and model uncertainty, are shown in the accompanying validation database.

3.14.5 Additional Specific Performance Measures

Calculation of the specific performance measures identified in the MEP and the Advisory Bulletin are shown in the accompanying validation database.

3.14.6 Individual Specific Performance Measures

Calculation of specific performance measures, as identified in the MEP and the Advisory Bulletin, for each experiment and data point, as well as the the average of all experiments, is shown in the accompanying validation database.

3.14.7 Model Input/Output Results

A tabulation of all simulations, including all specified input parameters and calculated outputs is provided in the accompanying validation database.

3.14.8 Specific Performance Measures Results

A tabulation of all calculated specific performance measures is provided in the accompanying validation database.

3.14.9 Input and Output Files

All relevant input and output files used in preparation of this document are included in the accompanying validation database.

4.0 CONCLUSIONS

4.1 SCIENTIFIC ASSESSMENT

DEGADIS is an integral model developed by Spicer and Havens derived from the HEGADAS mathematical model published by Colenbrander et al at Shell (1980). DEGADIS solves for the concentration, advecting downwind, with parameterized turbulent diffusion coefficients and top entrainment velocity. DEGADIS also solves for the temperature of the vapor, and includes heat transfer from the air, including relative humidity, and from the ground.

DEGADIS solves ordinary differential equations using the Runge-Kutta method using a variable step that is 4th order accurate. Although this methodology can be considered a source of uncertainty, it is not expected to be a large source of uncertainty for the results.

DEGADIS does not include a source term model to simulate any characteristics associated with the release, such as flow rates associated with the release, flashing of superheated liquids upon a release, the formation, vaporization, or rainout of aerosol droplets upon a release, or the formation, vaporization, or spreading of a liquid pool upon a release. DEGADIS requires the specification of a gaseous source term from the user.

DEGADIS is limited to handling a low-momentum source term where the diameter and vaporization rate are specified as a function of time, or a high momentum jet source term where the jet diameter, release rate, elevation, and duration are specified. DEGADIS is limited to a single source term. DEGADIS cannot be used to model multiple source terms (i.e., flashing and jetting sources that rainout to a pool, multiple release locations).

For an area source term, DEGADIS assumes the source is vertically oriented circular geometry with no momentum. Therefore, for area source terms, DEGADIS is limited to vertically oriented, low-momentum releases with regular geometries, such as vapors emanating from circular or rectangular sources (i.e., liquid pools or sumps). For area source terms for DEGADIS cannot be used for high-momentum releases (i.e. pressurized releases, flashing, jetting), or for releases that result in the emanation of vapors from irregular or high aspect ratio sources (i.e., trenches, or irregular liquid pools).

For a jet source term, DEGADIS assumes the source is vertically oriented circular geometry that accounts for turbulence associated with the momentum of the release, but does not account for turbulence associated with a release reaching grade or impinging onto a surface. Therefore, for jet source terms, DEGADIS is limited to vertically oriented releases that do not reach grade (i.e., vent stack releases that do not reach grade, flashing from vertically oriented piping, and gaseous releases from vertically oriented piping that do not reach grade). The DEGADIS jet plume model cannot be used for horizontally oriented source terms or releases that may reach grade level or impinge onto a surface (i.e., flashing from horizontally oriented piping, any release that reaches grade).

DEGADIS is limited to simulating steady state wind profiles. DEGADIS cannot model transient wind speed or direction. Assuming a steady state wind speed and direction is often sufficient for hazard analyses, but can pose limitation in validation against experimental data where varying wind speed and direction may affect the experimental results. The selection of wind direction is not pertinent or possible in DEGADIS, since it assumes a circular source term where the dispersion will be axi-symmetric. Assuming a steady wind direction will generally produce higher concentrations, because there would be less cloud meander and turbulent mixing caused from the change in wind direction. Assuming lower wind speeds will generally result in higher downwind concentrations and assuming a higher wind speed will generally result in lower downwind concentrations. DEGADIS generally produces the highest downwind concentrations at 2 m/s. DEGADIS should be specified with the lower wind speed that is reflective of the area or with wind speeds of 2 m/s to produce conservative results. For most applications pertinent to this study, DEGADIS will be used in accordance with 49 C.F.R. § 193.2059, which specifies the lowest wind speed that occurs 90% of time for the area or 2 m/s. Steady state wind speed and direction is not expected to be a large limitation of the model.

DEGADIS cannot account for sloped or varying terrain. Sloped or varying terrain will affect the gravity spreading of a dense gas release. For dense gas releases, such as LNG vapor, concentrations in the far field may be under-predicted along downward slopes and concentrations in the far field may be over-predicted along upward slopes. Correspondingly, cross-wise concentrations and cloud widths in the far field may be over-predicted for downward slopes and cross-wise concentrations and cloud widths in the far field may be under-predicted for upward slopes. On the contrary, gas may accumulate against an upward slope causing the model to under-predict gas concentrations and over-predict cross-wise concentrations and cloud widths in the near field or traverse along a downward slope causing the model to over-predict gas concentrations and under-predict cross-wise concentrations and cloud widths in the near field. DEGADIS was not validated against sloped terrain tests, since it is not designed to simulate those scenarios. Therefore, DEGADIS cannot be used to model dispersion along slopes or varying terrain.

DEGADIS is limited to the specification of a single surface roughness. DEGADIS cannot account for terrain with varying surface roughness length. Assuming a uniform surface roughness is often sufficient. Assuming a higher surface roughness will generally result in lower downwind concentrations and assuming a lower surface roughness will generally result in higher downwind concentrations. DEGADIS should be specified with the lowest surface roughness that is reflective of the area to produce conservative results. For most applications pertinent to this study, DEGADIS will be used in accordance with 49 C.F.R. § 193.2059, which specifies the surface roughness of 0.03 m, so this is not expected to be a large limitation of the model.

DEGADIS does not explicitly model turbulence generated in the flow field from obstructions and cannot take into account the change in flow field around obstructions that are relatively larger than the vapor cloud. For most instances, downwind concentrations assuming unobstructed terrain will be over-predictive since less turbulence, and subsequent mixing, would be generated in the flow field and no obstructions would restrict the movement of the dispersing vapor. However, there are instances where downwind concentrations could be under-predictive due to wind channeling effects (Melton & Cornwell, 2009, Gavelli 2011). Wind channeling may occur between adjacent LNG storage tanks, buildings, or large structures, which may result in the model being under-predictive for concentrations. Therefore, DEGADIS cannot be used to model releases that may disperse between large adjacent structures.

DEGADIS accounts for atmospheric turbulent mixing and dilution through the use of empirically derived turbulent mixing coefficients and top entrainment. DEGADIS does not explicitly calculate stochastic fluctuations due to turbulence in the flow field. Stochastic fluctuations in concentration can result in concentrations higher or lower than predicted. Therefore, it is recommended that concentrations should be provided with a safety factor of 2 for the LFL to account for estimated peak to mean turbulent fluctuations (MER Section 2.3.5). In addition, for area source terms, DEGADIS assumes a no-momentum release and does not take into account possible turbulence generated by the release. Therefore, for area source terms, DEGADIS cannot be used for high-momentum releases (i.e. pressurized releases, flashing, jetting). Assuming no turbulence at a low-momentum source (i.e., turbulence generated at the surface of a boiling pool) will generally result in lower downwind concentrations because there is less turbulent mixing. For jet source terms, DEGADIS accounts for turbulent mixing from the jet release, but does not account for turbulence associated with impingement of a jet or with a dense vapor cloud reaching grade. Therefore, for jet source terms, DEGADIS cannot be used for releases that may reach grade level or impinge onto a surface (i.e., flashing from horizontally oriented piping, any release that reaches grade).

4.2 VERIFICATION

The verification of the model has been limited to accuracy of the conservation relations (e.g. conservation of mass), and has not been documented. The model predates the European Commission's Model Evaluation Group publications and many other software quality assurance publications, certifications (International Organization for Standardization: Standard 9000 - Quality Management), or standards. The software is not proprietary and its executable and source code files are freely available to the public, which makes it possible for users to modify the source code and recompile the executable, making quality control unmanageable. To address the lack of quality assurance / quality control possible with DEGADIS, it is encouraged that simulations be verified by an independent party or agency.

4.3 VALIDATION

As discussed in Section 4.1, "Scientific Assessment," the DEGADIS model is limited to dispersion over unobstructed level terrain specified by the user. Therefore, the current validation study is limited to the following trials:

- LNG Field Trials: Maplin Sands 27, 34, 35; Burro 3, 7, 8, 9; Coyote 3, 5, 6;
- Other Field Trials: Thorney Island 45, 47;
- Wind Tunnel Experiments: CHRC A; BA-Hamburg DA0120 (Unobstructed), DAT223 (Unobstructed 2); and BA-TNO TUV01, FLS.

DEGADIS met most of the MEP quantitative acceptance criteria for short time averages with the exception of mean relative bias, MRB, and mean relative square error, MRSE, as shown in Table 2.2-1. As shown in Figure 4.3-1 and supported by the statistical performance measure values, DEGADIS is generally over-predictive, but exhibits a large degree of scatter and only about half of its predictions are within a factor of 2. However, the MEP specific performance measures and quantitative acceptance criteria are based on an average of all the trials, which can be misleading. Therefore, it was recognized in the Advisory Bulletin that the approval or disapproval of a model should not be contingent only on the average of the experiments meeting the MEP quantitative acceptance criteria. Careful examination of all the sensor data and trends must be considered in concert with the MEP quantitative acceptance criteria. As shown in Table 2.2-2, these trends provide additional insight into the model performance against subsets of data.

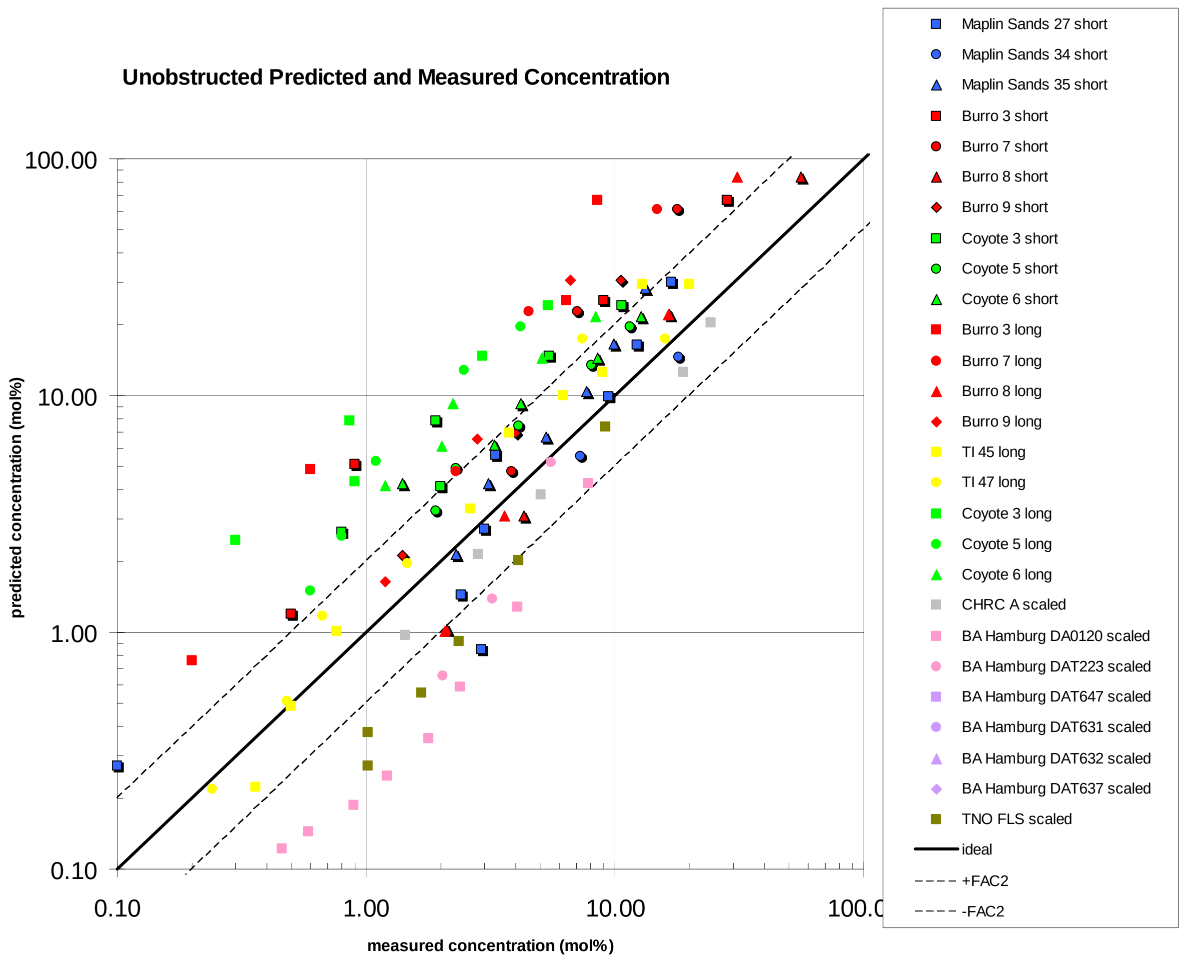


Figure 4.3-1 Predicted Concentration against Measured Concentration

DEGADIS is generally over-predictive for maximum arc-wise concentrations for field trials often by a factor of 2 or more. A large percentage of the data is over-predicted with over a third of the data being over-predicted by more than a factor of 2 contributing to why the FAC2 did not meet the acceptance criteria. Field trials with short time averages may be the most pertinent data set for LNG flammable hazards, and agree the best with the data. The over-prediction is more severe for field trials with long time averages. The higher CSF for longer time averages can be attributed to the little sensitivity the model shows to longer time averages compared to the sensitivity the experimental data exhibits. DEGADIS becomes less conservative as the vapor cloud disperses downwind, and may be under-predictive in the far field (at typically less than LFL concentrations). DEGADIS is less conservative for dispersion over water and may be under-predictive for low wind speeds (<2 m/s) and high atmospheric stabilities (F stability), which is especially pertinent to the current federal regulations. DEGADIS is generally under-predictive for wind tunnel experiments often by a factor of 2 or more. All wind tunnel data was under-predicted with the majority of the data being under-predicted by more than a factor of 2 contributing to the FAC2 not meeting the acceptance criteria. Similar to the field trials, DEGADIS becomes less conservative as the vapor disperses downwind, and may be under-predictive in the far field at lower concentrations. DEGADIS performs better for the CHRC test, which was designed to be used as a scale model for LNG dispersion.

DEGADIS compares much better with maximum gas concentration distances, and meets nearly all the acceptance criteria. DEGADIS shows similar trends for field trials and wind-tunnel tests. DEGADIS generally over-predicts the distance to a given concentration for field trials by approximately a factor of 1.5, and under-predicts wind-tunnel tests by approximately a factor of 1.5. The relatively better agreement is because large concentration differences may manifest themselves as much smaller differences in distance.

DEGADIS generally over-predicts point-wise gas concentrations that are located at an angle corresponding to the wind direction where the maximum arc-wise concentration often occurred, and under-predicts point-wise gas concentrations that are located farther from the “centerline”. The under-prediction of concentrations farther from the “centerline” is much more drastic than the over-prediction near the “centerline,” which results in an average under-prediction and a high degree of scatter. In addition, DEGADIS generally seems to under-predict short time averages and over-predict long time averages with a difference of a factor of 2 or more between them.

Similarly to maximum gas concentration distances, DEGADIS compares much better with cloud widths. However, DEGADIS generally under-predicts the cloud width by a factor of 1.5. Cloud widths are also less influenced by large concentration differences, which may manifest themselves as much smaller differences in cloud widths. Cloud widths are not a particular concern with 49 CFR Part 193, but may cause under prediction of the hazard footprint, which can affect risk analyses or performance based design of gas detectors.

DEGADIS may be less conservative or under-predictive for maximum arc-wise concentrations for field trials with low wind speed and high atmospheric stabilities, a particular concern for 49 CFR Part 193. Although the field trials are most applicable to the scenarios considered under the Part 193 regulations and generally show over-prediction, there are a number of uncertainties that indicate potential under-prediction by a factor of 2. Until these uncertainties are resolved, it is recommended that a safety factor of 2 be used when evaluating predicted maximum arc-wise concentrations from DEGADIS. Alternatively, a distance safety factor of 2 may be used.

4.4 SENSITIVITY ANALYSES

The sensitivity analyses for DEGADIS indicates little sensitivity to the pool spread velocity, vaporization rate, and pool diameter for spills over water. However, all the LNG field trial releases were conducted over water and the associated source terms will be different than those used on land. For spills over water with significant depth, the heat transfer to the pool is generally considered constant due to convective motion of the water. For spills over land, the heat transfer to the pool is generally considered to be transient due to conductive cooling of the substrate. Pressurized releases may further deviate from the more idealized source term for spills over water. Therefore for spills over land and pressurized releases, it is recommended that the source term is evaluated before usage.

Longer time averages result in slightly lower maximum arc-wise gas concentrations, and significantly higher maximum point-wise concentrations away from the centerline. The maximum point-wise gas concentrations are affected more significantly because DEGADIS parameterizes its horizontal turbulence coefficients based on time averaging to take into account cloud meander. In contrast, longer time averages of experimental data will only result in lesser concentrations. Therefore, comparison with longer experimental time averages may cause the model to appear more conservative than it actually is. Short time averages are more appropriate for the hazard and should be used when predicting flammable vapor centerline concentrations.

Many of the trials did not have wind speeds that differed by more than 10%. For trials that did not have wind speeds that differed by more than 10%, lower wind speeds generally produced higher downwind concentrations and dispersion distances, and higher wind speeds produced lower downwind concentrations and dispersion distances. The exceptions were Burro 8 where very low wind speeds (< 2 m/s) occurred and Maplin Sands 34 where very high wind speeds (> 8 m/s) occurred.

The surface roughness values have the largest uncertainties. The values specified in the MEP are generally low and result in higher concentrations and longer dispersion distances to the LFL, which may cause the model to appear more conservative than it actually is. However, even with less conservative parameters, the model still generally over-predicts concentrations. If the surface roughness is prescribed, such as the case in 49 C.F.R. § 193.2059, it should be made sure that the surface roughness is appropriate based on photographic documentation, visual observations, or meteorological data representative of the site. For LNG releases that disperse over land, a surface roughness of 0.03 may be justified, however, for LNG facilities that release over water, such as for offshore facilities or marine loading/unloading platforms that are situated away from the shoreline, a lower surface roughness may be more appropriate.

Lower atmospheric stabilities generally produced lower downwind concentrations and dispersion distances, and higher atmospheric stabilities produced higher downwind concentrations and dispersion distances. Where the surface roughness uncertainty was low, the atmospheric stability often formed the upper or lower bound of the predictions.

Ambient temperature and surface temperature had little fluctuation, and therefore no sensitivity cases were run. However, higher ambient temperatures and surface temperatures should generally produce lower gas concentrations and downwind dispersion distances.

None of the trials had ambient pressures that differed by more than 10% from atmospheric pressure, but in order to test the sensitivity, Burro 7, which had the lowest ambient pressure was tested. Higher ambient pressure showed slightly lower concentrations and downwind dispersion distances.

Many of the trials did not have ambient relative humidity that differed by more than 10%, but some of the values disagreed with those reported in the original data series reports. For trials that did not have ambient relative humidity that differed, lower ambient relative humidity generally produced higher gas concentrations in the near field, but lower gas concentrations in the far field, and vice-versa.

The water transfer submodel showed negligible differences when included in the predicted concentrations and distance to LFL.

The molecular weight specified in the MEP reflects the composition of the LNG and does not take into account preferential boiloff. The lower molecular weight of methane results in higher concentrations and longer dispersion distances to the LFL. However, even with less conservative parameters, the model still generally over-predicts concentrations. The molecular weight of methane is recommended to be used to account for potential preferential boiloff and conservatism.

Overall, the sensitivity analysis showed concentrations may differ by more than a factor of four and downwind dispersion distances to the LFL may differ by up to a factor of two, dependant on the uncertainty in the user input and sensitivity to that input.

4.5 MODEL SUITABILITY AND LIMITATIONS

DEGADIS requires a source term to be inputted into the model. The specification of the source term is a key parameter in determining the gas concentrations and dispersion distances, but is not examined under the MEP or the Advisory Bulletin. The suitability of the source term model must be reviewed before being used in Part 193 calculations.

DEGADIS may be used to model the maximum arc-wise concentration for:

- Dispersion from circularly shaped LNG pools;
- Dispersion from LNG pools with low-aspect ratios, including most impoundments;
- Dispersion from vertically oriented releases that do not reach grade, including releases from flashing, venting, vent stacks, and pressure relief discharge; or
- Dispersion over flat or upward sloped terrain.

DEGADIS may not be appropriate to be used to model the maximum arc-wise concentration for:

- Dispersion from irregularly shaped LNG pools
- Dispersion from LNG pools with high-aspect ratios, including some impoundments and nearly all trenches;
- Dispersion from vertically oriented releases that reach grade, including releases from flashing, venting, vent stacks, and pressure relief discharge;
- Dispersion from horizontally oriented releases, including flashing, jetting, venting, and pressure relief discharge;
- Dispersion from multiple coincident releases, including multiple release locations;
- Dispersion over varying or downward sloped terrain; or
- Dispersion between large obstructions that may cause wind-channeling.

DEGADIS may not be appropriate to model point-wise concentrations, and may be under-predictive for cloud widths.

The ambient conditions required under 49 CFR § 193.2059 should produce conservative results (i.e. higher downwind gas concentrations and dispersion distances).

DEGADIS should be used with a safety factor of 2 (i.e. ½ LFL) to compensate for uncertainties related to potential turbulent fluctuations, wind tunnel experiment validation results, and low wind speed and high atmospheric stability validation results.

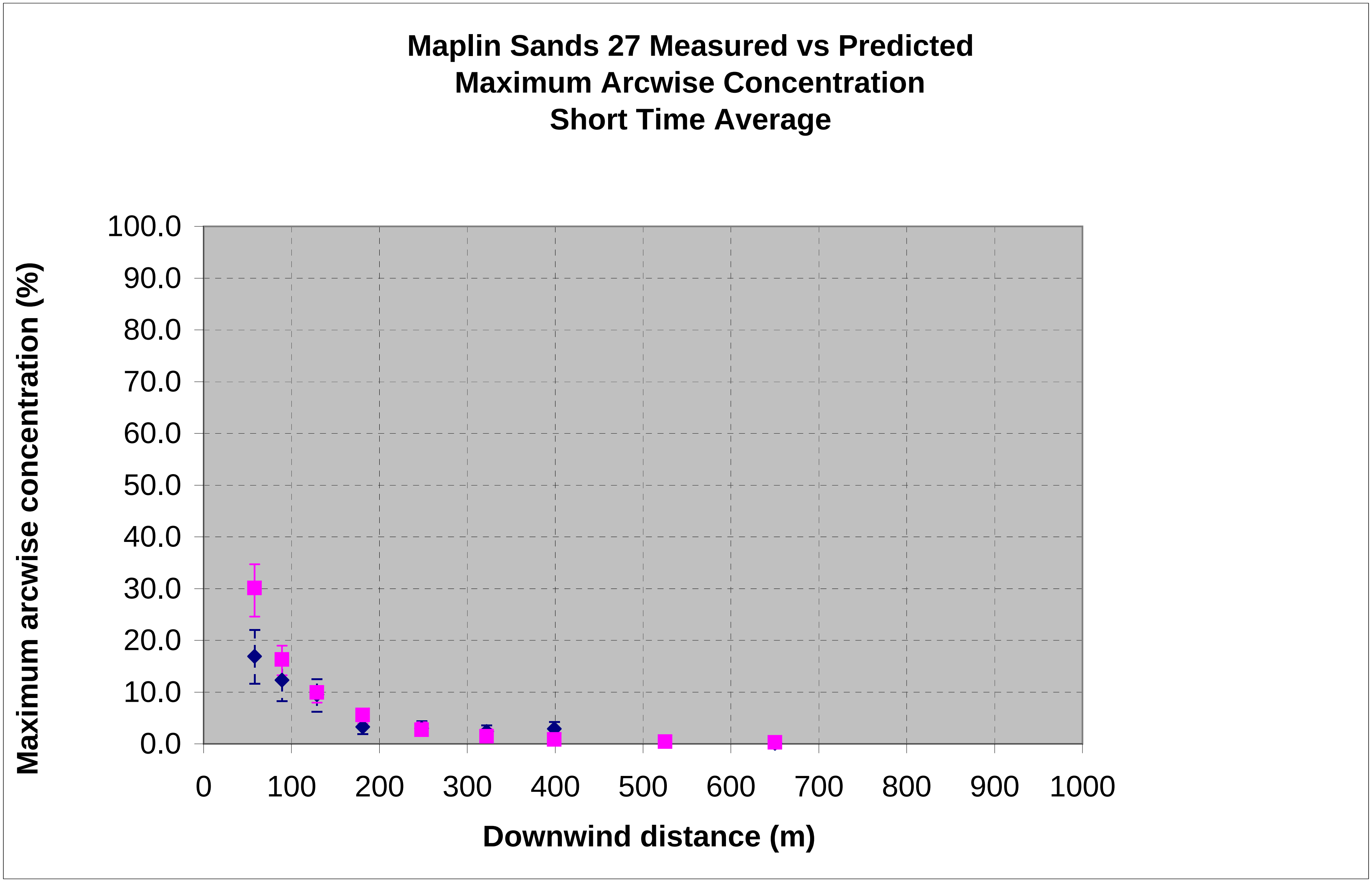
APPENDIX A: SENSITIVITY CASE RESULTS

Test	a	b	c	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_10	a_11	a_12	a_13	a_14	a_15
Maplin Sands 27																		
58m	30.9%	30.6%	30.4%	N/A	30.6%	30.1%	N/A	35.5%	25.4%	31.3%	N/A	31.3%	N/A	N/A	29.7%	N/A	30.9%	32.8%
89m	16.3%	16.3%	16.9%	N/A	13.7%	16.3%	N/A	19.0%	13.3%	16.3%	N/A	15.5%	N/A	N/A	14.5%	N/A	16.3%	18.1%
129m	10.1%	10.2%	10.0%	N/A	9.2%	9.9%	N/A	11.4%	8.5%	10.1%	N/A	9.8%	N/A	N/A	8.2%	N/A	10.1%	11.0%
181m	6.3%	6.4%	6.4%	N/A	6.8%	5.6%	N/A	7.0%	4.7%	6.8%	N/A	6.8%	N/A	N/A	4.8%	N/A	6.4%	7.1%
248m	3.3%	3.3%	4.1%	N/A	4.7%	2.7%	N/A	3.7%	2.2%	3.9%	N/A	4.6%	N/A	N/A	2.6%	N/A	3.3%	4.5%
322m	1.7%	1.7%	2.6%	N/A	3.0%	1.4%	N/A	1.9%	1.2%	2.0%	N/A	3.2%	N/A	N/A	1.4%	N/A	1.7%	2.7%
399m	1.0%	1.0%	1.5%	N/A	1.7%	0.8%	N/A	1.1%	0.7%	1.1%	N/A	2.3%	N/A	N/A	0.9%	N/A	1.0%	1.6%
650m	0.3%	0.3%	0.4%	N/A	0.4%	0.3%	N/A	0.3%	0.2%	0.3%	N/A	0.8%	N/A	N/A	0.3%	N/A	0.3%	0.4%
Dist to LFL	204m	206m	216m	N/A	236m	190m	N/A	214m	175m	220m	N/A	234m	N/A	N/A	177m	N/A	206m	233m
Maplin Sands 34																		
89m	14.6%	N/A	14.1%	12.7%	N/A	12.6%	N/A	14.8%	12.2%	14.4%	14.2%	N/A	N/A	N/A	12.2%	N/A	12.6%	N/A
180m	5.6%	N/A	5.5%	5.4%	N/A	5.0%	N/A	5.5%	4.8%	5.5%	4.0%	N/A	N/A	N/A	3.9%	N/A	4.9%	N/A
Dist to LFL	191m	N/A	191m	191m	N/A	180m	N/A	184m	176m	188m	161m	N/A	N/A	N/A	160m	N/A	180m	N/A
Maplin Sands 35																		
58m	28.7%	28.1%	21.7%	N/A	31.4%	25.7%	N/A	32.7%	24.2%	28.0%	26.5%	N/A	N/A	N/A	28.2%	N/A	28.4%	N/A
89m	16.6%	16.5%	13.6%	N/A	16.6%	15.8%	N/A	19.5%	14.2%	16.6%	16.2%	N/A	N/A	N/A	16.2%	N/A	16.6%	N/A
129m	10.4%	10.4%	8.8%	N/A	11.4%	9.9%	N/A	12.3%	8.8%	10.5%	9.9%	N/A	N/A	N/A	9.9%	N/A	10.4%	N/A
180m	6.7%	6.7%	5.8%	N/A	7.4%	6.4%	N/A	7.6%	5.7%	6.7%	5.5%	N/A	N/A	N/A	6.2%	N/A	6.7%	N/A
250m	4.3%	4.2%	3.7%	N/A	5.0%	4.0%	N/A	4.9%	3.6%	4.3%	2.7%	N/A	N/A	N/A	3.5%	N/A	4.3%	N/A
400m	2.1%	2.1%	1.9%	N/A	2.5%	2.0%	N/A	2.4%	1.8%	2.1%	1.0%	N/A	N/A	N/A	1.5%	N/A	2.1%	N/A
Dist to LFL	223m	222m	202m	N/A	249m	213m	N/A	246m	200m	223m	187m	N/A	N/A	N/A	206m	N/A	223m	N/A

Test	**a**	**b**	**c**	**a_1**	**a_2**	**a_3**	**a_4**	**a_5**	**a_6**	**a_7**	**a_8**	**a_9**	**a_10**	**a_11**	**a_12**	**a_13**	**a_14**	**a_15**
Burro 3																		
57m	66.7%	66.3%	64.4%	66.7%	68.3%	64.5%	67.0%	N/A	41.2%	N/A	N/A	68.0%	N/A	N/A	N/A	N/A	N/A	68.5%
140m	25.3%	25.2%	25.1%	25.3%	26.0%	24.8%	25.1%	N/A	12.2%	N/A	N/A	26.6%	N/A	N/A	N/A	N/A	N/A	27.5%
400m	5.1%	5.0%	4.9%	4.9%	5.2%	5.0%	5.1%	N/A	2.4%	N/A	N/A	5.3%	N/A	N/A	N/A	N/A	N/A	5.5%
800m	1.2%	1.2%	1.6%	0.8%	1.1%	1.3%	1.2%	N/A	0.5%	N/A	N/A	1.8%	N/A	N/A	N/A	N/A	N/A	1.7%
Dist to LFL	405m	402m	394m	395m	414m	397m	404m	N/A	257m	N/A	N/A	414m	N/A	N/A	N/A	N/A	N/A	424m
Burro 7																		
57m	61.2%	60.7%	49.4%	61.2%	N/A	N/A	61.4%	N/A	33.9%	60.9%	60.0%	N/A	N/A	60.0%	58.9%	N/A	N/A	64.1%
140m	22.7%	22.4%	2.2%	22.7%	N/A	N/A	23.2%	N/A	11.0%	22.5%	21.4%	N/A	N/A	21.5%	22.7%	N/A	N/A	26.7%
400m	4.8%	4.8%	4.4%	4.8%	N/A	N/A	4.8%	N/A	2.4%	4.8%	4.6%	N/A	N/A	4.6%	4.8%	N/A	N/A	5.3%
Dist to LFL	388m	387m	368m	388m	N/A	N/A	390m	N/A	242m	388m	381m	N/A	N/A	374m	386m	N/A	N/A	414m
Burro 8																		
57m	83.8%	100%	100%	83.8%	88.3%	89.8%	83.9%	N/A	67.2%	85.5%	N/A	80.2%	N/A	N/A	N/A	N/A	N/A	68.9%
140m	22.0%	22.5%	21.0%	22.0%	16.3%	25.1%	21.9%	N/A	15.7%	23.1%	N/A	21.8%	N/A	N/A	N/A	N/A	N/A	29.4%
400m	3.1%	2.9%	3.3%	3.1%	2.1%	3.6%	3.1%	N/A	3.5%	3.5%	N/A	2.9%	N/A	N/A	N/A	N/A	N/A	5.3%
800m	1.0%	1.0%	1.1%	1.0%	0.7%	1.2%	1.0%	N/A	1.3%	1.1%	N/A	1.0%	N/A	N/A	N/A	N/A	N/A	1.5%
Dist to LFL	289m	291m	308m	289m	221m	329m	290m	N/A	302m	328m	N/A	284m	N/A	N/A	N/A	N/A	N/A	415m
Burro 9																		
57m	76.4%	76.1%	73.6%	76.4%	N/A	N/A	76.5%	N/A	45.7%	76.5%	N/A	74.9%	N/A	N/A	76.9%	N/A	N/A	79.1%
140m	30.6%	29.5%	29.7%	30.6%	N/A	N/A	31.2%	N/A	15.9%	30.8%	N/A	30.4%	N/A	N/A	32.5%	N/A	N/A	37.5%
400m	6.9%	6.6%	6.3%	6.6%	N/A	N/A	6.9%	N/A	3.4%	6.9%	N/A	6.7%	N/A	N/A	6.6%	N/A	N/A	8.3%
800m	2.1%	2.2%	2.2%	1.6%	N/A	N/A	2.1%	N/A	0.9%	2.1%	N/A	1.4%	N/A	N/A	2.0%	N/A	N/A	2.7%
Dist to LFL	492m	482m	465m	491m	N/A	N/A	492m	N/A	307m	493m	N/A	481m	N/A	N/A	462m	N/A	N/A	537m

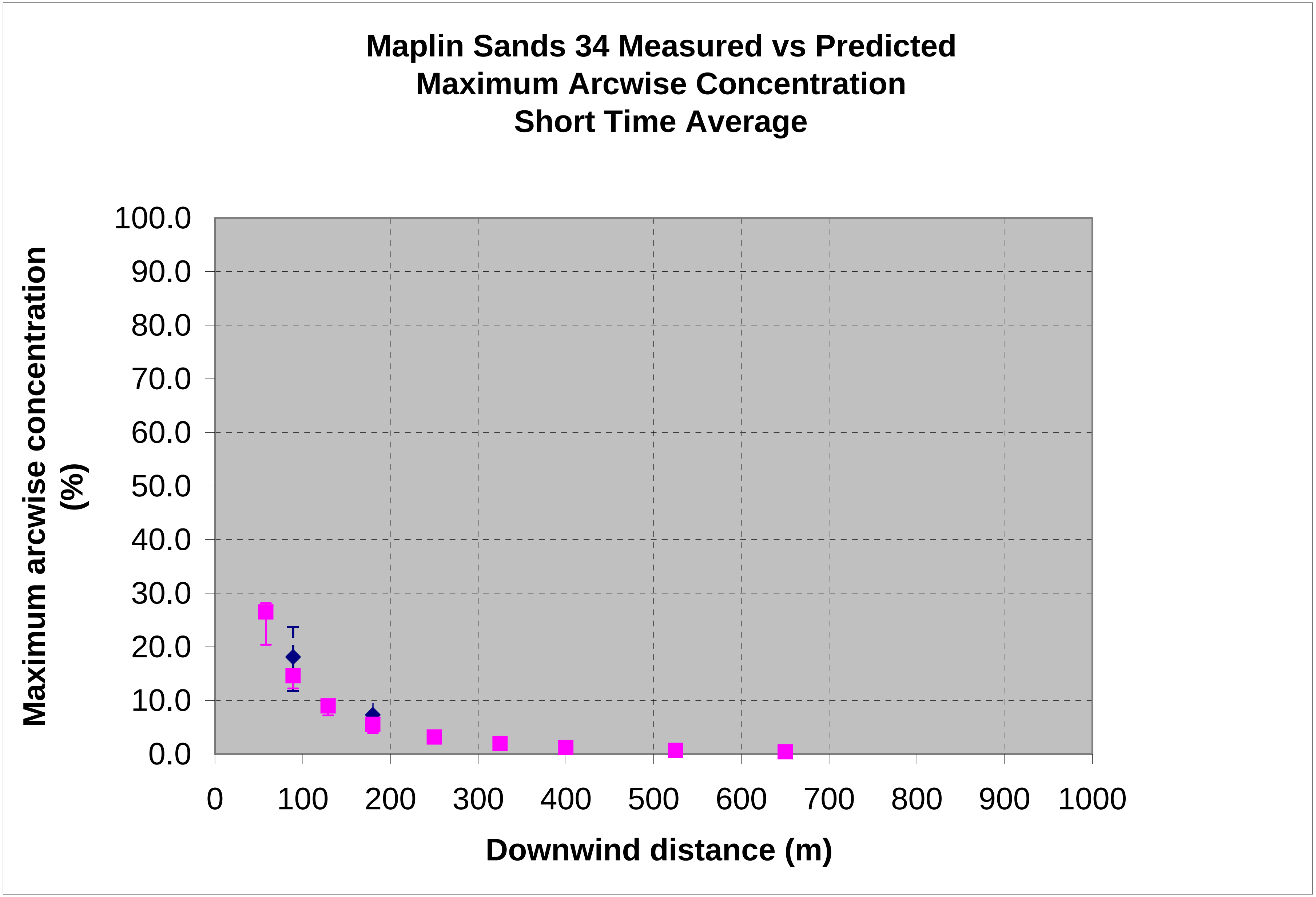
Test	a	b	c	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_10	a_11	a_12	a_13	a_14	a_15
Coyote 3																		
140m	23.9%	22.4%	21.4%	23.9%	N/A	N/A	23.6%	N/A	11.9%	23.2%	N/A	24.2%	N/A	N/A	24.0%	N/A	N/A	29.0%
200m	14.6%	13.7%	13.3%	14.6%	N/A	N/A	14.6%	N/A	7.4%	14.6%	N/A	15.0%	N/A	N/A	14.6%	N/A	N/A	18.6%
300m	7.9%	7.6%	7.3%	7.8%	N/A	N/A	7.8%	N/A	4.0%	7.7%	N/A	8.1%	N/A	N/A	7.6%	N/A	N/A	9.7%
400m	4.9%	4.8%	4.7%	4.3%	N/A	N/A	4.9%	N/A	2.2%	5.0%	N/A	5.1%	N/A	N/A	4.6%	N/A	N/A	6.2%
500m	3.0%	2.9%	2.9%	2.4%	N/A	N/A	3.2%	N/A	1.3%	2.9%	N/A	3.6%	N/A	N/A	2.8%	N/A	N/A	4.3%
Dist to LFL	392m	392m	385m	378m	N/A	N/A	396m	N/A	254m	399m	N/A	405m	N/A	N/A	383m	N/A	N/A	453m
Coyote 5																		
140m	19.6%	19.7%	14.9%	19.5%	N/A	N/A	19.4%	N/A	10.0%	19.9%	N/A	20.8%	N/A	N/A	20.8%	N/A	N/A	25.2%
200m	13.4%	12.5%	10.3%	12.7%	N/A	N/A	12.8%	N/A	6.8%	13.5%	N/A	13.8%	N/A	N/A	13.8%	N/A	N/A	16.9%
300m	7.5%	7.3%	6.3%	5.3%	N/A	N/A	7.3%	N/A	3.8%	7.6%	N/A	7.7%	N/A	N/A	7.3%	N/A	N/A	9.3%
400m	4.9%	4.7%	4.3%	2.5%	N/A	N/A	4.8%	N/A	2.3%	5.0%	N/A	5.1%	N/A	N/A	4.7%	N/A	N/A	5.9%
500m	3.3%	3.0%	3.0%	1.5%	N/A	N/A	3.1%	N/A	1.4%	3.3%	N/A	3.8%	N/A	N/A	3.4%	N/A	N/A	4.3%
Dist to LFL	396m	387m	358m	310m	N/A	N/A	392m	N/A	253m	400m	N/A	408m	N/A	N/A	387m	N/A	N/A	457m
Coyote 6																		
140m	21.6%	23.0%	24.8%	21.6%	N/A	N/A	22.6%	N/A	14.1%	21.7%	N/A	21.1%	N/A	N/A	29.4%	N/A	N/A	34.7%
200m	14.3%	14.7%	15.2%	14.3%	N/A	N/A	14.7%	N/A	8.9%	14.4%	N/A	14.2%	N/A	N/A	16.7%	N/A	N/A	21.0%
300m	9.2%	9.1%	9.1%	9.2%	N/A	N/A	9.3%	N/A	4.9%	9.3%	N/A	9.1%	N/A	N/A	8.1%	N/A	N/A	12.5%
400m	6.1%	6.8%	6.0%	6.1%	N/A	N/A	6.3%	N/A	3.3%	6.2%	N/A	6.4%	N/A	N/A	4.8%	N/A	N/A	8.0%
500m	4.3%	4.3%	4.2%	4.2%	N/A	N/A	4.4%	N/A	2.3%	4.3%	N/A	4.6%	N/A	N/A	3.3%	N/A	N/A	5.6%
Dist to LFL	457m	455m	451m	455m	N/A	N/A	459m	N/A	292m	462m	N/A	467m	N/A	N/A	393m	N/A	N/A	539m

Test	**a**	**b**	**c**	**a_1**	**a_2**	**a_3**	**a_4**	**a_5**	**a_6**	**a_7**	**a_8**	**a_9**	**a_10**	**a_11**	**a_12**	**a_13**	**a_14**	**a_15**
Thorney Island 45																		
40m	29.5%	28.2%	N/A	N/A	N/A	N/A	N/A	12.8%	32.4%	30.0%	26.7%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
53m	29.5%	28.2%	N/A	N/A	N/A	N/A	N/A	12.8%	16.0%	28.9%	20.4%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
72m	12.5%	22.4%	N/A	N/A	N/A	N/A	N/A	12.8%	11.5%	12.9%	12.4%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
90m	10.0%	15.2%	N/A	N/A	N/A	N/A	N/A	12.8%	7.9%	9.9%	7.8%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
112m	7.0%	8.8%	N/A	N/A	N/A	N/A	N/A	12.8%	4.6%	6.7%	4.9%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
158m	3.3%	3.3%	N/A	N/A	N/A	N/A	N/A	12.8%	1.9%	3.1%	2.1%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
250m	1.0%	0.9%	N/A	N/A	N/A	N/A	N/A	3.3%	0.6%	1.0%	0.7%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
335m	0.5%	0.5%	N/A	N/A	N/A	N/A	N/A	1.7%	0.3%	0.5%	0.4%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
472m	0.2%	0.2%	N/A	N/A	N/A	N/A	N/A	0.8%	0.1%	0.2%	0.2%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Thorney Island 47																		
50m	17.4%	17.0%	N/A	N/A	N/A	N/A	N/A	11.0%	20.4%	15.6%	25.1%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
90m	17.4%	17.0%	N/A	N/A	N/A	N/A	N/A	9.2%	20.4%	15.6%	9.0%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
212m	2.0%	6.8%	N/A	N/A	N/A	N/A	N/A	7.7%	1.3%	1.9%	2.1%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
250m	1.2%	4.0%	N/A	N/A	N/A	N/A	N/A	6.9%	0.8%	1.2%	1.2%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
335m	0.5%	1.4%	N/A	N/A	N/A	N/A	N/A	0.6%	0.3%	0.5%	0.7%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
472m	0.2%	0.5%	N/A	N/A	N/A	N/A	N/A	0.5%	0.1%	0.2%	0.3%	N/A	N/A	N/A	N/A	N/A	N/A	N/A



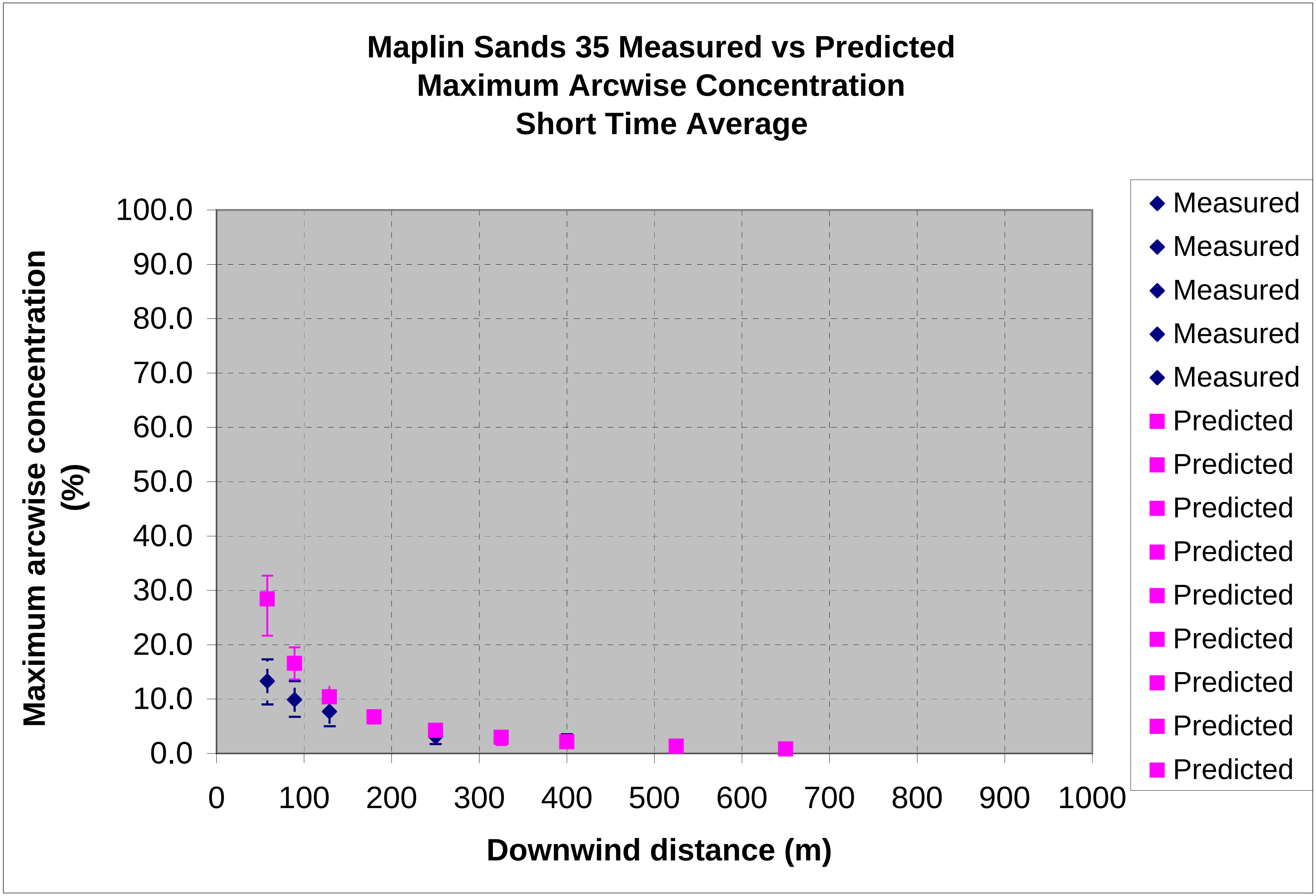
Maplin Sands 27 Measured vs Predicted
Maximum Arcwise Concentration
Short Time Average
Maximum arcwise concentration (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
100
200
300
400
500
600
700
800
900
1000
Downwind distance (m)

	Base Case	Source Term Alternative 1	Source Term Alternative 2	Averaging Time Alternative	Wind Speed Lower	Wind Speed Upper	MEP Wind Spee	Surface Roughness Lower	Surface Roughness Upper	Surface Roughness Alternative	Stability Lower	Stability Upper	Ambient Temperature	Ambient Pressure	Ambient Relative Humidity	Ambient Surface Temperature	Water Transfer Submodel	Molecular Weight
Run Name	a	b	c	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_10	a_11	a_12	a_13	a_14	a_15
Source Term	ABS/FERC	0.167kg/m^2/sec	0.085kg/m^2/sec		ABS/FERC	ABS/FERC		ABS/FERC	ABS/FERC	ABS/FERC		ABS/FERC			ABS/FERC		ABS/FERC	ABS/FERC
Wind Speed	5.6	5.6	5.6		4.4	6.1		5.6	5.6	5.6		5.6			5.6		5.6	5.6
Reference Height	10	10	10		10	10		10	10	10		10			10		10	10
Surface Roughness	3.00E-04	3.00E-04	3.00E-04		3.00E-04	3.00E-04		1.00E-04	1.00E-03	3.00E-04		3.00E-04			3.00E-04		3.00E-04	3.00E-04
Wind Stability	C	C	C		C	C		C	C	C		D			C		C	C
Averaging Time	3	3	3		3	3		3	3	3		3			3		3	3
Atmospheric Parameters																		
DELTA Y	0.10461	0.10461	0.10461		0.10461	0.10461		0.10461	0.10461	0.10461		0.06767			0.10461		0.10461	0.10461
BETA Y	0.9	0.9	0.9		0.9	0.9		0.9	0.9	0.9		0.9			0.9		0.9	0.9
Monin-Obukhov Length	-10.5	-10.5	-10.5		-10.5	-10.5		-7.5	-15.1	-22.3		infinite			-10.5		-10.5	-10.5
Sigma X Coefficient	0.02	0.02	0.02		0.02	0.02		0.02	0.02	0.02		0.04			0.02		0.02	0.02
Sigma X Power	1.22	1.22	1.22		1.22	1.22		1.22	1.22	1.22		1.14			1.22		1.22	1.22
Sigma X Minimum Dista	130.00	130.00	130.00		130.00	130.00		130.00	130.00	130.00		100.00			130.00		130.00	130.00
Wind Power Constant	0.08611	0.086	0.086		0.086	0.086		0.073	0.105	0.094		0.114			0.086		0.086	0.086
Friction Velocity	0.20954	0.20954	0.20954		0.16464	0.22825		0.19064	0.23549	0.20222		0.1882			0.20954		0.20954	0.20954
Ambient Temperature	288.1	288.1	288.1		288.1	288.1		288.1	288.1	288.1		288.1			288.1		288.1	288.1
Ambient Pressure	1	1	1		1	1		1	1	1		1			1		1	1
Ambient Relative Humidit	53	53	53		53	53		53	53	53		53			63		53	53
Isothermal?	N	N	N		N	N		N	N	N		N			N		N	N
Heat Transfer?	Y	Y	Y		Y	Y		Y	Y	Y		Y			Y		Y	Y
Surface Temperature	288.8	288.8	288.8		288.8	288.8		288.8	288.8	288.8		288.8			288.8		288.8	288.8
Correlation	1	1	1		1	1		1	1	1		1			1		1	1
Water Transfer?	Y	Y	Y		Y	Y		Y	Y	Y		Y			Y		N	N
Molecular Weight	17.11	17.11	17.11		17.11	17.11		17.11	17.11	17.11		17.11			17.11		17.11	16.04
Release Temperature	111.7	111.7	111.7		111.7	111.7		111.7	111.7	111.7		111.7			111.7		111.7	111.7
Density	1.792	1.792	1.792		1.792	1.792		1.792	1.792	1.792		1.792			1.792		1.792	1.792
Mean heat capacity const	5.60E-08	5.60E-08	5.60E-08		5.60E-08	5.60E-08		5.60E-08	5.60E-08	5.60E-08		5.60E-08			5.60E-08		5.60E-08	5.60E-08
Mean heat capacity powe	5	5	5		5	5		5	5	5		5			5		5	5
Upper Concentration	15.00%	15.00%	15.00%		80.00%	15.00%		15.00%	15.00%	15.00%		15.00%			15.00%		15.00%	15.00%
Lower Concentration	0.50%	5.00E-03	5.00E-03		0.50%	0.50%		5.00E-03	5.00E-03	5.00E-03		5.00E-03			5.00E-03		5.00E-03	5.00E-03
Height for isopleths	1	1.00	1.00		1.00	1.00		1.00	1.00	1.00		1.00			1.00		1.00	1.00
Max Concentration at:																		
58m centerline	30.9%	30.6%	30.4%		30.6%	30.1%		35.5%	25.4%	31.3%		31.3%			29.7%		30.9%	32.8%
89m centerline	16.3%	16.3%	16.9%		13.7%	16.3%		19.0%	13.3%	16.3%		15.5%			14.5%		16.3%	18.1%
129m centerline	10.1%	10.2%	10.0%		9.2%	9.9%		11.4%	8.5%	10.1%		9.8%			8.2%		10.1%	11.0%
181m centerline	6.3%	6.4%	6.4%		6.8%	5.6%		7.0%	4.7%	6.8%		6.8%			4.8%		6.4%	7.1%
248m centerline	3.3%	3.3%	4.1%		4.7%	2.7%		3.7%	2.2%	3.9%		4.6%			2.6%		3.3%	4.5%
322m centerline	1.7%	1.7%	2.6%		3.0%	1.4%		1.9%	1.2%	2.0%		3.2%			1.4%		1.7%	2.7%
399m centerline	1.0%	1.0%	1.5%		1.7%	0.8%		1.1%	0.7%	1.1%		2.3%			0.9%		1.0%	1.6%
525m centerline	0.5%	0.5%	0.7%		0.8%	0.4%		0.6%	0.4%	0.6%		1.3%			0.4%		0.5%	0.7%
650m centerline	0.3%	0.3%	0.4%		0.4%	0.3%		0.3%	0.2%	0.3%		0.8%			0.3%		0.3%	0.4%
Distance to:																		
16.9%	87	87	89		78	87		96	75	87		84			81		87	93
12.3%	108	109	112		96	110		120	95	108		104			97		109	119
9.5%	137	137	134		124	134		149	118	136		133			117		137	144
3.3%	247	247	283		307	228		261	210	264		314			222		248	297
3.0%	257	256	298		320	239		272	218	273		337			233		258	310
2.4%	280	281	331		350	261		296	240	299		390			257		280	341
2.9%	261	260	303		325	242		275	220	276		344			237		261	314
-	-	-	-		-	-		-	-	-		-			-		-	-
0.1%	1002	1017	1087		1118	973		1050	907	1023		1367			988		999	1116
LFL	204	206	216		236	190		214	175	220		234			177		206	233



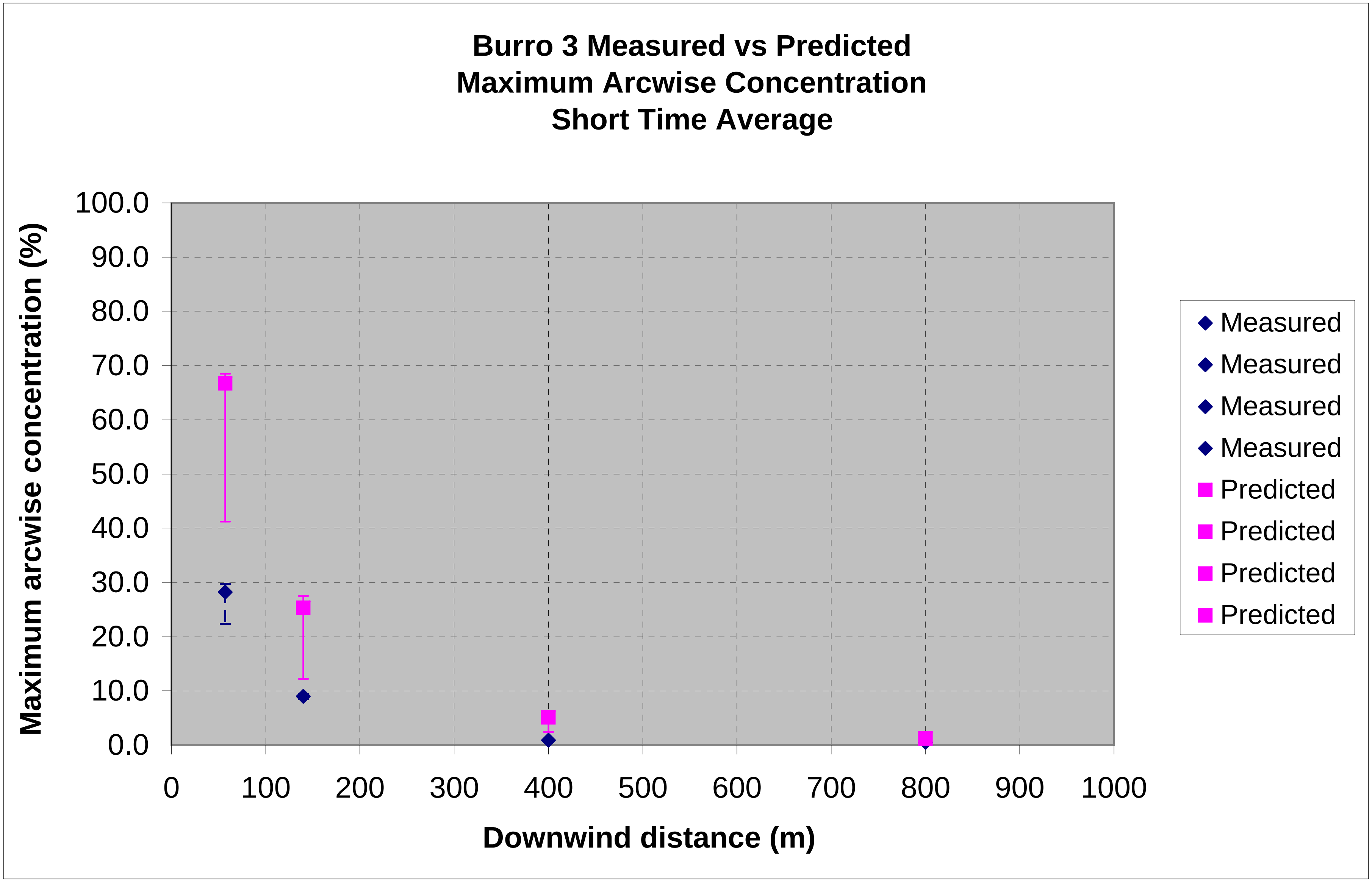
Maplin Sands 34 Measured vs Predicted
Maximum Arcwise Concentration
Short Time Average
Maximum arcwise concentration (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
100
200
300
400
500
600
700
800
900
1000
Downwind distance (m)

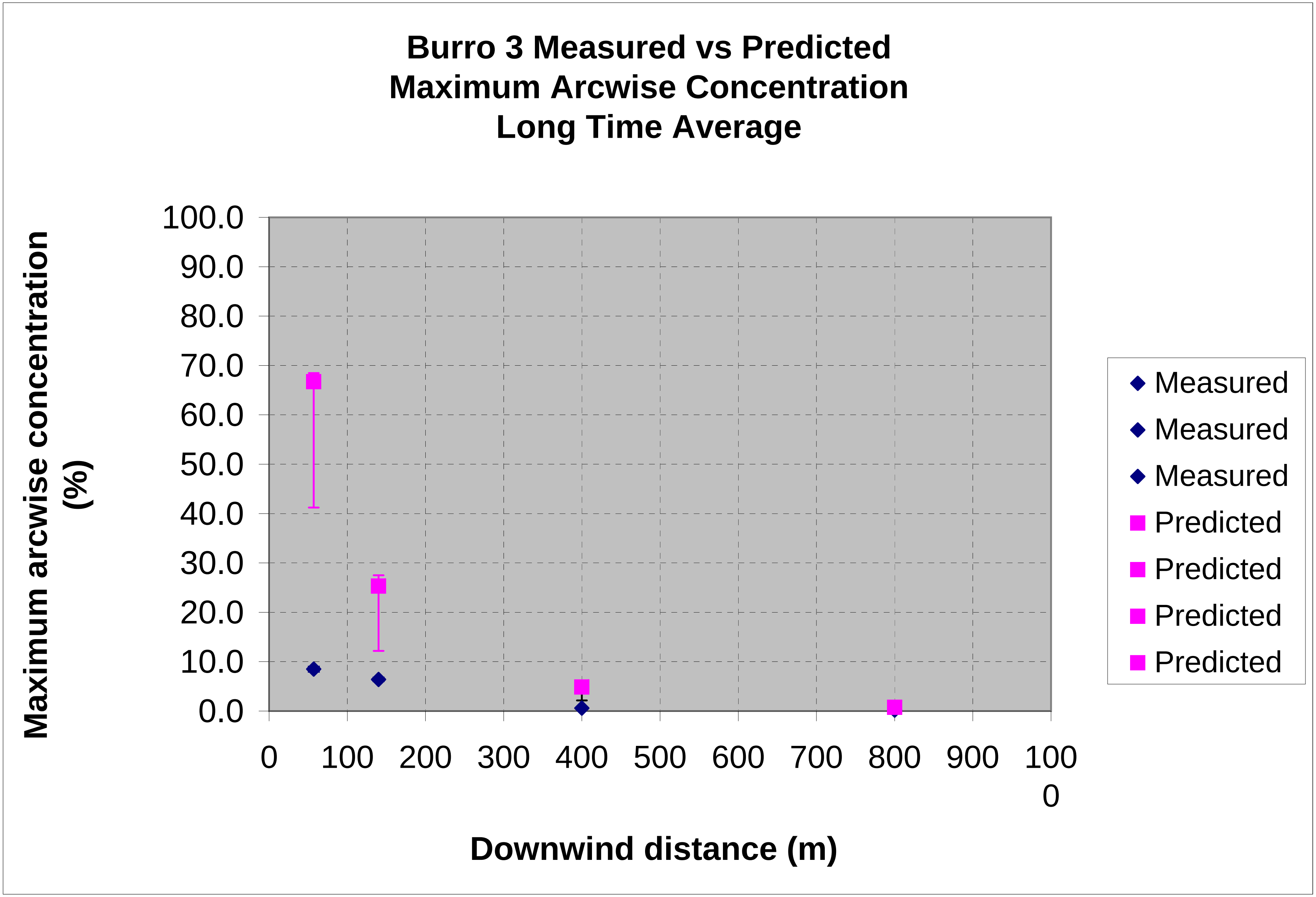
	Base Case	Source Term Alternative 1	Source Term Alternative 2	Averaging Time Alternative	Wind Speed Lower	Wind Speed Upper	Alternative	Surface Roughness Lower	Surface Roughness Upper	Monin Obukhov Length Specified	Stability Lower	Stability Upper	Ambient Temperature	Ambient Pressure	Ambient Relative Humidity	Ambient Surface Temperature	Water Transfer Submodel	Molecular Weight
Run Name	a	b	c	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_10	a_11	a_12	a_13	a_14	a_15
Source Term	ABS/FERC	.167kg/m**2*se	.085kg/m**2*sec		ABS/FERC	ABS/FERC		ABS/FERC	ABS/FERC	ABS/FERC	ABS/FERC				ABS/FERC		ABS/FERC	
Wind Speed	8.5	8.5	8.5		7.6	9.5		8.5	8.5	8.5	8.5				8.5		7.6	
Reference Height	10	10	10		10	10		10	10	10	10				10		10	
Surface Roughness	3.00E-04	3.00E-04	3.00E-04		3.00E-04	3.00E-04		1.00E-04	1.00E-03	3.00E-04	3.00E-04				3.00E-04		3.00E-04	
Wind Stability	D	D	D		D	D		D	D	D	C				D		D	
Averaging Time	3	3	3		3	3		3	3	3	3				3		3	
Atmospheric Parameters																		
DELTA Y	0.06767	0.06767	0.06767		0.06767	0.06767		0.06767	0.06767	0.06767	0.10461				0.06767		0.06767	
BETA Y	0.9	0.9	0.9		0.9	0.9		0.9	0.9	0.9	0.9				0.9		0.9	
Monin-Obukhov Length	infinite	infinite	infinite		infinite	infinite		infinite	infinite	-71.2	-10.5				infinite		infinite	
Sigma X Coefficient	0.04	0.04	0.04		0.04	0.04		0.04	0.04	0.04	0.02				0.04		0.04	
Sigma X Power	1.14	1.14	1.14		1.14	1.14		1.14	1.14	1.14	1.22				1.14		1.14	
Sigma X Minimum Distance	100.00	100.00	100.00		100.00	100.00		100.00	100.00	100.00	130.00				100.00		100.00	
Wind Power Constant	0.114	0.114	0.114		0.114	0.114		0.102	0.132	0.104	0.086				0.114		0.114	
Friction Velocity	0.28566	0.28566	0.28566		0.25542	0.31927		0.2584	0.323	0.2955	0.31805				0.28566		0.25542	
Ambient Temperature	288.4	288.4	288.4		288.4	288.4		288.4	288.4	288.4	288.4				288.4		288.4	
Ambient Pressure	1	1	1		1	1		1	1	1	1				1		1	
Ambient Relative Humidity	72	72	72		72	72		72	72	72	72				90		72	
Isothermal?	N	N	N		N	N		N	N	N	N				N		N	
Heat Transfer to be Included in cal	Y	Y	Y		Y	Y		Y	Y	Y	Y				Y		Y	
Surface Temperature	289.0	289.0	289.0		289.0	289.0		289.0	289.0	289.0	289.0				289.0		289.0	
Correlation	1	1	1		1	1		1	1	1	1				1		1	
Water Transfer?	Y	Y	Y		Y	Y		Y	Y	Y	Y				Y		N	
Molecular Weight	16.66	16.66	16.66		16.66	16.66		16.66	16.66	16.66	16.66				16.66		16.66	
Release Temperature	111.7	111.7	111.7		111.7	111.7		111.7	111.7	111.7	111.7				111.7		111.7	
Density at release temperature anc	1.792	1.792	1.792		1.792	1.792		1.792	1.792	1.792	1.792				1.792		1.792	
Mean heat capacity constant	5.60E-08	5.60E-08	5.60E-08		5.60E-08	5.60E-08		5.60E-08	5.60E-08	5.60E-08	5.60E-08				5.60E-08		5.60E-08	
Mean heat capacity power	5	5	5		5	5		5	94878733	5	5				5		5	
Upper Concentration	15.00%	15.00%	15.00%		15.00%	15.00%		15.00%	15.00%	15.00%	15.00%				80.00%		15.00%	
Lower Concentration of Interest	0.50%	0.50%	0.50%		0.50%	0.50%		0.50%	0.50%	0.50%	0.50%				0.50%		0.50%	
Height for isopleths	1	1	1		1	1		1	1	1	1				1		1	
Max Concentration at:																		
58m centerline concentration	26.5%	25.4%	20.4%		25.5%	24.3%		28.1%	22.4%	25.6%	24.7%				24.7%		25.5%	
89m centerline concentration	14.6%	14.1%	12.7%		12.6%	14.2%		14.8%	12.2%	14.4%	14.2%				12.2%		12.6%	
129m centerline concentration	9.0%	8.9%	8.2%		7.9%	9.1%		9.2%	7.9%	9.1%	8.4%				7.2%		7.9%	
180m centerline concentration	5.6%	5.5%	5.4%		5.0%	5.6%		5.5%	4.8%	5.5%	4.0%				3.9%		4.9%	
250m centerline concentration	3.2%	3.1%	3.6%		2.8%	3.2%		3.2%	2.7%	3.1%	2.1%				2.2%		2.8%	
325m centerline concentration	2.0%	1.9%	2.5%		1.7%	1.8%		2.0%	1.7%	1.9%	1.2%				1.4%		1.6%	
400m centerline concentration	1.2%	1.2%	1.8%		1.1%	1.2%		1.2%	1.0%	1.2%	0.7%				1.0%		1.0%	
525m centerline concentration	0.7%	0.7%	1.2%		0.6%	0.7%		0.7%	0.6%	0.7%	0.4%				0.6%		0.5%	
650m centerline concentration	0.4%	0.4%	0.8%		0.4%	0.4%		0.4%	0.4%	0.4%	0.2%				0.4%		0.1%	
Distance to:																		
18.1%	76	74	65		70	74		78	68	76	75				71		70	
7.3%	151	150	141		137	155		153	137	152	137				128		137	
LFL	191	191	191		180	192		184	176	188	161				160		180	



Maplin Sands 35 Measured vs Predicted
Maximum Arcwise Concentration
Short Time Average
Maximum arcwise concentration (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
100
200
300
400
500
600
700
800
900
1000
Downwind distance (m)
Measured
Measured
Measured
Measured
Measured
Predicted
Predicted
Predicted
Predicted
Predicted
Predicted
Predicted
Predicted
Predicted

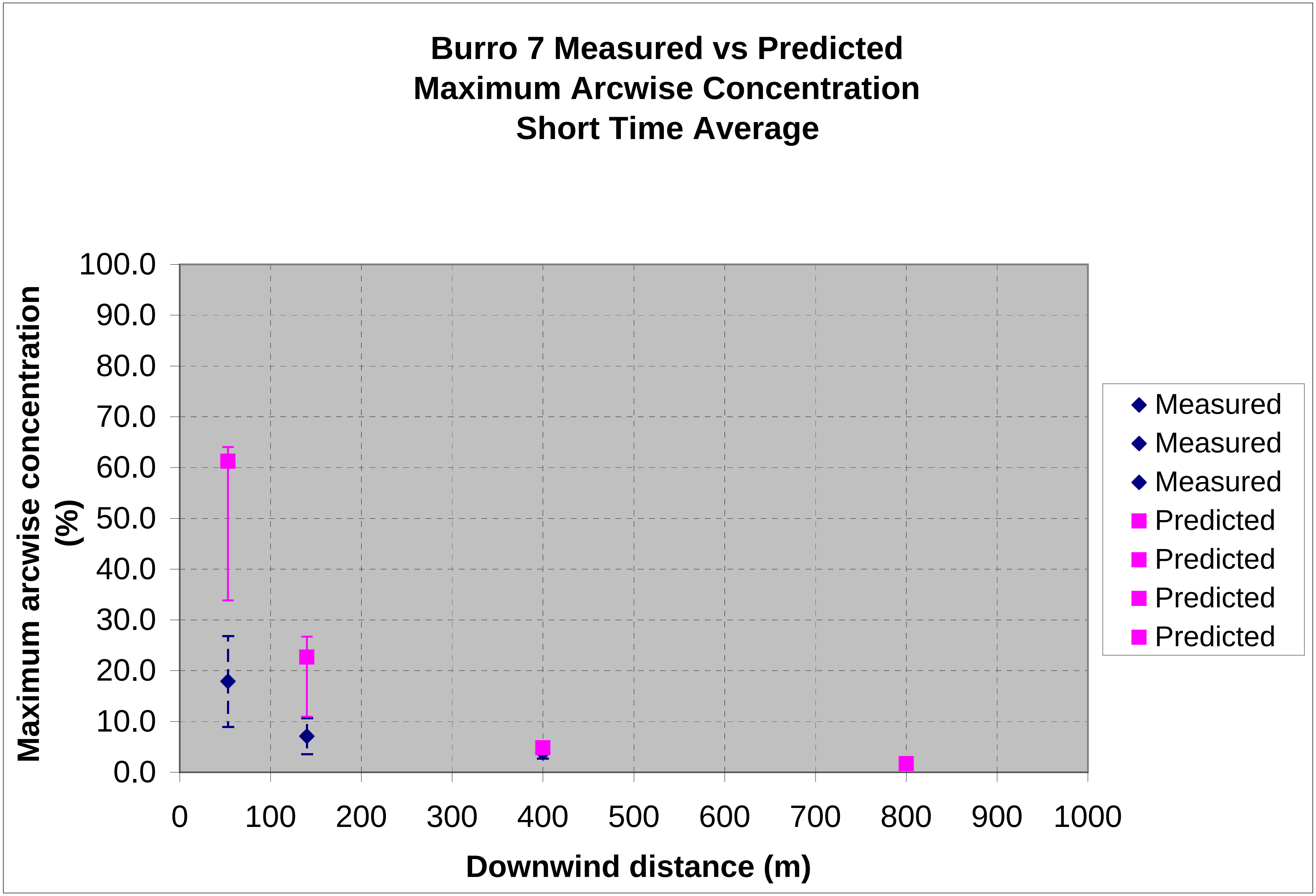
		Source Term		Averaging Time		Wind Speed		Surface Roughness		Monin-Obukhov Length	Stability		Ambient Temperature	Ambient Pressure	Ambient Relative Humidity	Ambient Surface Temperature	Water Transfer Submodel	Molecular Weight
	Base Case	Alternative 1	Alternative 2	Alternative	Lower	Upper	Alternative	Lower	Upper	Alternative	Lower	Upper						
Run Name	a	b	c	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_10	a_11	a_12	a_13	a_14	a_15
Source Term	ABS/FERC	.167kg/m**2-se	.085kg/m**2*sec		ABS/FERC	ABS/FERC		ABS/FERC	ABS/FERC	ABS/FERC	ABS/FERC				ABS/FERC		ABS/FERC	
Wind Speed	9.6	9.6	9.6		7.9	11		9.6	9.6	9.6	9.6				9.6		9.6	
Reference Height	10	10	10		10	10		10	10	10	10				10		10	
Surface Roughness	3.00E-04	3.00E-04	3.00E-04		3.00E-04	3.00E-04		1.00E-04	1.00E-03	3.00E-04	3.00E-04				3.00E-04		3.00E-04	
Wind Stability	D	D	D		D	D		D	D	D	C				D		D	
Averaging Time	3	3	3		3	3		3	3	3	3				3		3	
Atmospheric Parameters																		
DELTA Y	0.06767	0.06767	0.06767		0.06767	0.06767		0.06767	0.06767	0.06767	0.10461				0.06767		0.06767	
BETA Y	0.9	0.9	0.9		0.9	0.9		0.9	0.9	0.9	0.9				0.9		0.9	
Monin-Obukhov Length	infinite	infinite	infinite		infinite	infinite		infinite	infinite	-54	-10.5				infinite		infinite	
Sigma X Coefficient	4.00E-02	4.00E-02	4.00E-02		4.00E-02	4.00E-02		4.00E-02	4.00E-02	4.00E-02	2.00E-02				4.00E-02		4.00E-02	
Sigma X Power	1.14	1.14	1.14		1.14	1.14		1.14	1.14	1.14	1.22				1.14		1.14	
Sigma X Minimum Distance	100	100	100		100	100		100	100	100	130				100		100	
Wind Power Constant	0.11438	0.11438	0.11438		0.11438	0.11438		0.10172	0.13233	0.10182	0.08611				0.11438		0.11438	
Friction Velocity	0.32263	0.32263	0.32263		0.2655	0.36968		0.29185	0.3648	0.33619	0.35921				0.32263		0.32263	
Ambient Temperature	289.3	289.3	289.3		289.3	289.3		289.3	289.3	289.3	289.3				289.3		289.3	
Ambient Pressure	1	1	1		1	1		1	1	1	1				1		1	
Ambient Relative Humidity	63	63	63		63	63		63	63	63	63				77		63	
Isothermal?	N	N	N		N	N		N	N	N	N				N		N	
Heat Transfer?	Y	Y	Y		Y	Y		Y	Y	Y	Y				Y		Y	
Surface Temperature	289.8	289.8	289.8		289.8	289.8		289.8	289.8	289.8	289.8				289.8		289.8	
Correlation	1	1	1		1	1		1	1	1	1				1		1	
Water Transfer?	Y	N	N		Y	Y		Y	Y	Y	Y				Y		N	
Molecular Weight	16.39	16.39	16.39		16.39	16.39		16.39	16.39	16.39	16.39				16.39		16.39	
Release Temperature	111.7	111.7	111.7		111.7	111.7		111.7	111.7	111.7	111.7				111.7		111.7	
Density	1.792	1.792	1.792		1.792	1.792		1.792	1.792	1.792	1.792				1.792		1.792	
Mean heat capacity constant	5.60E-08	5.60E-08	5.60E-08		5.60E-08	5.60E-08		5.60E-08	5.60E-08	5.60E-08	5.60E-08				5.60E-08		5.60E-08	
Mean heat capacity power	5	5.00E+00	5.00E+00		5	5		5	5	5	5				5.00E+00		5.00E+00	
Upper Concentration	15.00%	15.00%	15.00%		15.00%	15.00%		15.00%	15.00%	15.00%	15.00%				15.00%		15.00%	
Lower Concentration	0.50%	0.50%	0.50%		0.50%	0.50%		0.50%	0.50%	0.50%	0.50%				0.50%		0.50%	
Height for isopleths	1	1	1		1	1		1	1	1	1				1		1	
Max Concentration at:																		
58m centerline	28.4%	28.1%	21.7%		31.4%	25.7%		32.7%	24.2%	28.0%	26.5%				28.2%		28.4%	
89m centerline	16.6%	16.5%	13.6%		16.6%	15.8%		19.5%	14.2%	16.6%	16.2%				16.2%		16.6%	
129m centerline	10.4%	10.4%	8.8%		11.4%	9.9%		12.3%	8.8%	10.5%	9.9%				9.9%		10.4%	
180m centerline	6.7%	6.7%	5.8%		7.4%	6.4%		7.6%	5.7%	6.7%	5.5%				6.2%		6.7%	
250m centerline	4.3%	4.2%	3.7%		5.0%	4.0%		4.9%	3.6%	4.3%	2.7%				3.5%		4.3%	
324m centerline	2.9%	2.9%	2.5%		3.5%	2.7%		3.4%	2.5%	2.9%	1.6%				2.3%		2.9%	
400m centerline	2.1%	2.1%	1.9%		2.5%	2.0%		2.4%	1.8%	2.1%	1.0%				1.5%		2.1%	
525m centerline	1.3%	1.3%	1.2%		1.4%	1.1%		1.6%	1.0%	1.3%	0.5%				0.8%		1.3%	
650m centerline	0.8%	0.8%	0.9%		0.8%	0.7%		1.0%	0.6%	0.8%	0.3%				0.5%		0.8%	
Distance to:																		
13.3%	107	106	91		106	102		121	94	106	101				104		107	
9.9%	135	134	117		143	129		151	118	135	129				129		135	
7.7%	163	162	145		175	156		179	144	164	150				157		163	
5.3%	213	214	193		236	204		235	192	215	183				200		213	
3.1%	311	309	284		352	298		343	279	310	233				268		313	
-	-	-	-		-	-		-	-	-	-				-		-	
2.3%	378	378	348		416	363		416	342	377	271				321		381	
-	-	-	-		-	-		-	-	-	-				-		-	
-	-	-	-		-	-		-	-	-	-				-		-	
LFL	223	222	202		249	213		246	200	223	187				206		223	


Burro 3 Measured vs Predicted
Maximum Arcwise Concentration
Short Time Average
Maximum arcwise concentration (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
100
200
300
400
500
600
700
800
900
1000
Downwind distance (m)
Measured
Measured
Measured
Measured
Predicted
Predicted
Predicted
Predicted

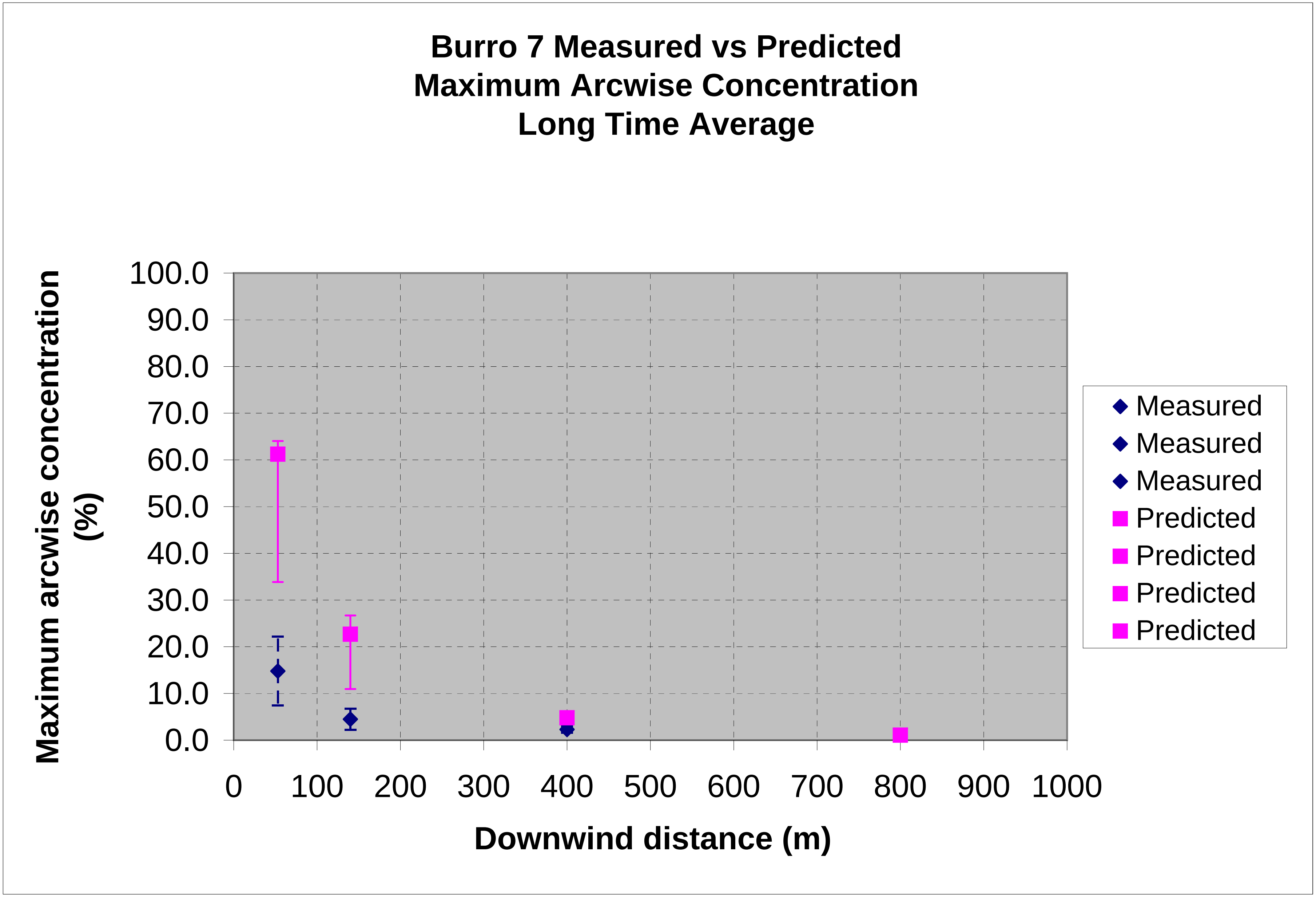


Burro 3 Measured vs Predicted
Maximum Arcwise Concentration
Long Time Average
Maximum arcwise concentration (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
100
200
300
400
500
600
700
800
900
1000
Downwind distance (m)
Measured
Measured
Measured
Predicted
Predicted
Predicted
Predicted

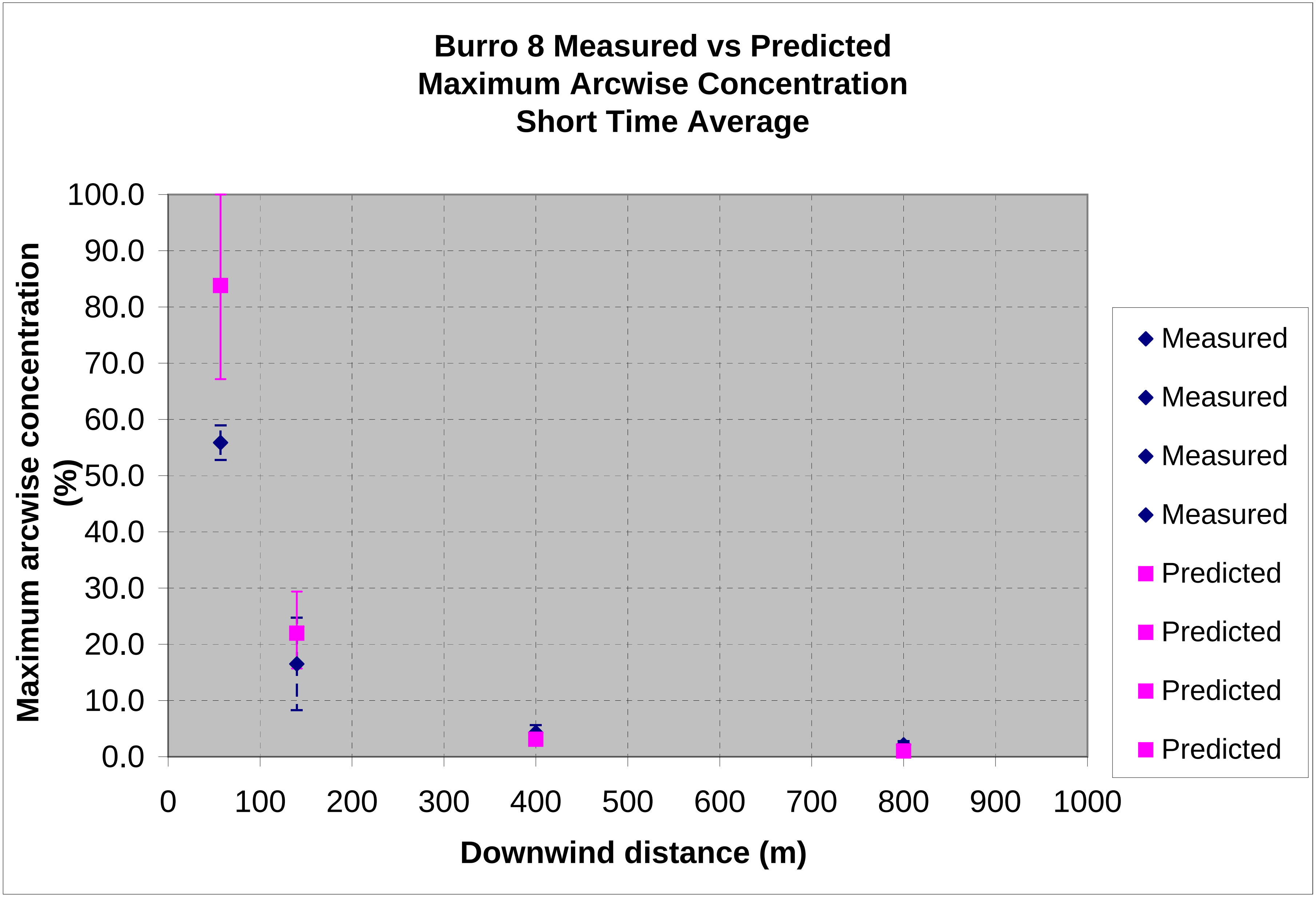
		Source Term		Averaging Time	Wind Speed			Surface Roughness		Monin-Obukhov Length	Stability		Ambient Temperature	Ambient Pressure	Ambient Relative Humidity	Ambient Surface Temperature	Water Transfer Submodel	Molecular Weight
	Base Case	Alternative 1	Alternative 2	Alternative	Lower	Upper	Alternative	Lower	Upper	Alternative	Lower	Upper						
Run Name	a	b	c	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_10	a_11	a_12	a_13	a_14	a_15
Source Term	ABS/FERC	0.167kg/m^2*sec	0.085kg/m^2*sec	ABS/FERC	ABS/FERC	ABS/FERC	ABS/FERC		case			ABS/FERC						ABS/FERC
Wind Speed	5.4	5.4	5.4	5.4	5.1	5.8	5.58		5.4			5.4						5.4
Reference Height	2	2	2	2	2	2	3		2			2						2
Surface Roughnes	2.00E-04	2.00E-04	2.00E-04	2.00E-04	2.00E-04	2.00E-04	2.00E-04		1.00E-02			2.00E-04						2.00E-04
Wind Stability	C	C	C	C	C	C	C		C			D						C
Averaging Time	1	1	1	100	1	1	1		1			1						1
Atmospheric Parameters																		
DELTA Y	0.10461	0.10461	0.10461	0.14675	0.10461	0.10461	0.10461		0.10461			0.06767						0.10461
BETA Y	0.9	0.9	0.9	0.9	0.9	0.9	0.9		0.9			0.9						0.9
Monin-Obukhov l	-9.26	-9.26	-9.26	-9.26	-9.26	-9.26	-9.26		-30.4			infinite						-9.26
Sigma X Coeffici	2.00E-02	2.00E-02	2.00E-02	2.00E-02	2.00E-02	2.00E-02	2.00E-02		2.00E-02			4.00E-02						2.00E-02
Sigma X Power	1.22	1.22	1.22	1.22	1.22	1.22	1.22		1.22			1.14						1.22
Sigma X Minimur	130	130	130	130	130	130	130		130			100						130
Wind Power Const	0.110	0.110	0.110	0.110	0.110	0.110	0.102		0.227			0.127						0.110
Friction Velocity	0.21611	0.21611	0.21611	0.21611	0.2041	0.23212	0.21659		0.36994			0.2052						0.21611
Ambient Temperat	307.75	307.75	307.75	307.75	307.75	307.75	307.75		307.75			307.75						307.75
Ambient Pressure	0.936	0.936	0.936	0.936	0.936	0.936	0.936		0.936			0.936						0.936
Ambient Relative H	5.2	5.2	5.2	5.2	5.2	5.2	5.2		5.2			5.2						5.2
Isothermal?	N	N	N	N	N	N	N		N			N						N
Heat Transfer to be	Y	Y	Y	Y	Y	Y	Y		Y			Y						Y
Surface Tempera	307.75	307.75	307.75	307.75	307.75	307.75	307.75		307.75			307.75						307.75
Correlation	1	1	1	1	1	1	1		1			1						1
Water Transfer?	N	N	N	N	N	N	N		N			N						N
Molecular Weight	17.26	17.26	17.26	17.26	17.26	17.26	17.26		17.26			17.26						16.04
Release Temperat	111.7	111.7	111.7	111.7	111.7	111.7	111.7		111.7			111.7						111.7
Density at release	1.6773	1.6773	1.6773	1.6773	1.6773	1.6773	1.6773		1.6773			1.6773						1.6773
Mean heat capacity	5.60E-08	5.60E-08	5.60E-08	5.60E-08	5.60E-08	5.60E-08	5.60E-08		5.60E-08			5.60E-08						5.60E-08
Mean heat capacity	5.00E+00	5.00E+00	5.00E+00	5.00E+00	5.00E+00	5.00E+00	5.00E+00		5.00E+00			5.00E+00						5.00E+00
Upper Concentratio	80.00%	80.00%	15.00%	80.00%	80.00%	80.00%	80.00%		80.00%			80.00%						80.00%
Lower Concentratio	0.50%	1.00%	0.50%	0.50%	0.50%	0.50%	0.50%		1.00%			0.50%						0.50%
Height for isopleths	1	1	1	1	1	1	1		1			1						1
Max Concentration at:																		
57m centerline	66.7%	66.3%	64.4%	66.7%	68.3%	64.5%	67.0%		41.2%			68.0%						68.5%
140m centerline	25.3%	25.2%	25.1%	25.3%	26.0%	24.8%	25.1%		12.2%			26.6%						27.5%
400m centerline	5.1%	5.0%	4.9%	4.9%	5.2%	5.0%	5.1%		2.4%			5.3%						5.5%
800m centerline	1.2%	1.2%	1.6%	0.8%	1.1%	1.3%	1.2%		0.5%			1.8%						1.7%
x=40, y=-40.6, z=1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%		0.0%			0.0%						0.0%
x=49, y=-28.7, z=1	0.8%	1.0%	1.1%	1.2%	1.0%	0.5%	0.8%		1.3%			0.4%						0.8%
x=55.6, y=-14.9, z=	13.2%	12.8%	11.2%	12.4%	13.8%	12.4%	13.0%		19.8%			14.2%						13.0%
x=55.6, y=14.9, z=	14.1%	13.4%	11.4%	13.5%	14.4%	13.5%	13.9%		21.1%			14.2%						13.7%
x=49, y=28.7, z=1	1.5%	1.8%	2.0%	2.0%	1.8%	1.1%	1.4%		2.4%			1.0%						1.5%
x=37, y=38, z=1	0.0%	0.2%	0.0%	0.1%	0.1%	0.0%	0.0%		0.1%			0.0%						0.0%
x=127, y=58, z=1	0.4%	0.4%	0.7%	0.7%	0.4%	0.3%	0.4%		0.2%			0.1%						0.5%
x=140, y=0, z=1	13.5%	13.3%	12.1%	13.5%	14.0%	13.1%	13.4%		9.4%			14.0%						14.0%
x=395.5, y=-59.8, z	1.0%	1.0%	1.4%	1.1%	1.0%	0.9%	1.0%		0.3%			0.8%						1.4%
x=796, y=79.9, z=1	0.5%	0.6%	0.7%	0.5%	0.5%	0.6%	0.5%		0.2%			0.5%						0.8%
x=184, y=159, z=1	0.0%	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%		0.0%			0.0%						0.1%
Distance to:																		
28.2%	127	127	128	127	131	126	127		77			134						137
9.0%	279	276	275	279	281	274	278		173			285						294
0.9%	892	904	990	750	879	895	887		622			1104						1023
0.5%	1129	1142	1237	944	1114	997	1123		812			1418						1279
LFL	405	402	394	395	414	397	404		257			414						424

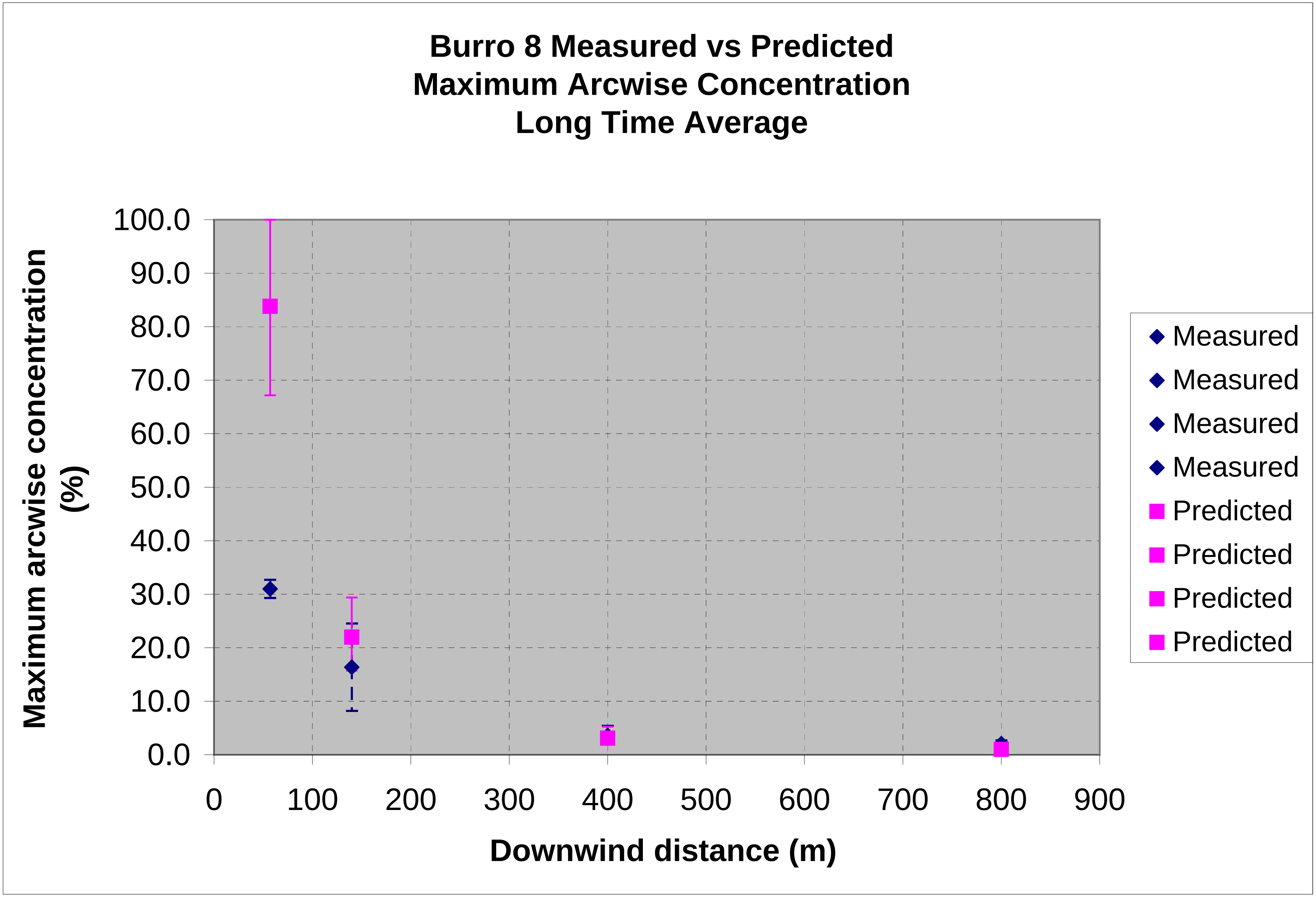


Burro 7 Measured vs Predicted
Maximum Arcwise Concentration
Short Time Average
Maximum arcwise concentration (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
100
200
300
400
500
600
700
800
900
1000
Downwind distance (m)
Measured
Measured
Measured
Predicted
Predicted
Predicted
Predicted

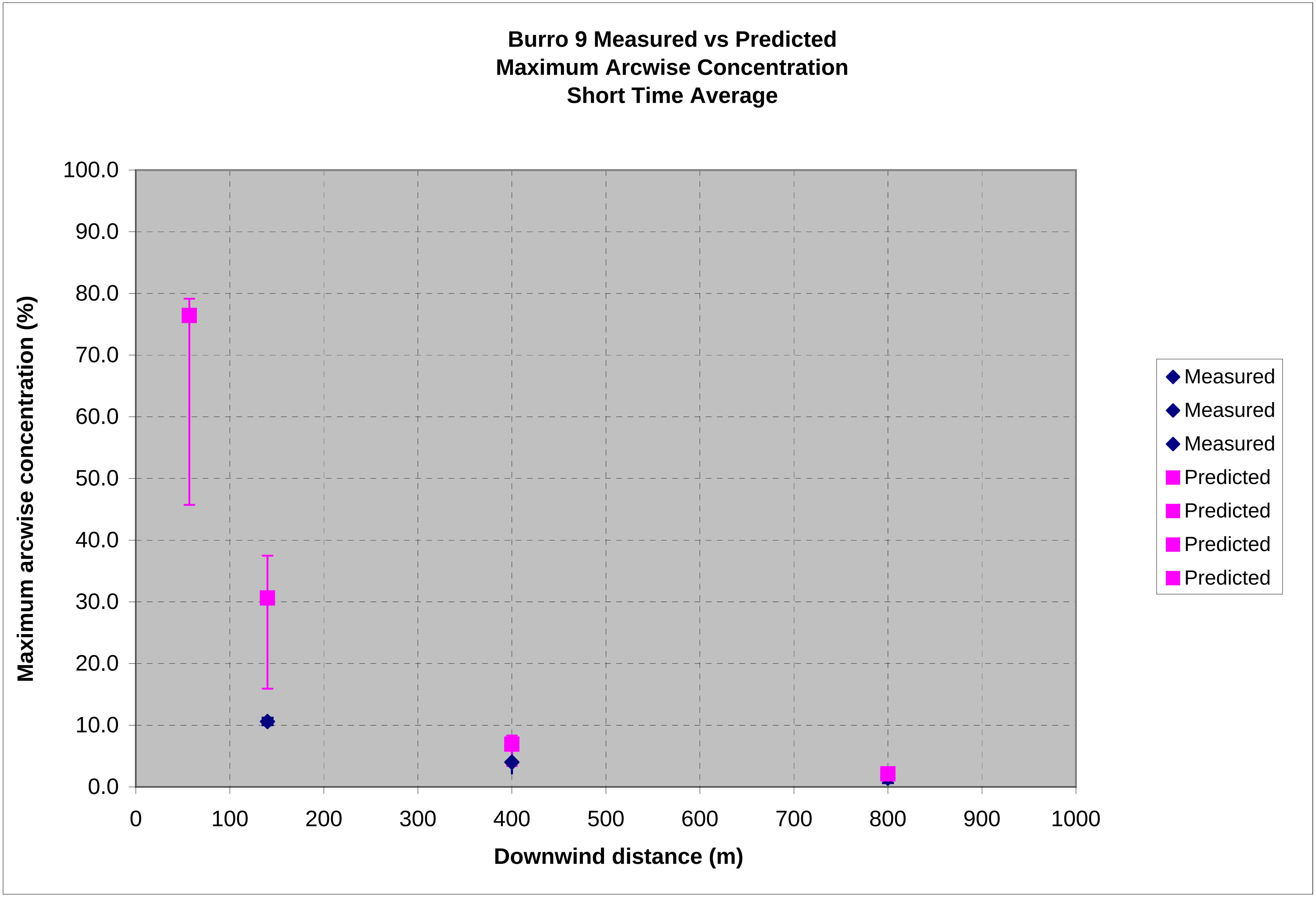

Burro 7 Measured vs Predicted
Maximum Arcwise Concentration
Long Time Average
Maximum arcwise concentration (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
100
200
300
400
500
600
700
800
900
1000
Downwind distance (m)
Measured
Measured
Measured
Predicted
Predicted
Predicted
Predicted

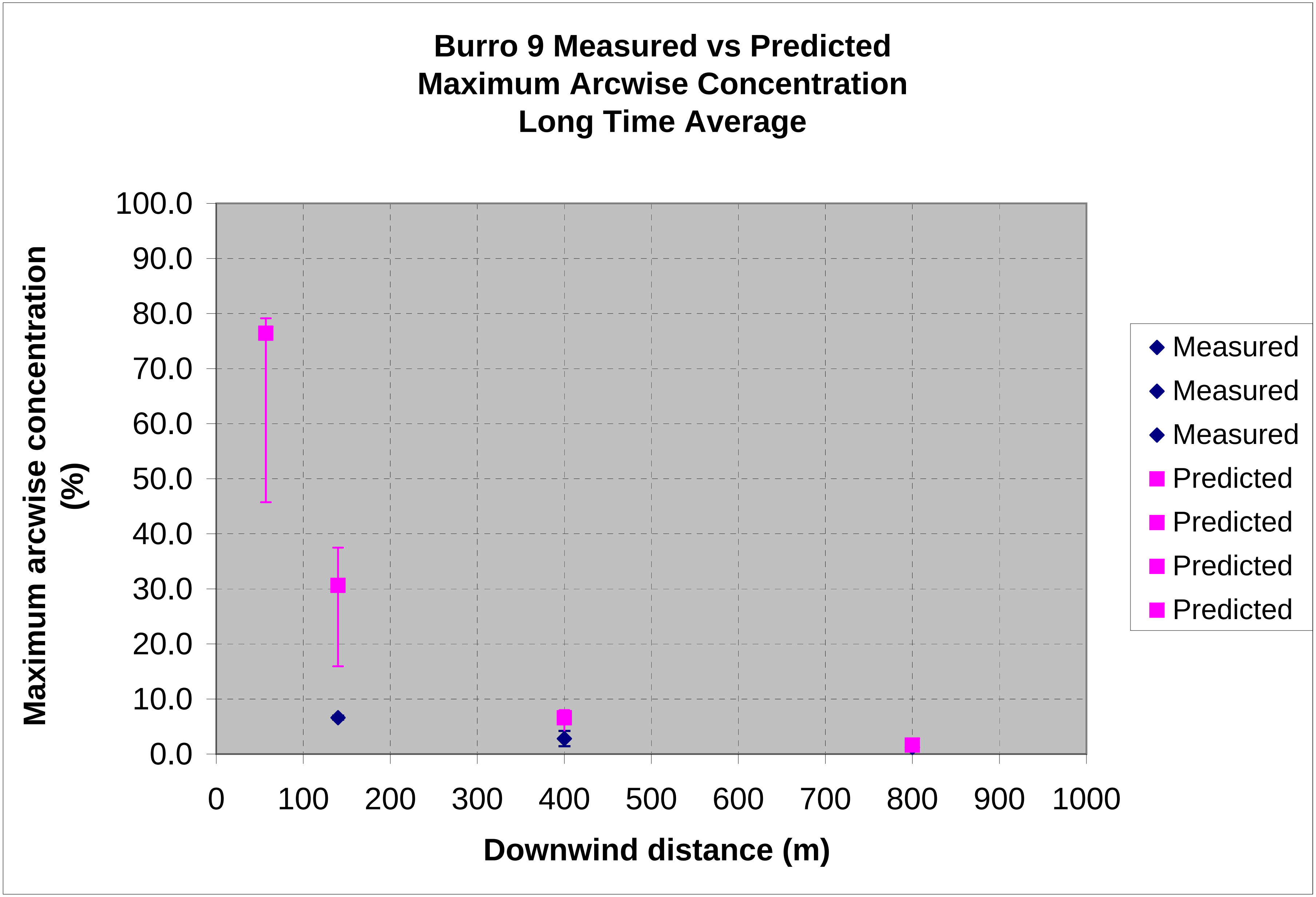
	Base Case	Source Term Alternative 1	Source Term Alternative 2	Averaging Time Alternative	Wind Speed Lower	Wind Speed Upper	Wind Speed Alternative	Surface Roughness Lower	Surface Roughness Upper	Monin-Obukhov Length Alternative	Stability Lower	Stability Upper	Ambient Pressure	Ambient Relative Humidity	Water Transfer Submodel	Molecular Weight
Run Name	a	b	c	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_11	a_12	a_14	a_15
Source Term	ABS/FERC	0.167kg/m^2*sec	0.085kg/m^2*sec	ABS/FERC			ABS/FERC		ABS/FERC	ABS/FERC	ABS/FERC		ABS/FERC	ABS/FERC		ABS/FERC
Wind Speed	8.4	8.4	8.4	8.4			8.75		8.4	8.4	8.4		8.4	8.4		8.4
Reference Height	2	2	2	2			3		2	2	2		2	2		2
Surface Roughnes	2.00E-04	2.00E-04	2.00E-04	2.00E-04			2.00E-04		1.00E-02	2.00E-04	2.00E-04		2.00E-04	2.00E-04		2.00E-04
Wind Stability	D	D	D	D			D		D	D	C		D	D		D
Averaging Time	1	1	1	140			1		1	1	1		1	1		1
Atmospheric Parameters																
DELTA Y	0.06767	0.06767	0.06767	0.10166			0.06767		0.06767	0.06767	0.10461		0.06767	0.06767		0.06767
BETA Y	0.9	0.9	0.9	0.9			0.9		0.9	0.9	0.9		0.9	0.9		0.9
Monin-Obukhov	infinite	infinite	infinite	infinite			infinite		infinite	-114	-9.26		power	infinite		infinite
Sigma X Coeffici	4.00E-02	4.00E-02	4.00E-02	4.00E-02			4.00E-02		4.00E-02	4.00E-02	2.00E-02		4.00E-02	4.00E-02		4.00E-02
Sigma X Power	1.14	1.14	1.14	1.14			1.14		1.14	1.14	1.22		1.14	1.14		1.14
Sigma X Minimu	100	100	100	100			100		100	100	130		100	100		100
Wind Power Const	0.127	0.127	0.127	0.127			0.122		0.110	0.125	0.110		0.127	0.127		0.127
Friction Velocity	0.3192	0.3192	0.3192	0.3192			0.31848		0.55437	0.32134	0.33617		0.3192	0.3192		0.3192
Ambient Temperat	306.96	306.96	306.96	306.96			306.96		306.96	306.96	306.96		306.96	306.96		306.96
Ambient Pressure	0.928	0.928	0.928	0.928			0.928		0.928	0.928	0.928		1	0.928		0.928
Ambient Relative H	7.4	7.4	7.4	7.4			7.4		7.4	7.4	7.4		7.4	5		7.4
Isothermal?	N	N	N	N			N		N	N	N		N	N		N
Heat Transfer to b	Y	Y	Y	Y			Y		Y	Y	Y		Y	Y		Y
Surface Tempera	306.96	306.96	306.96	306.96			306.96		306.96	306.96	306.96		306.96	306.96		306.96
Correlation	1	1	1	1			1		1	1	1		1	1		1
Water Transfer?	N	N	N	N			N		N	N	N		N	N		N
Molecular Weight	18.22	18.22	18.22	18.22			18.22		18.22	18.22	18.22		18.22	18.22		16.04
Release Temperat	111.7	111.7	111.7	111.7			111.7		111.7	111.7	111.7		111.7	111.7		111.7
Density at release	1.663	1.663	1.663	1.663			1.663		1.663	1.663	1.663		1.792	1.663		1.663
Mean heat capacit	5.60E-08	5.60E-08	5.60E-08	5.60E-08			5.60E-08		5.60E-08	5.60E-08	5.60E-08		5.60E-08	5.60E-08		5.60E-08
Mean heat capacit	5.00E+00	5.00E+00	5.00E+00	5.00E+00			5.00E+00		5.00E+00	5.00E+00	5.00E+00		5.00E+00	5.00E+00		5.00E+00
Upper Concentrati	8.00E-01	8.00E-01	8.00E-01	8.00E-01			8.00E-01		8.00E-01	8.00E-01	8.00E-01		8.00E-01	8.00E-01		8.00E-01
Lower Concentrati	5.00E-03	1.00E-02	5.00E-03	5.00E-03			5.00E-03		5.00E-03	5.00E-03	5.00E-03		5.00E-03	5.00E-03		5.00E-03
Height for isopleth	1	1	1	1			1		1	1	1		1	1		1
Max Concentration at:																
57m centerline	61.2%	60.7%	49.4%	61.2%			61.4%		33.9%	60.9%	60.0%		60.0%	58.9%		64.1%
140m centerline	22.7%	22.4%	20.2%	22.7%			23.2%		11.0%	22.5%	21.4%		21.5%	22.7%		26.7%
400m centerline	4.8%	4.8%	4.4%	4.8%			4.8%		2.4%	4.8%	4.6%		4.6%	4.8%		5.3%
800m centerline	1.7%	1.7%	1.5%	1.1%			1.7%		0.9%	1.7%	0.9%		1.6%	1.7%		1.8%
x=57, y=0, z=1	10.2%	9.6%	13.2%	9.5%			10.0%		12.0%	10.1%	9.0%		9.2%	10.2%		9.9%
x=55.6, y=14.9, z=1	15.5%	15.3%	15.0%	15.5%			15.5%		19.6%	15.8%	16.1%		15.2%	15.4%		14.9%
x=49, y=-28.7, z=1	14.1%	13.7%	15.0%	12.9%			13.8%		17.7%	13.9%	12.5%		13.1%	14.0%		13.5%
x=37, y=38, z=1	0.2%	0.1%	0.7%	0.5%			0.2%		0.2%	0.2%	0.4%		0.1%	0.2%		0.2%
x=140, y=0, z=1	0.6%	0.6%	1.2%	1.1%			0.6%		0.4%	0.6%	0.9%		0.5%	0.7%		1.1%
x=137, y=30, z=1	12.8%	12.7%	11.2%	12.7%			13.2%		8.6%	12.9%	12.3%		12.4%	12.8%		13.6%
x=127, y=58, z=1	10.6%	10.5%	10.6%	9.7%			10.8%		7.3%	10.5%	9.1%		9.7%	10.8%		12.5%
x=112, y=84, z=1	0.1%	0.1%	0.2%	0.2%			0.1%		0.0%	0.1%	0.2%		0.0%	0.1%		0.1%
x=382, y=118, z=1	4.0%	4.0%	3.6%	4.0%			4.1%		2.2%	4.0%	3.9%		3.8%	4.0%		4.3%
x=360, y=174, z=1	0.3%	0.3%	0.6%	0.5%			0.3%		0.2%	0.3%	0.4%		0.2%	0.3%		0.8%
Distance to:																
17.9%	167	166	155	167			167		94	167	160		161	167		184
7.1%	310	307	292	310			310		192	310	306		300	309		334
3.9%	468	462	435	461			468		287	468	440		452	465		491
LFL	388	387	368	388			390		242	388	381		374	386		414


Burro 8 Measured vs Predicted
Maximum Arcwise Concentration
Short Time Average
Maximum arcwise concentration (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
100
200
300
400
500
600
700
800
900
1000
Downwind distance (m)
Measured
Measured
Measured
Measured
Predicted
Predicted
Predicted
Predicted


Burro 8 Measured vs Predicted
Maximum Arcwise Concentration
Long Time Average
Maximum arcwise concentration (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
100
200
300
400
500
600
700
800
900
Downwind distance (m)
Measured
Measured
Measured
Measured
Predicted
Predicted
Predicted
Predicted

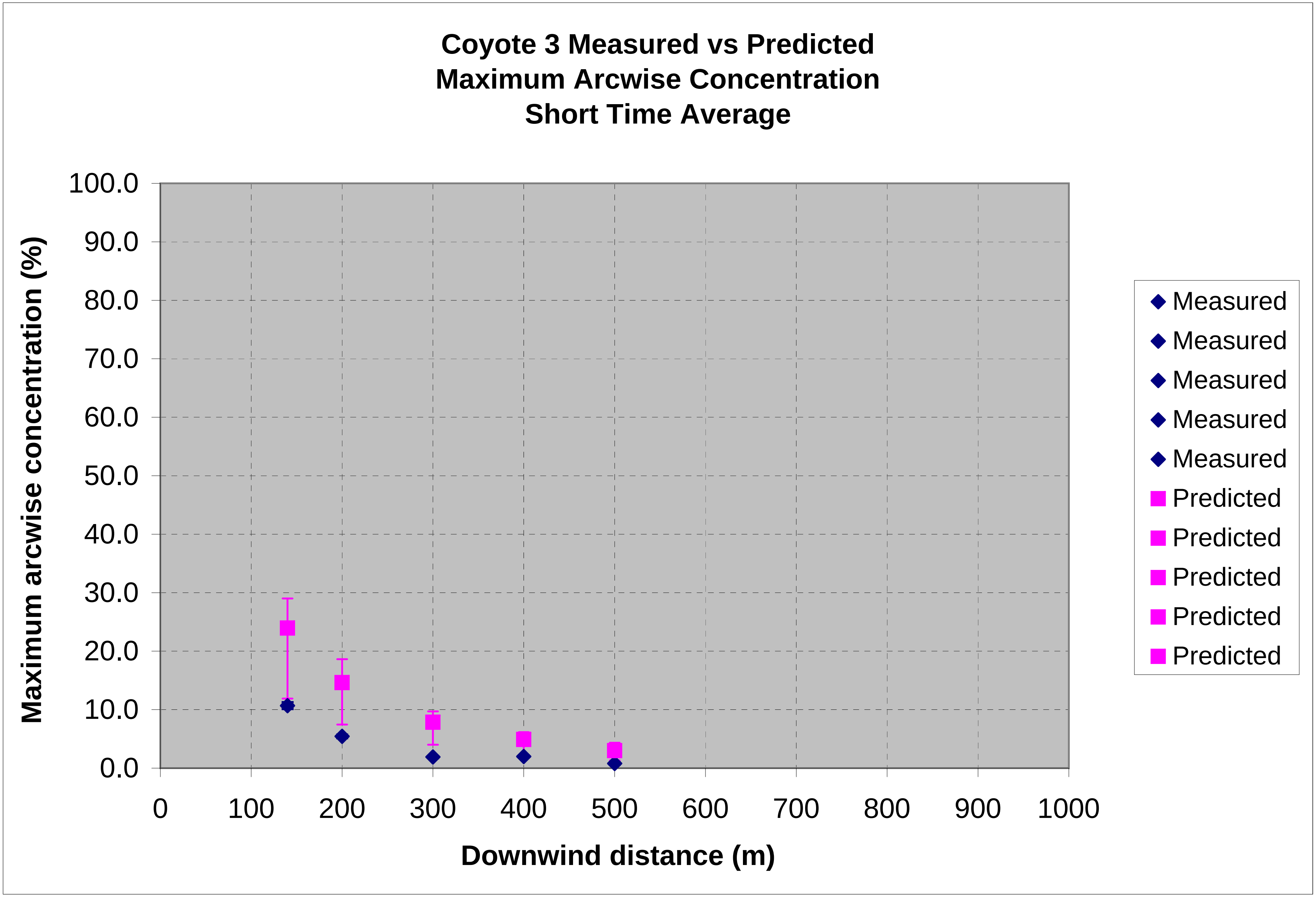
		Source Term		Averaging Time		Wind Speed		Surface Roughness		Monin-Obukhov Length	Stability		Ambient Temperature	Ambient Pressure	Ambient Relative Humidity	Ambient Surface Temperature	Water Transfer Submodel	Molecular Weight
	Base Case	Alternative 1	Alternative 2	Alternative	Lower	Upper	Alternative	Lower	Upper	Alternative	Lower	Upper						
Run Name	a	b	c	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_10	a_11	a_12	a_13	a_14	a_15
Source Term	ABS/FERC	0.167kg/m^2*sec	0.085kg/m^2*se	ABS/FERC	ABS/FERC	ABS/FERC	ABS/FERC		ABS/FERC	ABS/FERC		ABS/FERC						ABS/FERC
Wind Speed	1.8	1.8	1.8	1.8	1.5	2	1.94		1.8	1.8		1.8						1.8
Reference Height	2	2	2	2	2	2	3		2	2		2						2
Surface Roughness	2.00E-04	2.00E-04	2.00E-04	2.00E-04	2.00E-04	2.00E-04	2.00E-04		1.00E-02	1.33E-03		2.00E-04						2.00E-04
Wind Stability	E	E	E	E	E	E	E		E	E		F						E
Averaging Time	1	1	1	100	1	1	1		1	1		1						1
Atmospheric Parameters																		
DELTA Y	0.04617	0.04617	0.04617	0.07128	0.04617	0.04617	0.04617		0.04617	0.04617		0.02544						0.04617
BETA Y	0.9	0.9	0.9	0.9	0.9	0.9	0.9		0.9	0.9		0.9						0.9
Monin-Obukhov Length	9.26	9.26	9.26	9.26	9.26	9.26	9.26		30.4	16.5		6.06						9.26
Sigma X Coefficient	1.70E-01	1.70E-01	1.70E-01	1.70E-01	1.70E-01	1.70E-01	1.70E-01		1.70E-01	1.70E-01		1.70E-01						1.70E-01
Sigma X Power	0.97	0.97	0.97	0.97	0.97	0.97	0.97		0.97	0.97		0.97						0.97
Sigma X Minimum Distance	50	50	50	50	50	50	50		50	50		50						50
Wind Power Constant	0.168	0.168	0.168	0.168	0.168	0.168	0.178		0.262	0.195		0.188						0.168
Friction Velocity	0.06161	0.06161	0.06161	0.06161	0.05134	0.06846	0.06096		0.11226	0.07988		0.05853						0.06161
Ambient Temperature	306.02	306.02	306.02	306.02	306.02	306.02	306.02		306.02	306.02		306.02						306.02
Ambient Pressure	0.929	0.929	0.929	0.929	0.929	0.929	0.929		0.929	0.929		0.929						0.929
Ambient Relative Humidity	4.5	4.5	4.5	4.5	4.5	4.5	4.5		4.5	4.5		4.5						4.5
Isothermal?	N	N	N	N	N	N	N		N	N		N						N
Heat Transfer?	Y	Y	Y	Y	Y	Y	Y		Y	Y		Y						Y
Surface Temperature	306.02	306.02	306.02	306.02	306.02	306.02	306.02		306.02	306.02		306.02						306.02
Correlation	1	1	1	1	1	1	1		1	1		1						1
Water Transfer?	N	N	N	N	N	N	N		N	N		N						N
Molecular Weight	18.12	18.12	18.12	18.12	18.12	18.12	18.12		18.12	18.12		18.12						16.04
Release Temperature	111.7	111.7	111.7	111.7	111.7	111.7	111.7		111.7	111.7		111.7						111.7
Density	1.6648	1.6648	1.6648	1.6648	1.6648	1.6648	1.6648		1.6648	1.6648		1.6648						1.6648
Mean heat capacity constant	5.60E-08	5.60E-08	5.60E-08	5.60E-08	5.60E-08	5.60E-08	5.60E-08		5.60E-08	5.60E-08		5.60E-08						5.60E-08
Mean heat capacity power	5	5.00E+00	5.00E+00	5.00E+00	5.00E+00	5.00E+00	5		5.00E+00	5.00E+00		5.00E+00						5.00E+00
Upper Concentration	0.8	8.00E-01	8.00E-01	8.00E-01	8.00E-01	8.00E-01	0.8		8.00E-01	8.00E-01		8.00E-01						8.00E-01
Lower Concentration	0.005	5.00E-03	5.00E-03	5.00E-03	5.00E-03	5.00E-03	5.00E-03		5.00E-03	5.00E-03		5.00E-03						5.00E-03
Height for isopleths	1	1	1	1	1	1	1		1	1		1						1
Max Concentration at:																		
57m centerline	83.8%	100.0%	100.0%	83.8%	88.3%	89.8%	83.9%		67.2%	85.5%		80.2%						68.9%
140m centerline	22.0%	22.5%	21.0%	22.0%	16.3%	25.1%	21.9%		15.7%	23.1%		21.8%						29.4%
400m centerline	3.1%	2.9%	3.3%	3.1%	2.1%	3.6%	3.1%		3.5%	3.5%		2.9%						5.3%
800m centerline	1.0%	1.0%	1.1%	1.0%	0.7%	1.2%	1.0%		1.3%	1.1%		1.0%						1.5%
x=40, y=-40.6, z=1	32.2%	22.7%	30.6%	32.2%	16.3%	24.3%	11.9%		34.4%	25.0%		29.4%						30.9%
x=49, y=-28.7, z=1	30.1%	24.8%	30.2%	30.1%	15.2%	24.7%	14.4%		43.6%	26.4%		28.3%						30.5%
x=57, y=0, z=1	29.5%	25.3%	30.2%	29.5%	14.9%	25.3%	14.3%		42.4%	26.9%		27.9%						30.1%
x=55.6, y=14.9, z=1	30.3%	24.7%	30.2%	30.3%	15.3%	24.6%	14.3%		43.9%	26.2%		28.4%						30.7%
x=49, y=-28.7, z=1	33.0%	21.3%	31.0%	33.0%	16.8%	24.2%	5.4%		10.6%	20.3%		30.6%						30.9%
x=37, y=38, z=1	34.5%	13.5%	35.3%	34.5%	18.5%	1.0%	0.0%		0.0%	0.2%		35.1%						32.7%
x=112, y=-84, z=1	12.4%	16.2%	10.5%	11.5%	13.0%	12.0%	12.3%		0.4%	13.6%		13.9%						20.9%
x=127, y=-58, z=1	17.2%	16.2%	17.6%	17.2%	13.1%	18.1%	17.1%		12.6%	17.9%		15.2%						20.0%
x=137, y=-30, z=1	16.5%	15.1%	16.9%	16.5%	12.3%	17.1%	16.4%		14.0%	17.4%		14.8%						19.5%
x=140, y=0, z=1	16.8%	15.6%	17.2%	16.8%	12.6%	17.5%	16.7%		14.3%	17.5%		15.0%						19.7%
x=137, y=30, z=1	17.7%	17.2%	16.7%	17.3%	13.8%	19.1%	17.6%		3.2%	18.9%		15.5%						20.5%
x=127, y=58, z=1	0.9%	3.5%	0.8%	1.7%	2.2%	0.7%	1.0%		0.0%	0.7%		0.4%						6.9%
x=112, y=84, z=1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%		0.0%	0.0%		0.0%						0.0%
x=360, y=174, z=1	0.1%	0.1%	0.0%	0.1%	0.0%	0.1%	0.1%		0.0%	0.2%		0.0%						0.9%
x=382, y=118, z=1	2.5%	2.4%	2.6%	2.3%	1.8%	3.0%	2.5%		0.9%	3.2%		2.5%						4.9%
x=395.5, y=-59.8, z=1	3.0%	2.8%	3.2%	3.0%	2.0%	3.5%	3.0%		3.4%	3.4%		2.8%						4.9%
x=400, y=0, z=1	1.3%	1.6%	1.3%	1.4%	1.1%	1.7%	1.3%		0.3%	2.2%		1.5%						4.0%
x=395.5, y=59.8, z=1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%		0.0%	0.0%		0.0%						0.3%
x=784, y=-159, z=1	1.0%	1.0%	1.0%	1.0%	0.7%	1.2%	1.0%		1.0%	1.1%		1.0%						1.5%
x=796, y=-79.9, z=1	0.7%	0.7%	0.6%	0.6%	0.5%	0.8%	0.7%		0.3%	0.8%		0.7%						1.3%
x=800, y=0, z=1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%		0.0%	0.0%		0.0%						0.1%
Distance to:																		
55.9%	83	89	84	83	81	83	84		65	77		82						90
16.5%	156	160	160	164	138	182	164		135	183		156						210
4.3%	324	313	338	324	255	370	322		342	368		304						441
2.1%	501	503	535	501	397	558	503		566	540		498						667
LFL	289	291	308	289	221	329	290		302	328		284						415

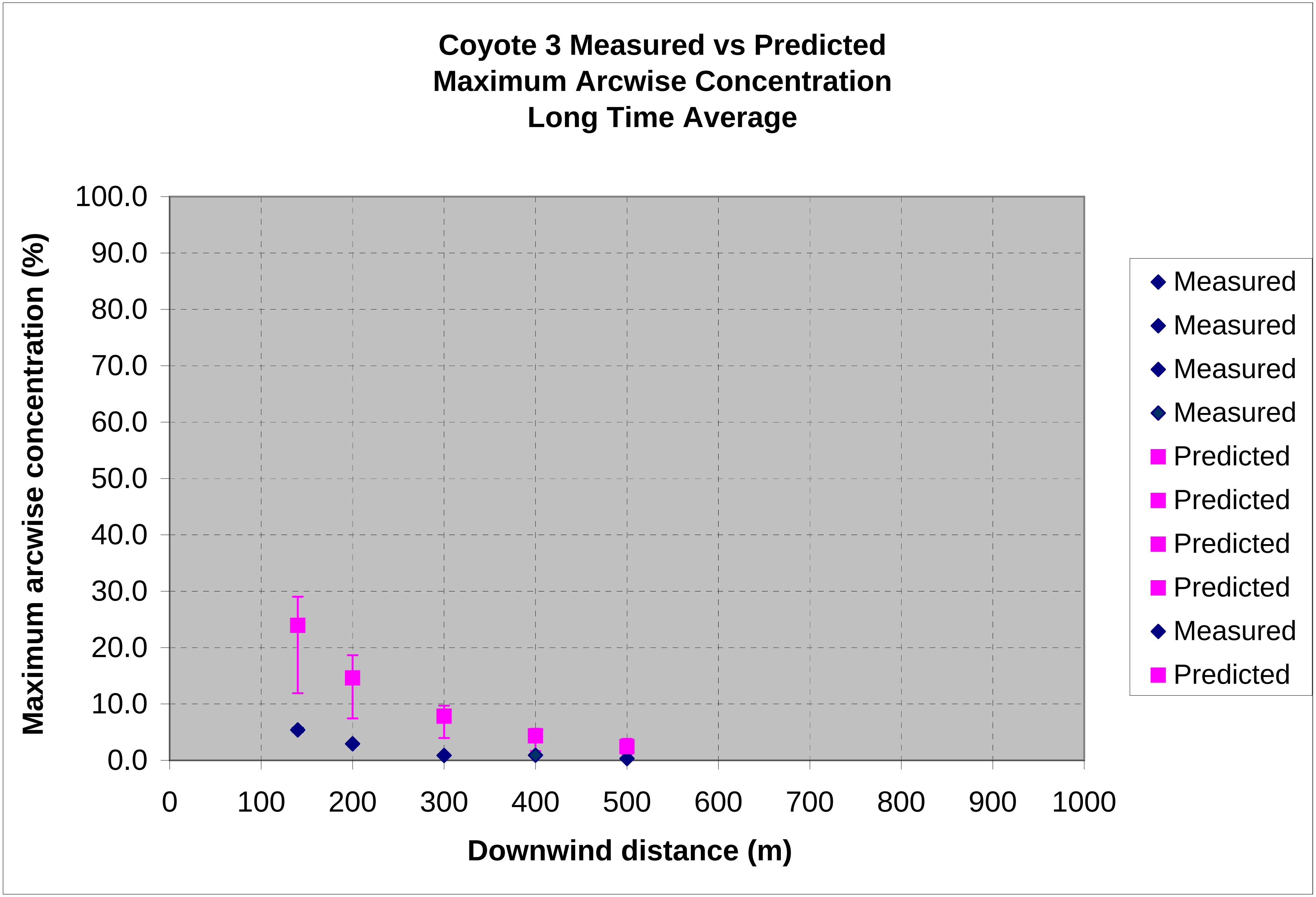

Burro 9 Measured vs Predicted
Maximum Arcwise Concentration
Short Time Average
Maximum arcwise concentration (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
100
200
300
400
500
600
700
800
900
1000
Downwind distance (m)
Measured
Measured
Measured
Predicted
Predicted
Predicted
Predicted



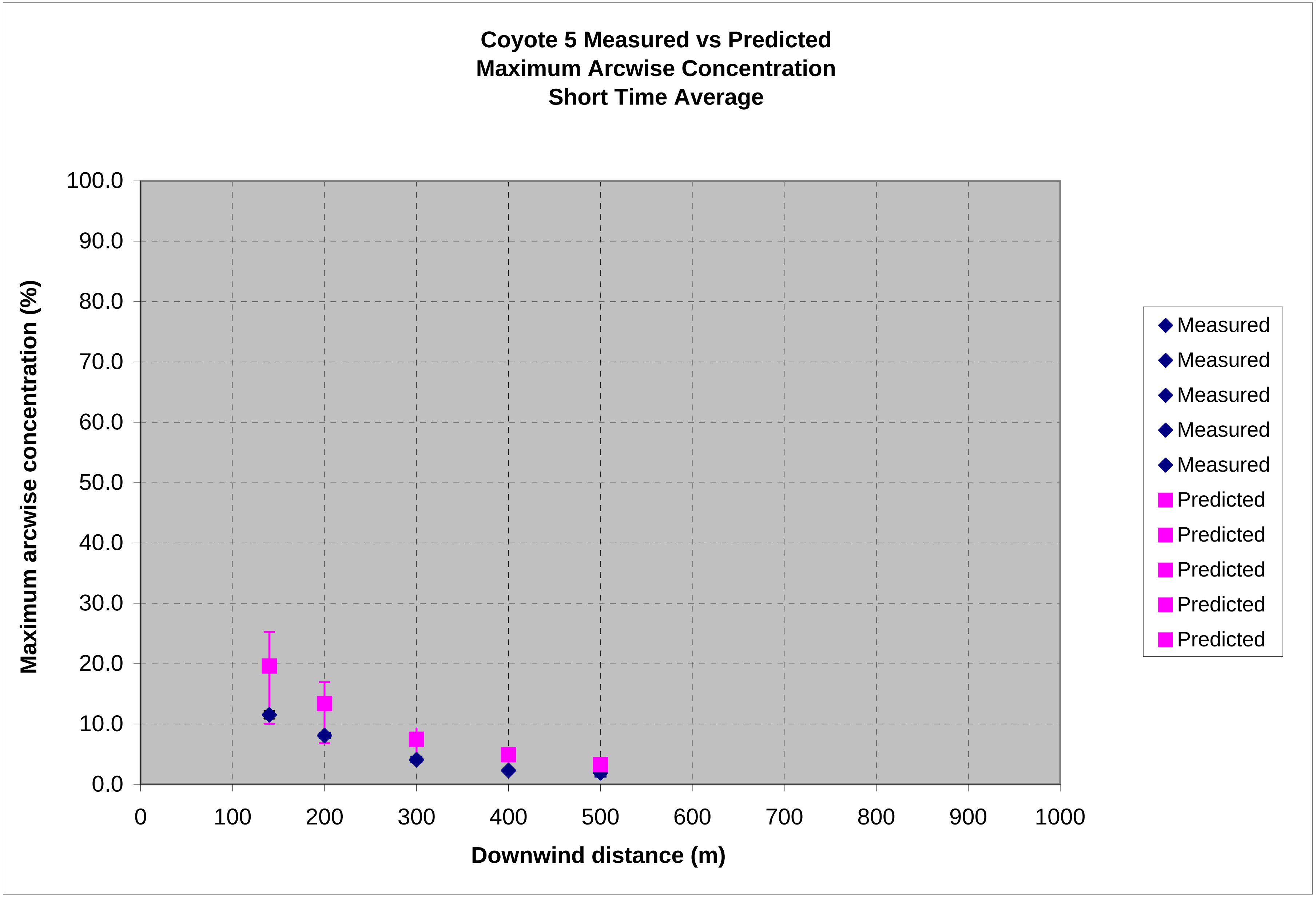
Burro 9 Measured vs Predicted
Maximum Arcwise Concentration
Long Time Average
Maximum arcwise concentration (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
100
200
300
400
500
600
700
800
900
1000
Downwind distance (m)
Measured
Measured
Measured
Predicted
Predicted
Predicted
Predicted

		Source Term		Averaging Time		Wind Speed		Surface Roughness		Monin-Obukhov Length	Stability		Ambient Temperature	Ambient Pressure	Ambient Relative Humidity	Ambient Surface Temperature	Water Transfer Submodel	Molecular Weight
	Base Case	Alternative 1	Alternative 2	Alternative	Lower	Upper	Alternative	Lower	Upper	Alternative	Lower	Upper						
Run Name	a	b	c	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_10	a_11	a_12	a_13	a_14	a_15
Source Term	ABS/FERC	0.167kg/m^2*sec	0.085kg/m^2*sec	ABS/FERC			ABS/FERC		ABS/FERC	ABS/FERC		ABS/FERC			ABS/FERC			ABS/FERC
Wind Speed	5.7	5.7	5.7	5.7			5.94		5.7	5.7		5.7			5.7			5.7
Reference Height	2	2	2	2			3		2	2		2			2			2
Surface Roughness	2.00E-04	2.00E-04	2.00E-04	2.00E-04			2.00E-04		1.00E-02	2.00E-04		2.00E-04			2.00E-04			2.00E-04
Wind Stability	D	D	D	D			D		D	D		C			D			D
Averaging Time	1	1	1	100			1		1	1		1			1			1
Atmospheric Parameters																		
DELTA Y	0.06767	0.06767	0.06767	0.09504			0.06767		0.06767	0.06767		0.10461			0.06767			0.06767
BETA Y	0.9	0.9	0.9	0.9			0.9		0.9	0.9		0.9			0.9			0.9
Monin-Obukhov Length	infinite	infinite	infinite	infinite			infinite		infinite	-141		-9.26			infinite			infinite
Sigma X Coefficient	4.00E-02	4.00E-02	4.00E-02	4.00E-02			4.00E-02		4.00E-02	4.00E-02		2.00E-02			4.00E-02			4.00E-02
Sigma X Power	1.14E+00	1.14E+00	1.14E+00	1.14E+00			1.14E+00		1.14E+00	1.14E+00		1.22E+00			1.14E+00			1.14E+00
Sigma X Minimum Distance	1.00E+02	1.00E+02	1.00E+02	1.00E+02			1.00E+02		1.00E+02	1.00E+02		1.30E+02			1.00E+02			1.00E+02
Wind Power Constant	0.127	0.127	0.127	0.127			0.122		0.240	0.125		0.110			0.127			0.127
Friction Velocity	0.2166	0.2166	0.2166	0.2166			0.21621		0.37618	0.21779		0.22811			0.2166			0.2166
Ambient Temperature	308.52	308.52	308.52	308.52			308.52		308.52	308.52		308.52			308.52			308.52
Ambient Pressure	0.928	0.928	0.928	0.928			0.928		0.928	0.928		0.928			0.928			0.928
Ambient Relative Humidity	14.4	14.4	14.4	14.4			14.4		14.4	14.4		14.4			6.5			14.4
Isothermal?	N	N	N	N			N		N	N		N			N			N
Heat Transfer?	Y	Y	Y	Y			Y		Y	Y		Y			Y			Y
Surface Temperature	308.52	308.52	308.52	308.52			308.52		308.52	308.52		308.52			308.52			308.52
Correlation	1	1	1	1			1		1	1		1			1			1
Water Transfer?	N	N	N	N			N		N	N		N			N			N
Molecular Weight	18.82	18.82	18.82	18.82			18.82		18.82	18.82		18.82			18.82			16.04
Release Temperature	111.7	111.7	111.7	111.7			111.7		111.7	111.7		111.7			111.7			111.7
Density	1.663	1.663	1.663	1.663			1.663		1.663	1.663		1.663			1.663			1.663
Mean heat capacity constant	5.60E-08	5.60E-08	5.60E-08	5.60E-08			5.60E-08		5.60E-08	5.60E-08		5.60E-08			5.60E-08			5.60E-08
Mean heat capacity power	5	5	5	5			5		5	5		5			5			5
Upper Concentration	80.0%	80.0%	80.0%	80.0%			80.0%		80.0%	80.0%		80.0%			80.0%			80.0%
Lower Concentration	0.5%	0.5%	0.5%	0.5%			0.5%		0.5%	0.5%		0.5%			0.5%			0.5%
Height for isopleths	1	1	1	1			1		1	1		1			1			1
Max Concentration at:																		
57m centerline	76.4%	76.1%	73.6%	76.4%			76.5%		45.7%	76.5%		74.9%			76.9%			79.1%
140m centerline	30.6%	29.5%	29.7%	30.6%			31.2%		15.9%	30.8%		30.4%			32.5%			37.5%
400m centerline	6.9%	6.6%	6.3%	6.6%			6.9%		3.4%	6.9%		6.7%			6.6%			8.3%
800m centerline	2.1%	2.2%	2.2%	1.6%			2.1%		0.9%	2.1%		1.4%			2.0%			2.7%
x=127, y=-58, z=1	4.4%	4.53%	6.35%	5.03%			4.63%		1.86%	4.48%		5.23%			5.77%			7.77%
x=137, y=-30, z=1	18.2%	17.11%	15.88%	18.23%			18.51%		12.74%	18.21%		18.02%			17.72%			19.29%
x=140, y=0, z=1	18.3%	17.18%	15.93%	18.27%			18.50%		12.80%	18.19%		18.03%			17.71%			19.27%
x=127, y=58, z=1	0.0%	0.00%	0.01%	0.01%			0.00%		0.00%	0.00%		0.02%			0.00%			0.01%
x=382, y=-118, z=1	0.9%	0.92%	1.43%	1.10%			0.86%		0.08%	0.87%		1.14%			0.90%			2.48%
x=395.5, y=-59.8, z=1	5.9%	5.60%	5.25%	5.91%			5.94%		3.04%	5.93%		5.77%			5.70%			6.74%
x=400, y=0, z=1	3.0%	3.06%	3.66%	2.98%			3.02%		0.61%	3.03%		2.90%			2.99%			5.43%
x=784, y=-159, z=1	0.6%	0.73%	1.04%	0.73%			0.63%		0.21%	0.64%		0.69%			0.60%			1.72%
x=796, y=-79.9, z=1	1.8%	1.92%	1.99%	1.46%			1.82%		0.79%	1.83%		1.27%			1.70%			2.43%
x=800, y=0, z=1	0.1%	0.15%	0.31%	0.24%			0.12%		0.03%	0.12%		0.26%			0.11%			0.69%
Distance to:																		
-	-	-	-	-			-		-	-		-			-			0
10.6%	298	291	285	298			300		185	299		296			292			341
4.0%	552	556	539	546			553		359	553		528			532			620
1.4%	960	993	1022	841			959		658	959		800			929			1160
LFL	492	482	465	491			492		307	493		481			462			537

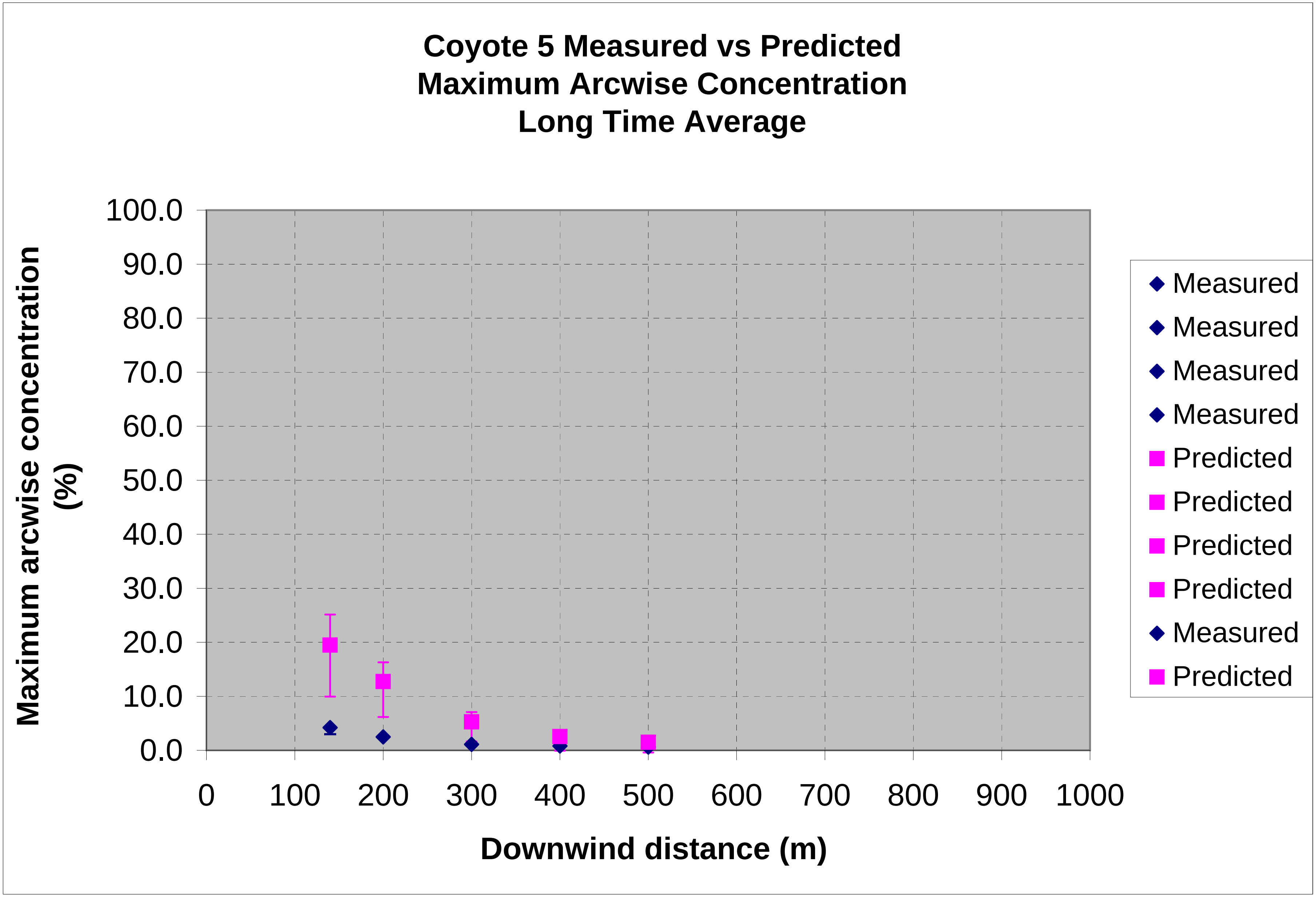

Coyote 3 Measured vs Predicted
Maximum Arcwise Concentration
Short Time Average
Maximum arcwise concentration (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
100
200
300
400
500
600
700
800
900
1000
Downwind distance (m)
Measured
Measured
Measured
Measured
Measured
Predicted
Predicted
Predicted
Predicted
Predicted


Coyote 3 Measured vs Predicted
Maximum Arcwise Concentration
Long Time Average
Maximum arcwise concentration (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
100
200
300
400
500
600
700
800
900
1000
Downwind distance (m)
Measured
Measured
Measured
Measured
Predicted
Predicted
Predicted
Predicted
Measured
Predicted

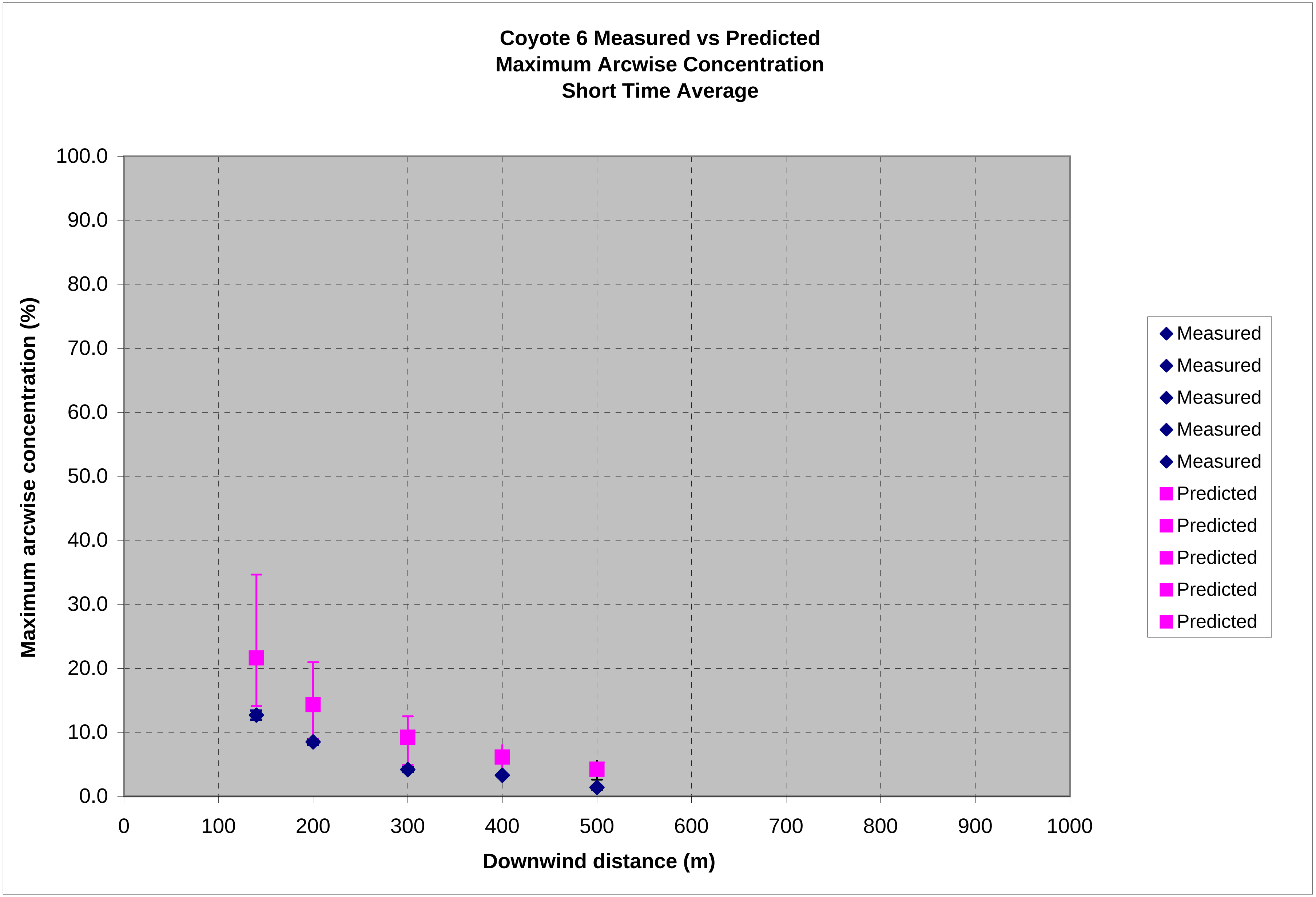
		Source Term		Averaging Time	Wind Speed			Surface Roughness		Monin-Obukhov Length	Stability		Ambient Temperature	Ambient Pressure	Ambient Relative Humidity	Ambient Surface Temperature	Water Transfer Submodel	Molecular Weight
	Base Case	Alternative 1	Alternative 2	Alternative	Lower	Upper	Alternative	Lower	Upper	Alternative	Lower	Upper						
Run Name	a	b	c	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_10	a_11	a_12	a_13	a_14	a_15
Source Term	ABS/FERC	0.167kg/m^2*se	0.085kg/m^2*sec	ABS/FERC			ABS/FERC		ABS/FERC	ABS/FERC		ABS/FERC			ABS/FERC			ABS/FERC
Wind Speed	6	6	6	6			6.77		6	6		6			6			6
Reference Height	2	2	2	2			3		2	2		2			2			2
Surface Roughness	2.00E-04	2.00E-04	2.00E-04	2.00E-04			2.00E-04		1.00E-02	2.00E-04		2.00E-04			2.00E-04			2.00E-04
Wind Stability	C	C	C	C			C		C	C		D			C			C
Averaging Time	1	1	1	50			1		1	1		1			1			1
Atmospheric Parameters																		
DELTA Y	0.10461	0.10461	0.10461	0.12776			0.10461		0.10461	0.10461		0.06767			0.10461			0.10461
BETA Y	0.9	0.9	0.9	0.9			0.9		0.9	0.9		0.9			0.9			0.9
Monin-Obukhov Length	-9.26	-9.26	-9.26	-9.26			-9.26		-30.4	-6.32		infinite			-9.26			-9.26
Sigma X Coefficient	2.00E-02	2.00E-02	2.00E-02	2.00E-02			2.00E-02		2.00E-02	2.00E-02		4.00E-02			2.00E-02			2.00E-02
Sigma X Power	1.22E+00	1.22E+00	1.22E+00	1.22E+00			1.22E+00		1.22E+00	1.22E+00		1.14E+00			1.22E+00			1.22E+00
Sigma X Minimum Distance	1.30E+02	1.30E+02	1.30E+02	1.30E+02			1.30E+02		1.30E+02	1.30E+02		1.00E+02			1.30E+02			1.30E+02
Wind Power Constant	0.110	0.110	0.110	0.110			0.102		0.227	0.106		0.127			0.110			0.110
Friction Velocity	0.24012	0.24012	0.24012	0.24012			0.26278		0.41104	0.24362		0.228			0.24012			0.24012
Ambient Temperature	311.45	311.45	311.45	311.45			311.45		311.45	311.45		311.45			311.45			311.45
Ambient Pressure	0.924	0.924	0.924	0.924			0.924		0.924	0.924		0.924			0.924			0.924
Ambient Relative Humidity	11.3	11.3	11.3	11.3			11.3		11.3	11.3		11.3			3.5			11.3
Isothermal?	N	N	N	N			N		N	N		N			N			N
Heat Transfer?	Y	Y	Y	Y			Y		Y	Y		Y			Y			Y
Surface Temperature	311.45	311.45	311.45	311.45			311.45		311.45	311.45		311.45			311.45			311.45
Correlation	1	1	1	1			1		1	1		1			1			1
Water Transfer?	N	N	N	N			N		N	N		N			N			N
Molecular Weight	19.51	19.51	19.51	19.51			19.51		19.51	19.51		19.51			19.51			16.04
Release Temperature	111.7	111.7	111.7	111.7			111.7		111.7	111.7		111.7			111.7			111.7
Density	1.6558	1.6558	1.6558	1.6558			1.6558		1.6558	1.6558		1.6558			1.6558			1.6558
Mean heat capacity constant	5.60E-08	5.60E-08	5.60E-08	5.60E-08			5.60E-08		5.60E-08	5.60E-08		5.60E-08			5.60E-08			5.60E-08
Mean heat capacity power	5	5.00E+00	5.00E+00	5.00E+00			5.00E+00		5.00E+00	5.00E+00		5.00E+00			5			5.00E+00
Upper Concentration	80.0%	8.00E-01	8.00E-01	8.00E-01			8.00E-01		8.00E-01	8.00E-01		8.00E-01			80.0%			8.00E-01
Lower Concentration	0.5%	5.00E-03	5.00E-03	5.00E-03			5.00E-03		5.00E-03	5.00E-03		5.00E-03			0.5%			5.00E-03
Height for isopleths	1	1	1	1			1		1	1		1			1			1
Max Concentration at:																		
140m centerline	23.9%	22.4%	21.4%	23.9%			23.6%		11.9%	23.2%		24.2%			24.0%			29.0%
200m centerline	14.6%	13.7%	13.3%	14.6%			14.6%		7.4%	14.6%		15.0%			14.6%			18.6%
300m centerline	7.9%	7.6%	7.3%	7.8%			7.8%		4.0%	7.7%		8.1%			7.6%			9.7%
400m centerline	4.9%	4.8%	4.7%	4.3%			4.9%		2.2%	5.0%		5.1%			4.6%			6.2%
500m centerline	3.0%	2.9%	2.9%	2.4%			3.2%		1.3%	2.9%		3.6%			2.8%			4.3%
x=140, y=0, z=1	0.5%	0.4%	0.5%	0.7%			0.4%		0.3%	0.5%		0.2%			0.6%			1.0%
x=112, y=84, z=1	4.6%	4.0%	4.4%	4.8%			4.1%		2.8%	4.5%		4.2%			5.2%			6.9%
x=127, y=58, z=1	14.2%	13.2%	12.5%	14.2%			13.7%		9.4%	13.8%		14.3%			13.4%			15.0%
x=137, y=30, z=1	11.0%	10.0%	10.0%	10.6%			10.3%		7.0%	10.8%		12.3%			11.2%			13.4%
x=186.5, y=72, z=1	10.3%	9.6%	9.3%	10.3%			10.1%		6.3%	10.3%		10.5%			10.1%			11.8%
x=196.6, y=36.9, z=1	4.0%	3.5%	3.7%	4.0%			3.7%		2.0%	3.9%		3.9%			4.3%			6.6%
x=200, y=0, z=1	0.1%	0.0%	0.1%	0.1%			0.0%		0.0%	0.1%		0.0%			0.1%			0.2%
x=296, y=48.3, z=1	0.5%	0.5%	0.6%	0.7%			0.5%		0.2%	0.5%		0.3%			0.6%			1.5%
x=395.5, y=59.8, z=1	0.1%	0.1%	0.1%	0.1%			0.1%		0.0%	0.1%		0.0%			0.1%			0.4%
x=382, y=118, z=1	2.6%	2.5%	2.5%	2.5%			2.6%		1.1%	2.6%		2.8%			2.4%			4.3%
x=330, y=226, z=1	0.1%	0.1%	0.1%	0.2%			0.1%		0.0%	0.1%		0.1%			0.1%			0.6%
x=495, y=71.2, z=1	0.0%	0.0%	0.0%	0.0%			0.0%		0.0%	0.0%		0.0%			0.0%			0.1%
Distance to:																		
10.7%	257	238	232	241			241		151	246		246			239			285
5.4%	379	373	366	367			380		243	374		386			369			435
1.9%	593	589	589	542			608		424	584		697			580			807
2.0%	582	577	578	534			599		416	575		683			567			788
0.8%	832	824	833	764			850		634	820		998			772			1076
LFL	392	392	385	378			396		254	399		405			383			453



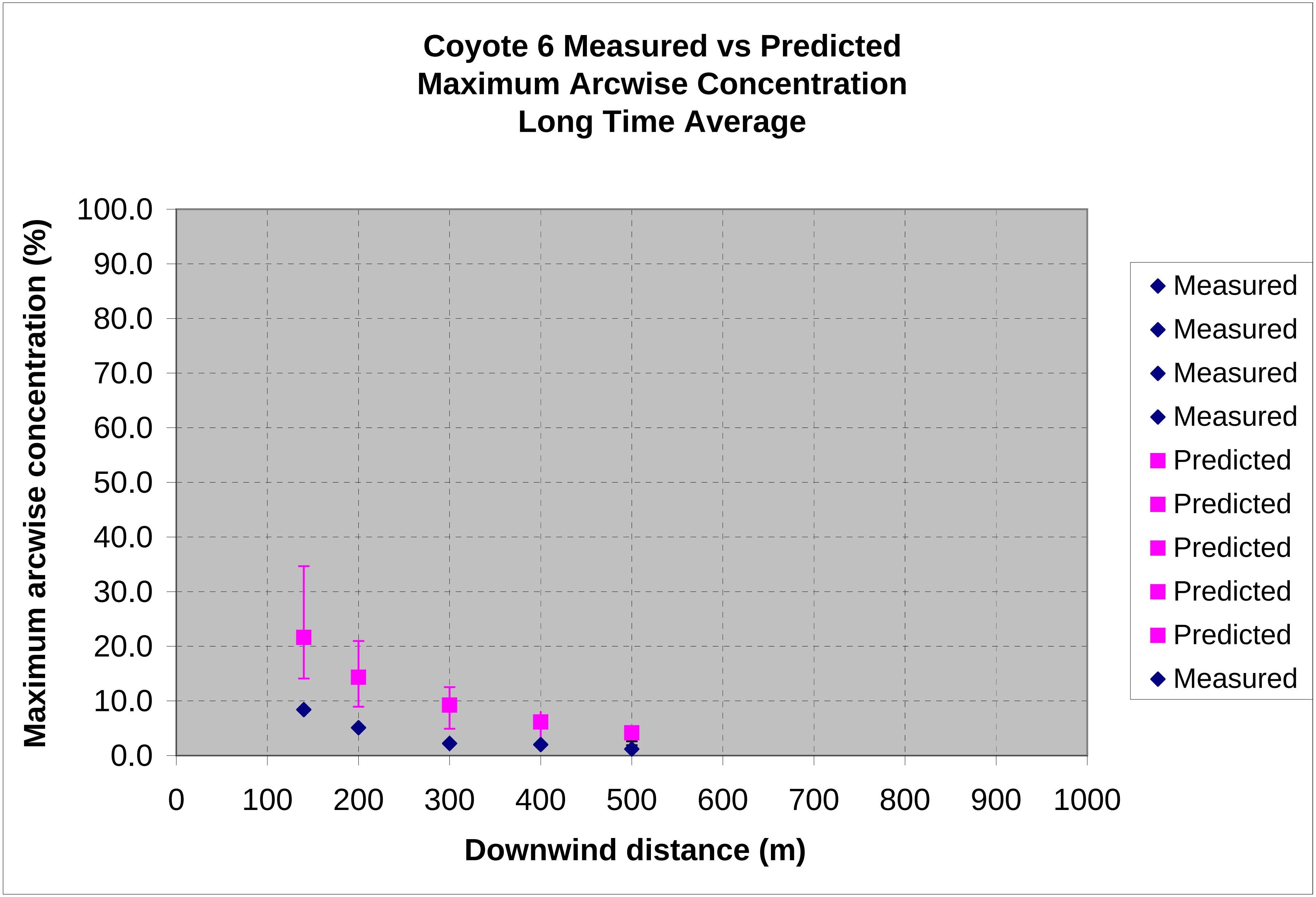
Coyote 5 Measured vs Predicted
Maximum Arcwise Concentration
Short Time Average
Maximum arcwise concentration (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
100
200
300
400
500
600
700
800
900
1000
Downwind distance (m)
Measured
Measured
Measured
Measured
Measured
Predicted
Predicted
Predicted
Predicted
Predicted


Coyote 5 Measured vs Predicted
Maximum Arcwise Concentration
Long Time Average
Maximum arcwise concentration (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
100
200
300
400
500
600
700
800
900
1000
Downwind distance (m)
Measured
Measured
Measured
Measured
Predicted
Predicted
Predicted
Predicted
Measured
Predicted

	Base Case	Source Term Alternative 1	Source Term Alternative 2	Averaging Time Alternative	Wind Speed Lower	Wind Speed Upper	Alternative	Surface Roughness Lower	Surface Roughness Upper	Monin-Obukhov Length Alternative	Stability Lower	Stability Upper	Ambient Temperature	Ambient Pressure	Ambient Relative Humidity	Ambient Surface Temperature	Water Transfer Submodel	Molecular Weight
Run Name	a	b	c	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_10	a_11	a_12	a_13	a_14	a_15
Source Term	ABS/FERC	0.167kg/m^2*se	0.085kg/m^2*se	ABS/FERC			ABS/FERC		ABS/FERC	ABS/FERC		ABS/FERC			ABS/FERC			ABS/FERC
Wind Speed	9.7	9.7	9.7	9.7			10.47		9.7	9.7		9.7			9.7			9.7
Reference Height	2	2	2	2			3		2	2		2			2			2
Surface Roughness	2.00E-04	2.00E-04	2.00E-04	2.00E-04			2.00E-04		1.00E-02	2.00E-04		2.00E-04			2.00E-04			2.00E-04
Wind Stability	C	C	C	C			C		C	C		D			C			C
Averaging Time	1	1	1	90			1		1	1		1			1			1
Atmospheric Parameters																		
DELTA Y	0.10461	0.10461	0.10461	0.14369			0.10461		0.10461	0.10461		0.06767			0.10461			0.10461
BETA Y	0.9	0.9	0.9	0.9			0.9		0.9	0.9		0.9			0.9			0.9
Monin-Obukhov Length	-9.26	-9.26	-9.26	-9.26			-9.26		-30.4	-26.5		infinite			-9.26			-9.26
Sigma X Coefficient	2.00E-02	2.00E-02	2.00E-02	2.00E-02			2.00E-02		2.00E-02	2.00E-02		4.00E-02			2.00E-02			2.00E-02
Sigma X Power	1.22E+00	1.22E+00	1.22E+00	1.22E+00			1.22E+00		1.22E+00	1.22E+00		1.14E+00			1.22E+00			1.22E+00
Sigma X Minimum Distance	1.30E+02	1.30E+02	1.30E+02	1.30E+02			1.30E+02		1.30E+02	1.30E+02		1.00E+02			1.30E+02			1.30E+02
Wind Power Constant	0.110	0.110	0.110	0.110			0.102		0.227	0.118		0.127			0.110			0.110
Friction Velocity	0.3882	0.3882	0.3882	0.3882			0.40639		0.66452	0.3775		0.3686			0.3882			0.3882
Ambient Temperature	301.49	301.49	301.49	301.49			301.49		301.49	301.49		301.49			301.49			301.49
Ambient Pressure	0.927	0.927	0.927	0.927			0.927		0.927	0.927		0.927			0.927			0.927
Ambient Relative Humidity	22.1	22.1	22.1	22.1			22.1		22.1	22.1		22.1			7.2			22.1
Isothermal?	N	N	N	N			N		N	N		N			N			N
Heat Transfer?	Y	Y	Y	Y			Y		Y	Y		Y			Y			Y
Surface Temperature	301.49	301.49	301.49	310.49			301.49		301.49	301.49		301.49			301.49			301.49
Correlation	1	1	1	1			1		1	1		1			1			1
Water Transfer?	N	N	N	N			N		N	N		N			N			N
Molecular Weight	20.19	20.19	20.19	20.19			20.19		20.19	20.19		20.19			20.19			16.04
Release Temperature	111.7	111.7	111.7	111.7			111.7		111.7	111.7		111.7			111.7			111.7
Density	1.6612	1.6612	1.6612	1.6612			1.6612		1.6612	1.6612		1.6612			1.6612			1.6612
Mean heat capacity constant	5.60E-08	5.60E-08	5.60E-08	5.60E-08			5.60E-08		5.60E-08	5.60E-08		5.60E-08			1.78E+03			5.60E-08
Mean heat capacity power	5.00E+00	5.00E+00	5.00E+00	5.00E+00			5.00E+00		5.00E+00	5.00E+00		5.00E+00						5.00E+00
Upper Concentration	8.00E-01	8.00E-01	8.00E-01	8.00E-01			8.00E-01		8.00E-01	8.00E-01		8.00E-01			8.00E-01			8.00E-01
Lower Concentration	5.00E-03	5.00E-03	5.00E-03	5.00E-03			5.00E-03		5.00E-03	5.00E-03		5.00E-03			5.00E-03			5.00E-03
Height for isopleths	1	1	1	1			1		1	1		1			1			1
Max Concentration at:																		
140m centerline	19.6%	19.7%	14.9%	19.5%			19.4%		10.0%	19.9%		20.8%			20.8%			25.2%
200m centerline	13.4%	12.5%	10.3%	12.7%			12.8%		6.8%	13.5%		13.8%			13.8%			16.9%
300m centerline	7.5%	7.3%	6.3%	5.3%			7.3%		3.8%	7.6%		7.7%			7.3%			9.3%
400m centerline	4.9%	4.7%	4.3%	2.5%			4.8%		2.3%	5.0%		5.1%			4.7%			5.9%
500m centerline	3.3%	3.0%	3.0%	1.5%			3.1%		1.4%	3.3%		3.8%			3.4%			4.3%
x=140, y=0, z=1	12.45%	12.5%	10.2%	12.4%			12.5%		8.2%	12.5%		13.0%			11.9%			14.2%
x=127, y=-58, z=1	0.00%	0.0%	0.0%	0.0%			0.0%		0.0%	0.0%		0.0%			0.0%			0.0%
x=137, y=-30, z=1	5.08%	4.9%	4.9%	5.0%			4.8%		2.8%	5.2%		5.5%			6.3%			7.7%
x=200, y=0, z=1	9.55%	8.9%	7.6%	8.9%			9.2%		5.7%	9.6%		9.8%			9.3%			11.3%
x=196.6, y=36.9, z=1	1.01%	0.8%	1.0%	1.2%			0.9%		0.4%	1.1%		0.7%			1.6%			2.1%
x=196.6, y=-36.9, z=1	3.81%	3.3%	3.5%	3.6%			3.5%		1.9%	3.9%		3.9%			4.8%			6.1%
x=296, y=-48.3, z=1	0.43%	0.4%	0.4%	0.6%			0.4%		0.1%	0.5%		0.2%			0.7%			1.0%
x=296, y=48.3, z=1	2.15%	1.9%	2.0%	1.9%			1.9%		0.9%	2.2%		2.1%			2.6%			3.7%
x=300, y=0, z=1	5.68%	5.5%	4.9%	4.2%			5.5%		3.1%	5.8%		6.1%			5.6%			7.0%
x=395.5, y=59.8, z=1	0.18%	0.2%	0.2%	0.3%			0.2%		0.1%	0.2%		0.1%			0.3%			0.5%
x=395.5, y=-59.8, z=1	1.23%	1.2%	1.2%	1.0%			1.2%		0.6%	1.3%		1.2%			1.5%			2.3%
x=400, y=0, z=1	3.71%	3.6%	3.4%	2.1%			3.6%		1.9%	3.8%		4.2%			3.7%			4.7%
x=495, y=71.2, z=1	0.10%	0.1%	0.1%	0.2%			0.1%		0.0%	0.1%		0.0%			0.2%			0.3%
x=495, y=-71.2, z=1	0.85%	0.8%	0.8%	0.6%			0.8%		0.3%	0.9%		0.7%			1.0%			1.6%
Distance to:																		
11.5%	222	213	181	212			218		124	224		225			223			259
8.1%	283	277	245	252			280		172	287		290			279			335
4.1%	451	431	413	338			430		289	456		475			468			513
2.3%	572	562	568	415			563		398	577		700			615			721
1.9%	634	611	624	444			606		433	641		789			668			808
LFL	396	387	358	310			392		253	400		408			387			457

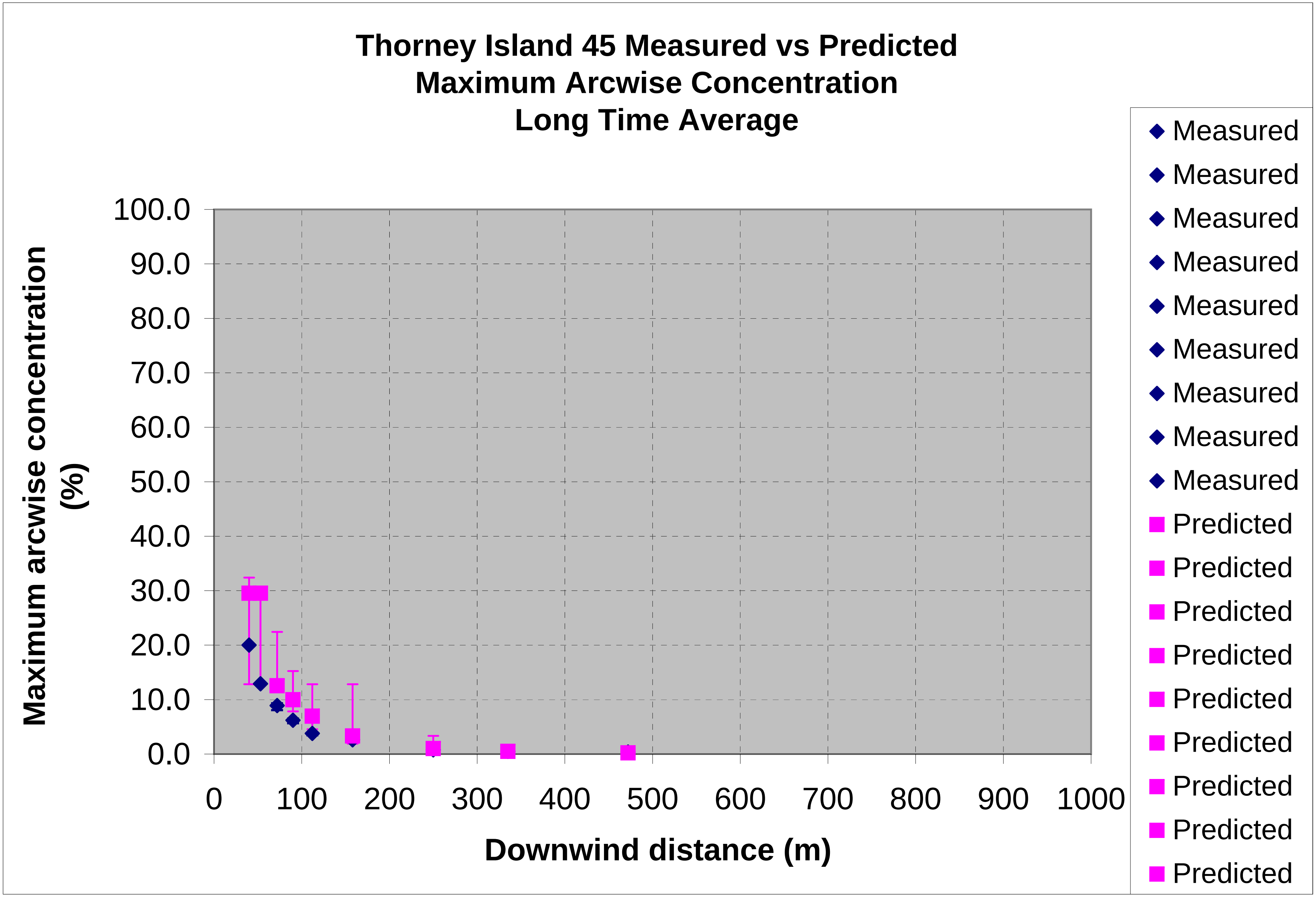


Coyote 6 Measured vs Predicted
Maximum Arcwise Concentration
Short Time Average
Maximum arcwise concentration (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
100
200
300
400
500
600
700
800
900
1000
Downwind distance (m)
Measured
Measured
Measured
Measured
Measured
Predicted
Predicted
Predicted
Predicted
Predicted



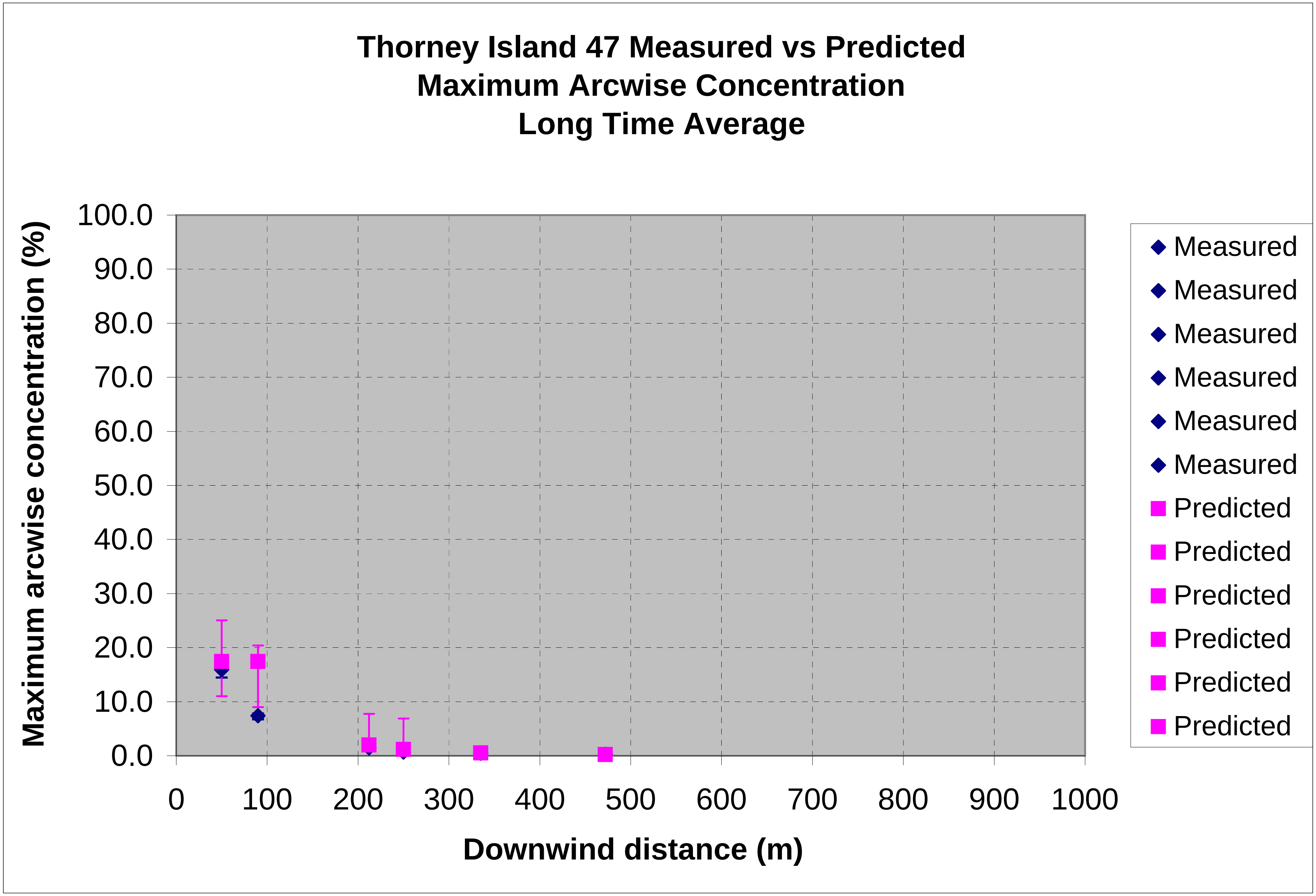
Coyote 6 Measured vs Predicted
Maximum Arcwise Concentration
Long Time Average
Maximum arcwise concentration (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
100
200
300
400
500
600
700
800
900
1000
Downwind distance (m)
Measured
Measured
Measured
Measured
Predicted
Predicted
Predicted
Predicted
Predicted
Measured

		Source Term		Averaging Time		Wind Speed		Surface Roughness		Monin-Obukhov Length	Stability		Ambient Temperature	Ambient Pressure	Ambient Relative Humidity	Ambient Surface Temperature	Water Transfer Submodel	Molecular Weight
	Base Case	Alternative 1	Alternative 2	Alternative	Lower	Upper	Alternative	Lower	Upper	Alternative	Lower	Upper						
Run Name	a	b	c	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_10	a_11	a_12	a_13	a_14	a_15
Source Term	ABS/FERC	0.167kg/m^2*sec	0.085kg/m^2*sec	ABS/FERC			ABS/FERC		ABS/FERC	ABS/FERC		ABS/FERC			ABS/FERC			ABS/FERC
Wind Speed	4.6	4.6	4.6	4.6			5.04		4.6	4.6		4.6			4.6			4.6
Reference Height	2	2	2	2			3		2	2		2			2			2
Surface Roughness	2.00E-04	2.00E-04	2.00E-04	2.00E-04			2.00E-04		1.00E-02	2.00E-04		2.00E-04			2.00E-04			2.00E-04
Wind Stability	D	D	D	D			D		D	D		E			D			D
Averaging Time	1	1	1	70			1		1	1		1			1			1
Atmospheric Parameters																		
DELTA Y	0.06767	0.06767	0.06767	0.0885			0.06767		0.06767	0.06767		0.04617			0.06767			0.06767
BETA Y	0.9	0.9	0.9	0.9			0.9		0.9	0.9		0.9			0.9			0.9
Monin-Obukhov Length	infinite	infinite	infinite	infinite			infinite		infinite	73.5		9.26			infinite			infinite
Sigma X Coefficient	4.00E-02	4.00E-02	4.00E-02	4.00E-02			4.00E-02		4.00E-02	4.00E-02		1.70E-01			4.00E-02			4.00E-02
Sigma X Power	1.14E+00	1.14E+00	1.14E+00	1.14E+00			1.14E+00		1.14E+00	1.14E+00		9.70E-01			1.14E+00			1.14E+00
Sigma X Minimum Distance	1.00E+02	1.00E+02	1.00E+02	1.00E+02			1.00E+02		1.00E+02	1.00E+02		5.00E+01			1.00E+02			1.00E+02
Wind Power Constant	0.127	0.127	0.127	0.127			0.122		0.240	0.132		0.168			0.127			0.127
Friction Velocity	0.1748	0.1748	0.1748	0.1748			0.18345		0.30358	0.17241		0.15746			0.1748			0.1748
Ambient Temperature	297.26	297.26	297.26	297.26			297.26		297.26	297.26		297.26			297.26			297.26
Ambient Pressure	0.93	0.93	0.93	0.93			0.93		0.93	0.93		0.93			0.93			0.93
Ambient Relative Humidity	22.8	22.8	22.8	22.8			22.8		22.8	22.8		22.8			4.5			22.8
Isothermal?	N	N	N	N			N		N	N		N			N			N
Heat Transfer?	Y	Y	Y	Y			Y		Y	Y		Y			Y			Y
Surface Temperature	297.26	297.26	297.26	297.26			297.26		297.26	297.26		297.26			297.26			297.26
Correlation	1	1	1	1			1		1	1		1			1			1
Water Transfer?	N	N	N	N			N		N	N		N			N			N
Molecular Weight	19.09	19.09	19.09	19.09			19.09		19.09	19.09		19.09			19.09			16.04
Release Temperature	111.7	111.7	111.7	111.7			111.7		111.7	111.7		111.7			111.7			111.7
Density	1.6666	1.6666	1.6666	1.6666			1.6666		1.6666	1.6666		1.6666			1.6666			1.6666
Mean heat capacity constant	5.60E-08	5.60E-08	5.60E-08	5.60E-08			5.60E-08		5.60E-08	5.60E-08		5.60E-08			5.60E-08			5.60E-08
Mean heat capacity power	5.00E+00	5.00E+00	5.00E+00	5.00E+00			5.00E+00		5.00E+00	5.00E+00		5.00E+00			5.00E+00			5.00E+00
Upper Concentration	8.00E-01	8.00E-01	8.00E-01	8.00E-01			8.00E-01		8.00E-01	8.00E-01		8.00E-01			8.00E-01			8.00E-01
Lower Concentration	5.00E-03	5.00E-03	5.00E-03	5.00E-03			5.00E-03		5.00E-03	5.00E-03		5.00E-03			5.00E-03			5.00E-03
Height for isopleths	1	1	1	1			1		1	1		1			1			1
Max Concentration at:																		
140m centerline	21.6%	23.0%	24.8%	21.6%			22.6%		14.1%	21.7%		21.1%			29.4%			34.7%
200m centerline	14.3%	14.7%	15.2%	14.3%			14.7%		8.9%	14.4%		14.2%			16.7%			21.0%
300m centerline	9.2%	9.1%	9.1%	9.2%			9.3%		4.9%	9.3%		9.1%			8.1%			12.5%
400m centerline	6.1%	6.8%	6.0%	6.1%			6.3%		3.3%	6.2%		6.4%			4.8%			8.0%
500m centerline	4.3%	4.3%	4.2%	4.2%			4.4%		2.3%	4.3%		4.6%			3.3%			5.6%
600m centerline	3.1%	3.2%	3.1%	2.8%			3.2%		1.6%	3.2%		3.4%			2.5%			4.2%
x=140, y=0, z=1	15.7%	15.8%	15.9%	15.5%			16.0%		11.6%	15.8%		15.5%			17.2%			19.1%
x=127, y=-58, z=1	0.0%	0.0%	0.0%	0.0%			0.0%		0.0%	0.0%		0.0%			0.0%			0.0%
x=137, y=-30, z=1	2.9%	4.6%	5.8%	3.4%			2.7%		1.4%	2.9%		2.5%			5.9%			8.2%
x=200, y=0, z=1	1.4%	2.6%	3.4%	1.9%			1.3%		0.6%	1.5%		1.0%			3.4%			5.0%
x=196.6, y=36.9, z=1	1.8%	2.7%	3.3%	2.2%			1.7%		0.7%	1.9%		1.5%			3.4%			5.8%
x=196.6, y=-36.9, z=1	11.2%	11.2%	11.2%	11.2%			11.4%		7.9%	11.3%		11.1%			12.2%			14.2%
x=296, y=-48.3, z=1	0.3%	0.6%	0.8%	0.6%			0.3%		0.1%	0.4%		0.2%			0.9%			1.8%
x=296, y=48.3, z=1	10.2%	10.8%	11.1%	9.7%			10.2%		6.1%	10.3%		11.0%			12.0%			14.3%
x=300, y=0, z=1	5.1%	5.5%	5.9%	4.9%			5.1%		1.7%	5.2%		5.4%			4.5%			9.1%
x=395.5, y=59.8, z=1	7.8%	7.5%	7.4%	7.8%			7.8%		4.4%	7.8%		7.6%			7.0%			9.6%
x=395.5, y=-59.8, z=1	5.5%	5.4%	5.2%	5.4%			5.5%		2.9%	5.5%		5.6%			4.4%			6.6%
x=400, y=0, z=1	2.0%	2.5%	2.8%	2.1%			2.1%		0.5%	2.1%		2.2%			1.5%			5.3%
x=495, y=71.2, z=1	3.9%	3.9%	3.8%	3.7%			3.9%		2.0%	3.9%		4.1%			3.1%			4.8%
Distance to:																		
12.7%	229	227	232	229			234		154	231		228			237			297
8.5%	319	315	314	319			323		206	321		323			291			388
4.2%	504	506	502	498			510		337	509		527			432			597
3.3%	583	587	578	562			590		401	589		612			504			696
1.4%	883	911	924	799			881		631	891		1014			803			1072
LFL	457	455	451	455			459		292	462		467			393			539

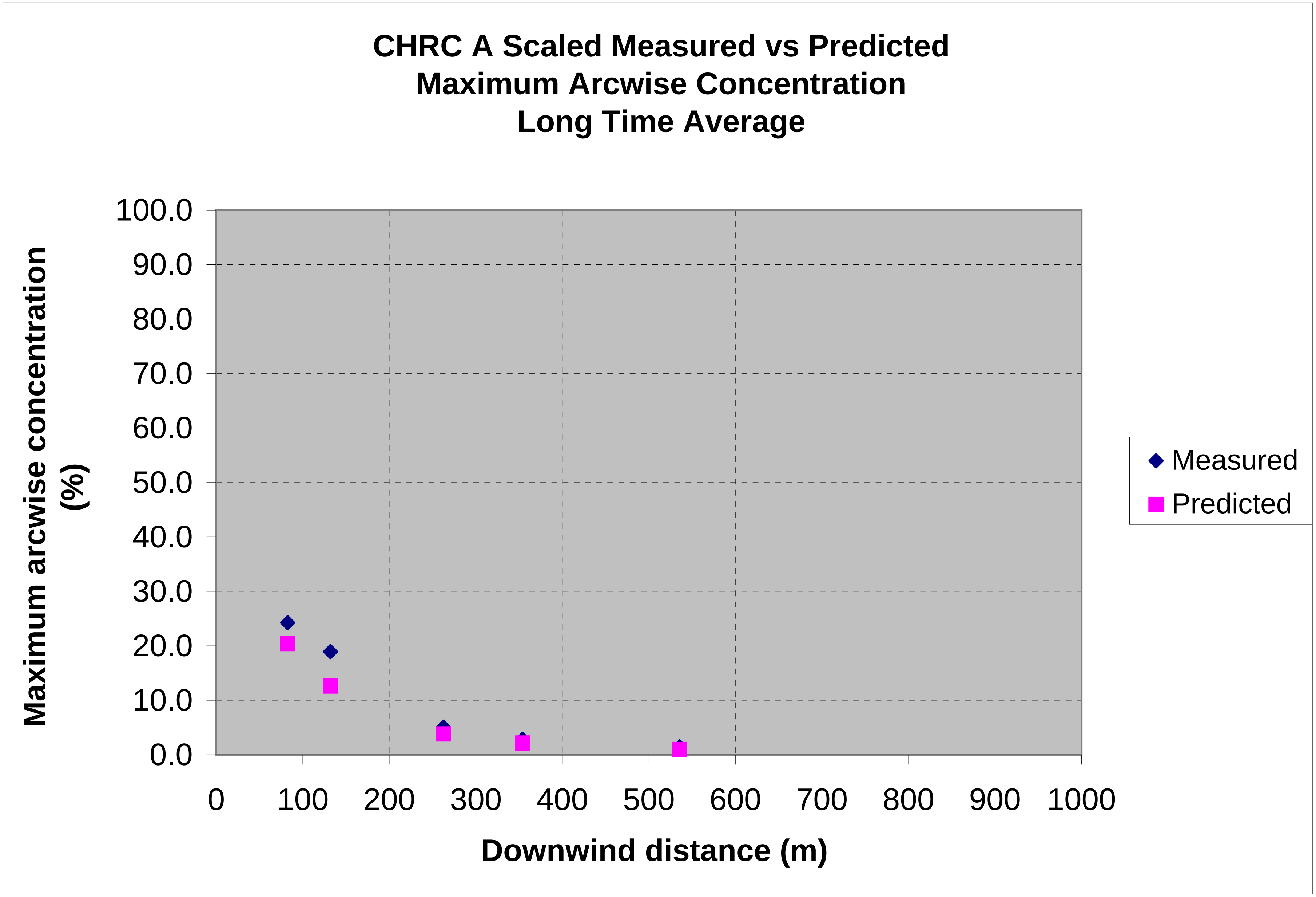


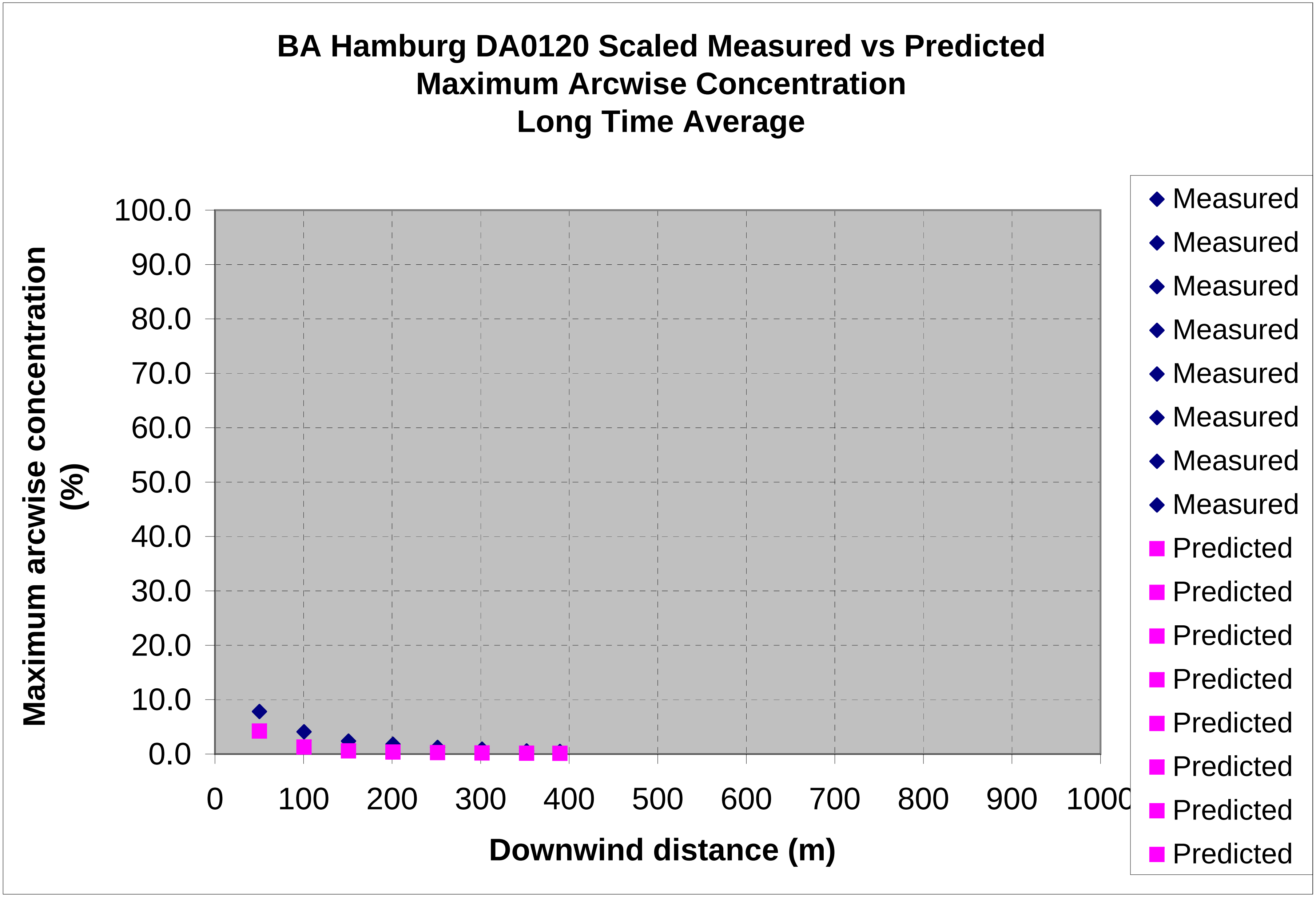
Thorney Island 45 Measured vs Predicted
Maximum Arcwise Concentration
Long Time Average
Maximum arcwise concentration (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
100
200
300
400
500
600
700
800
900
1000
Downwind distance (m)
Measured
Measured
Measured
Measured
Measured
Measured
Measured
Measured
Measured
Predicted
Predicted
Predicted
Predicted
Predicted
Predicted
Predicted
Predicted
Predicted

	Base Case	Source Term Alternative 1	Averaging Time Alternative	Wind Speed Lower	Upper	Alternative	Surface Roughness Lower	Upper	Monin-Obukhov Length Alternative	Stability Lower	Upper	Ambient Temperature	Ambient Pressure	Ambient Relative Humidity	Ambient Surface Temperature	Water Transfer Submodel	Molecular Weight
Run Name	a	b	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_10	a_11	a_12	a_13	a_14	a_15
Source Term	ı diamter, 10.67k	steady state					2m diamter, 10.67k	diamter, 10.67k	diamter, 10.67k	diamter, 10.67kg/s							
Wind Speed	2.3	2.3					2.3	2.3	2.3	2.3							
Reference Height	10	10					10	10	10	10							
Surface Roughness	1.00E-02	1.00E-02					2.00E-05	3.00E-02	1.00E-02	1.00E-02							
Wind Stability	F	F					F	F	F	E							
Averaging Time	30	30					30	30	30	30							
Atmospheric Parameters																	
DELTA Y	0.03702	0.03702					0.03702	0.03702	0.03702	0.05603							
BETA Y	0.9	0.9					0.9	0.9	0.9	0.9							
Monin-Obukhov Length	11.8	11.8					4.08	14.3	13.3	30.4							
Sigma X Coefficient	1.70E-01						1.70E-01	1.70E-01	1.70E-01	1.70E-01							
Sigma X Power	9.70E-01						9.70E-01	9.70E-01	9.70E-01	9.70E-01							
Sigma X Minimum Distance	5.00E+01						5.00E+01	5.00E+01	5.00E+01	5.00E+01							
Wind Power Constant	0.349	0.349					0.318	0.386	0.334	0.257							
Friction Velocity	0.07396	0.07396					0.03268	0.08839	0.07709	0.09523							
Ambient Temperature	286.25	286.25					286.25	286.25	286.25	286.25							
Ambient Pressure	1	1					1	1	1	1							
Ambient Relative Humidity	100	100					100	100	100	100							
Isothermal?	N	N					N	N	N	N							
Heat Transfer?	Y	Y					Y	Y	Y	Y							
Surface Temperature	286.25	285.95					285.95	285.95	285.95	285.95							
Correlation	1	1					1	1	1	1							
Water Transfer?	N	N					N	N	N	N							
Molecular Weight	57.8	58.7					57.8	57.8	57.8	57.8							
Release Temperature	286.25	286.25					286.25	286.25	286.25	286.25							
Density	2.477	2.477					2.477	2.477	2.477	2.477							
Mean heat capacity constant	586.68	577.28					586.27	586.27	586.27	586.27							
Mean heat capacity power																	
Upper Concentration	2.50E-01	2.50E-01					2.50E-01	2.50E-01	2.50E-01	2.50E-01							
Lower Concentration	1.00E-04	1.00E-04					1.00E-04	1.00E-04	1.00E-04	1.00E-04							
Height for isopleths	0.5	0.5					0.5	0.5	0.5	0.5							
Max Concentration at:																	
40m centerline	29.5%	28.2%					12.8%	32.4%	30.0%	26.7%							
53m centerline	29.5%	28.2%					12.8%	16.0%	28.9%	20.4%							
72m centerline	12.5%	22.4%					12.8%	11.5%	12.9%	12.4%							
90m centerline	10.0%	15.2%					12.8%	7.9%	9.9%	7.8%							
112m centerline	7.0%	8.8%					12.8%	4.6%	6.7%	4.9%							
158m centerline	3.3%	3.3%					12.8%	1.9%	3.1%	2.1%							
250m centerline	1.0%	0.9%					3.3%	0.6%	1.0%	0.7%							
335m centerline	0.5%	0.5%					1.7%	0.3%	0.5%	0.4%							
472m centerline	0.2%	0.2%					0.8%	0.1%	0.2%	0.2%							
Distance to:																	
20.0%	21	78					11	37	33	54							
12.9%	69	96					33	66	72	71							
8.9%	97	112					199	86	97	85							
6.2%	119	128					199	99	117	101							
3.8%	150	153						120	145	124							
2.6%	173	173					283	141	169	144							
0.8%	282	272					484	224	275	239							
0.5%	331	321					579	264	327	288							
0.4%	384	371					663	304	375	335							

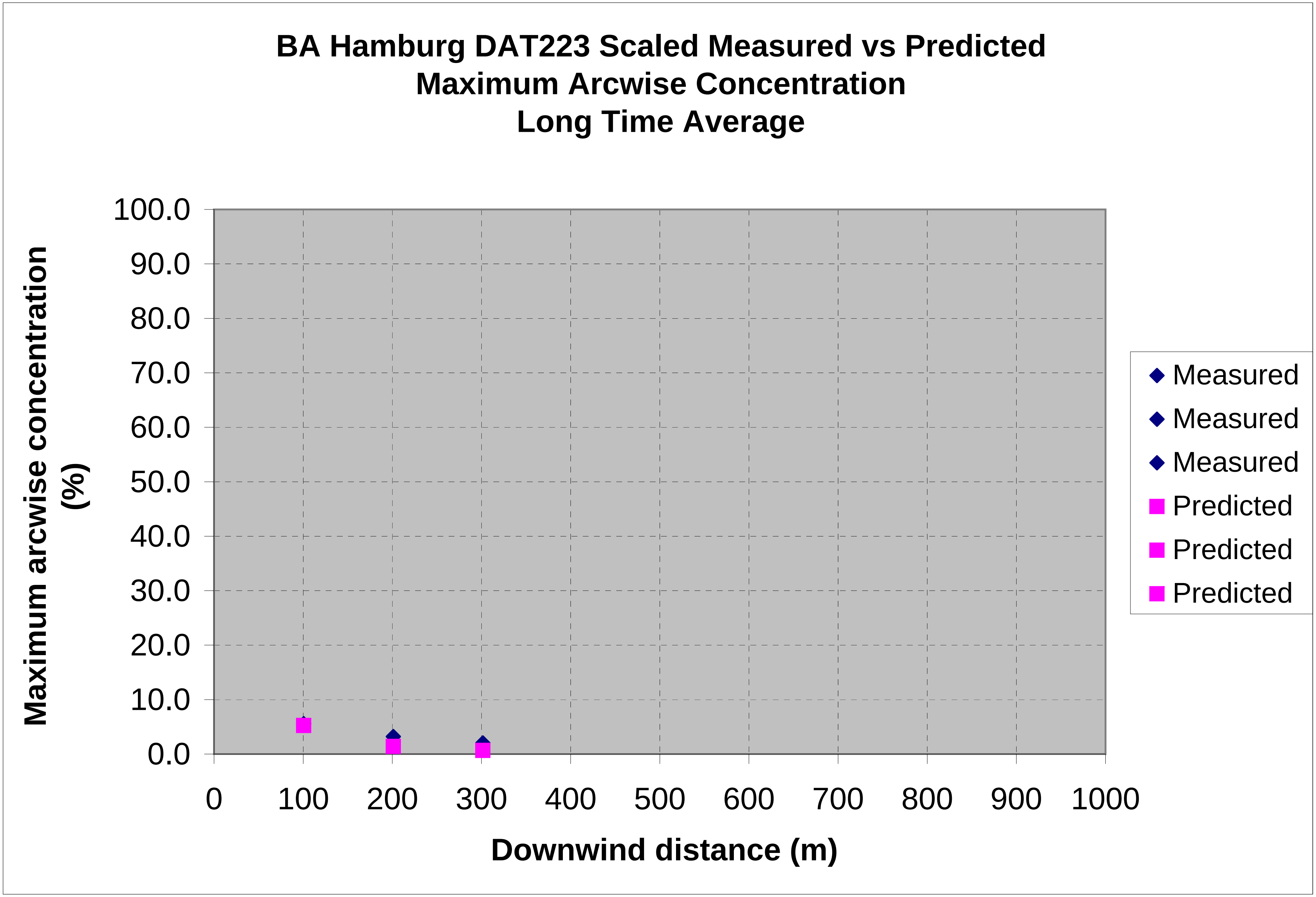

Thorney Island 47 Measured vs Predicted
Maximum Arcwise Concentration
Long Time Average
Maximum arcwise concentration (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
100
200
300
400
500
600
700
800
900
1000
Downwind distance (m)
Measured
Measured
Measured
Measured
Measured
Measured
Predicted
Predicted
Predicted
Predicted
Predicted
Predicted

									Monin-Obukhov			Ambient	Ambient	Ambient	Ambient	Water Transfer	Molecular
		Source Term	Averaging Time		Wind Speed		Surface Roughness		Length	Stability		Temperature	Pressure	Relative	Surface	Submodel	Weight
	Base Case	Alternative 1	Alternative	Lower	Upper	Alternative	Lower	Upper	Alternative	Lower	Upper						
Run Name	a	b	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_10	a_11	a_12	a_13	a_14	a_15
Source Term	2m diamter, 10.:	steady state, 2m diamter, 10.22kg/s					2m diamter, 10.:	2m diamter, 10.:	2m diamter, 10.:	2m diamter, 10.22kg/s							
Wind Speed	1.50	1.50					1.50	1.50	1.50	1.50							
Reference Height	10.00	10.00					10.00	10.00	10.00	10.00							
Surface Roughness	1.00E-02	1.00E-02					2.00E-05	3.00E-02	1.00E-02	1.00E-02							
Wind Stability	F	F					F	F	F	E							
Averaging Time	30.00	30.00					30.00	30.00	30.00	30.00							
Atmospheric Parameters																	
DELTA Y	0.04	0.04					0.04	0.04	0.04	0.06							
BETA Y	0.90	0.90					0.90	0.90	0.90	0.90							
Monin-Obukhov Length	11.80	11.80					4.08	14.30	**10.00**	30.40							
Sigma X Coefficient	1.70E-01						1.70E-01	1.70E-01	1.70E-01	1.70E-01							
Sigma X Power	9.70E-01						9.70E-01	9.70E-01	9.70E-01	9.70E-01							
Sigma X Minimum Distance	5.00E+01						5.00E+01	5.00E+01	5.00E+01	5.00E+01							
Wind Power Constant	0.349	0.349					0.318	0.386	0.372	0.257							
Friction Velocity	0.05	0.05					0.02	0.06	0.05	0.06							
Ambient Temperature	287.45	287.45					287.45	287.45	287.45	287.45							
Ambient Pressure	1.00	1.00					1.00	1.00	1.00	1.00							
Ambient Relative Humidity	97.40	97.40					97.40	97.40	97.40	97.40							
Isothermal?	N	N					N	N	N	N							
Heat Transfer?	Y	Y					Y	Y	Y	Y							
Surface Temperature	287.65	287.65					287.65	287.65	287.65	287.65							
Correlation	1.00	1.00					1.00	1.00	1.00	1.00							
Water Transfer?	N	N					N	N	N	N							
Molecular Weight	57.80	57.80					57.80	57.80	57.80	57.80							
Release Temperature	287.45	286.45					287.45	287.45	287.45	287.45							
Density	2.48	2.51					2.51	2.51	2.51	2.51							
Mean heat capacity constant	586.68	586.68					586.27	586.27	586.27	586.27							
Mean heat capacity power																	
Upper Concentration	20.00%	20.00%					20.00%	20.00%	20.00%	20.00%							
Lower Concentration	0.20%	0.10%					0.10%	0.10%	0.10%	0.10%							
Height for isopleths	0.50	0.50					0.50	0.50	0.50	0.50							
Max Concentration at:																	
50m centerline	17.4%	17.0%					11.0%	20.4%	15.6%	25.1%							
90m centerline	17.4%	17.0%					9.2%	20.4%	15.6%	9.0%							
212m centerline	2.0%	6.8%					7.7%	1.3%	1.9%	2.1%							
250m centerline	1.2%	4.0%					6.9%	0.8%	1.2%	1.2%							
335m centerline	0.5%	1.4%					0.6%	0.3%	0.5%	0.7%							
472m centerline	0.2%	0.5%					0.5%	0.1%	0.2%	0.3%							
Distance to:																	
15.9%	136	145					19	21	20	82							
7.4%	139	236					236	113	158	114							
1.5%	237	333					271	196	217	249							
0.7%	312	441					441	258	294	335							
0.5%	349	500					500	301	344	379							
0.2%	456	679					679	384	439	499							

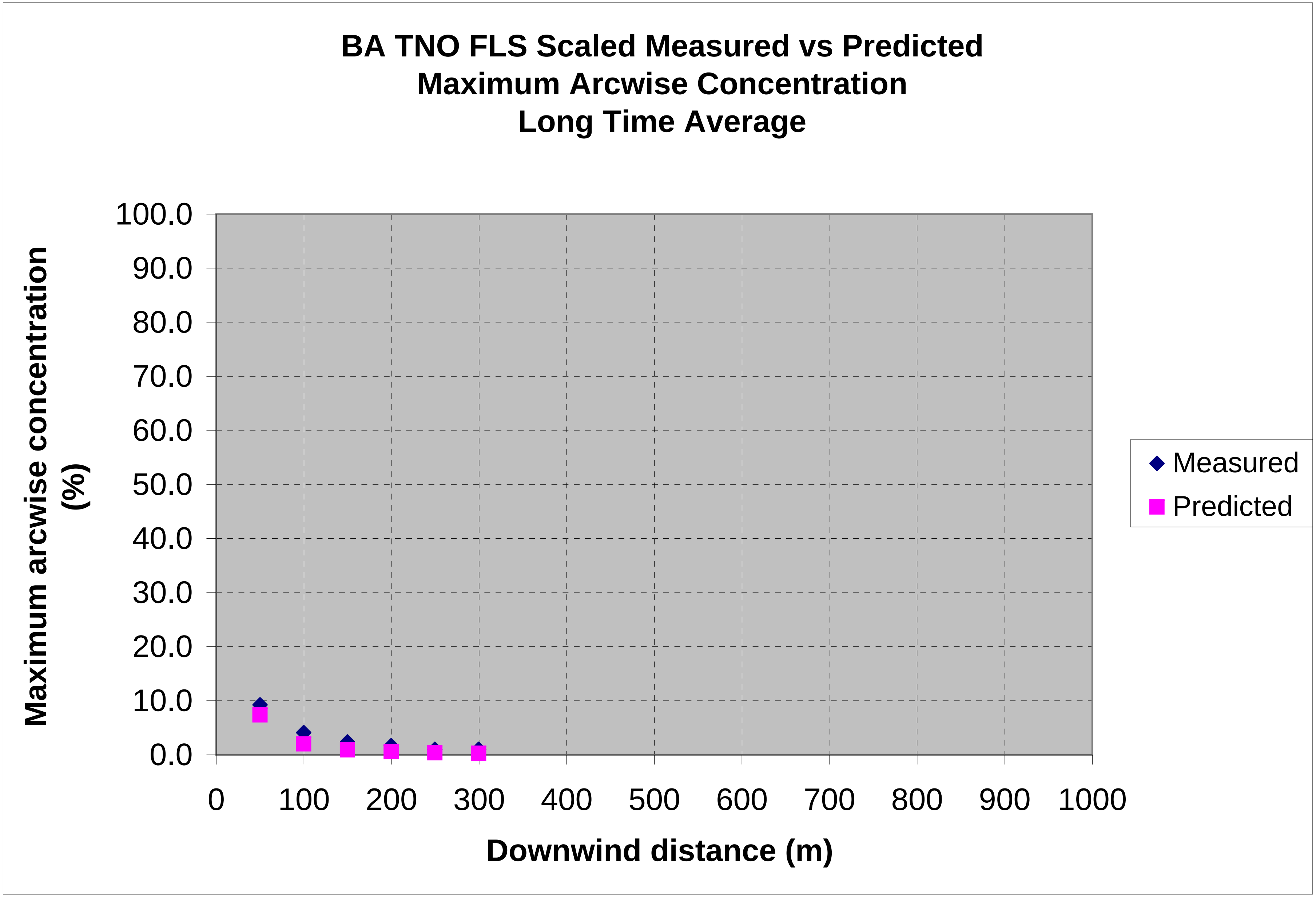

CHRC A Scaled Measured vs Predicted
Maximum Arcwise Concentration
Long Time Average
Maximum arcwise concentration (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
100
200
300
400
500
600
700
800
900
1000
Downwind distance (m)
Measured
Predicted



BA Hamburg DA0120 Scaled Measured vs Predicted
Maximum Arcwise Concentration
Long Time Average
Maximum arcwise concentration (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
100
200
300
400
500
600
700
800
900
1000
Downwind distance (m)
Measured
Measured
Measured
Measured
Measured
Measured
Measured
Measured
Predicted
Predicted
Predicted
Predicted
Predicted
Predicted
Predicted
Predicted



BA Hamburg DAT223 Scaled Measured vs Predicted
Maximum Arcwise Concentration
Long Time Average
Maximum arcwise concentration (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
100
200
300
400
500
600
700
800
900
1000
Downwind distance (m)
Measured
Measured
Measured
Predicted
Predicted
Predicted


BA TNO FLS Scaled Measured vs Predicted
Maximum Arcwise Concentration
Long Time Average
Maximum arcwise concentration (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
100
200
300
400
500
600
700
800
900
1000
Downwind distance (m)
Measured
Predicted

APPENDIX B: REFERENCES

REFERENCES

AcuTech Consulting Group (2009). Final Report: Review of the LNG Vapor Dispersion Model Evaluation Protocol. The National Association of State Fire Marshals.

Blackmore, D.R., Eyre, J.A., Summers, G.G. (1982), Dispersion and Combustion Behaviour of Gas Clouds Resulting from Large Spillages of LNG and LPG on the Sea. Transactions of the Institute of Marine Engineers, Volume 94, Paper 92, 1982. Institute of Marine Engineers.

Blackmore, D.R., Colenbrander, G.W., Puttock, J.S., (1984). Maplin Sands Experiments 1980: Dispersion of Refrigerated Liquid Propane and LNG, NATO Challendges of Modern Society—Air Pollution Modelling and Its Application 3, Volume 5, Pages 353-373, Plenum, New York, USA.

Brutstaert, W. (1982). Evaporation into the Atmosphere: Theory, History, and Applications. Kluwer Academic Publishers, Netherlands.

Coldrick, S., Lea, C.J., Ivings, M.J. (2010). Validation Database for Evaluating Vapor Dispersion Models for Safety Analysis of LNG Facilities, Version 11.0. The Fire Protection Research Foundation, Quincy, Massachusetts.

Colenbrander, G.W., (1980). A Mathematical Model for the Transient Behavior of Dense Vapor Clouds, 3rd International Symposium on Loss Prevention and Safety Promotion in the Process Industries, Basel, Switzerland, 1980.

Colenbrander, G.W., Evans, A., Puttock, J.S. (1983). Dense Gas Dispersion Behavior: Experimental Observations and Model Developments. International Symposium on Loss Prevention and Safety Promotion in the Process Industries, Harrogate, England, September 1983.

Colenbrander, G.W., Evans, A., Puttock, J.S. (1984a). Spill Tests of LNG and Refrigerated Liquid Propane on the Sea, Maplin Sands, 1980: Dispersion Data Digest; Trial 27. Shell Research Limited, TNER.84.028.

Colenbrander, G.W., Evans, A., Puttock, J.S. (1984b). Spill Tests of LNG and Refrigerated Liquid Propane on the Sea, Maplin Sands, 1980: Dispersion Data Digest; Trial 34. Shell Research Limited, TNER.84.030.

Colenbrander, G.W., Evans, A., Puttock, J.S. (1984c). Spill Tests of LNG and Refrigerated Liquid Propane on the Sea, Maplin Sands, 1980: Dispersion Data Digest; Trial 35. Shell Research Limited, TNER.84.031.

Eyre, J.A., Hirst, W.J.S. (1983), Maplin Sands Experiments 1980: Combustion of Large LNG and Refrigerated Liquid Propane Spills on the Sea. Proceedings, 2nd Symposium on Heavy Gas and Risk Assessment II, West Germany, May 25-26, 1983, D Reidel Publishing Company, Netherlands.

Ermak, D.L, Chapman, R., Goldwire, H.C., Gouveia, F.J., Rodean, H.C. (1989). Heavy Gas Dispersion Test Summary Report. Lawrence Livermore National Laboratory.

Federal Energy Regulatory Commission (FERC) (2004a). Consequence Assessment Methods for Incidents Involving Releases from Liquefied Natural Gas Carriers. Docket No. AD04-6-000.

Federal Energy Regulatory Commission (FERC) (2004b). Staff's Responses to Comments on the Consequence Assessment Methods for Incidents Involving Releases from Liquefied Natural Gas Carriers. Docket No. AD04-6-000.

Havens, J., (1982),Dispersion of Dense Vapors, Volume 2, MIT-GRI LNG Safety and Research Workshop. GRI 82/0019.2, Gas Research Institute (GRI).

Havens, J., Spicer, T.O., (1985), Development of an Atmospheric Dispersion Model for Heavier-Than-Air Gas Mixtures, Volume 1, Final Report Contract DT-CG-23-80-C-20029, United States Coast Guard, Washington, D.C.

Havens, J., (1988), A Dispersion Model for Elevated Dense Gas Jet Chemical Releases, Volume 1, EPA 450/4-88-006a, Environmental Protection Agency.

Havens, J., Spicer, T. (1990). LNG Vapor Dispersion Prediction with the DEGADIS Dense Gas Dispersion Model. Report GRI 89/0242, Gas Research Institute (GRI), 1990.

Gavelli, F., Davis, S.G., Hansen, O.H., (2011), User Beware: When Simple Consequence Models Can Give the Wrong Answers, Proceedings of AIChE Spring Meeting, 7th Global Congress on Process Safety, Chicago, IL, March 16, 2011.

Goldwire, H.C., Rodean, H.C., Cederwall, R.T., Kansa, E.J., Koopman, R.P., McClure, J.W., McRae, T.G., Morris, L.K., Kamppinen, L., Kiefer, R.D., Urtiew, P.A., Lind, C.D. (1983a). Coyote Series Data Report LLNL/NWC 1981 LNG Spill Tests, Dispersion, Vapor Burn, and Rapid Phase Transition. Lawrence Livermore National Laboratory, UCID-19953, Volume 1.

Goldwire, H.C., Rodean, H.C., Cederwall, R.T., Kansa, E.J., Koopman, R.P., McClure, J.W., McRae, T.G., Morris, L.K., Kamppinen, L., Kiefer, R.D., Urtiew, P.A., Lind, C.D. (1983b). Coyote Series Data Report LLNL/NWC 1981 LNG Spill Tests, Dispersion, Vapor Burn, and Rapid Phase Transition. Lawrence Livermore National Laboratory, UCID-19953, Volume 2.

Hanna, S.R., Strimaitis, D.G., Chang, J.C. (1993). Final Report: Hazard Response Modeling Uncertainty (A Quantitative Method), Vol II - Evaluation of Commonly Used Hazardous Gas Dispersion Models. Air Force Engineering & Services Center, Environics Division, AD-A270-095, ESL-TR-91-28.

REFERENCES (cont'd)

Ivings, M.J., Jagger, S.F., Lea, C.J., Webber, D.M. (2007). Evaluating Vapor Dispersion Models for Safety Analysis of LNG Facilities. The Fire Protection Research Foundation, Quincy, Massachusetts.

Johnson, D.R. (1985), Thorney Island: Its Geography and Meteorology, Heavy Gas Dispersion Trials at Thorney Island, Proceedings of a Symposium held at University of Sheffield, Great Britain, April 3-5, 1984, Elsevier, 1985.

Kantha, H.L., Phillips, O.M., Azad, R.S. (1977), On Turbulent Entrainment at a Stable Density Interface. Journal of Fluid Mechanics, Vol. 79, pp 753-768.

Koopman, R.P, Cederwall, R.T., Ermak, D.L., Goldwire, H.C., McClure, J.W., McRae, T.G., Morgan, D.L., Rodean, H.C., Shinn, J.H. (1981). Description and Analysis of Burro Series 40-m3 LNG Spill Experiments. Lawrence Livermore National Laboratory, UCRL-53186.

Koopman, R.P, Baker, J., Cederwall, R.T., Goldwire, H.C., Hogan, W.J., Kamppinen, L.M., Kiefer, R.D., McClure, J.W., McRae, T.G., Morgan, D.L., Morris, L.K., Spann, M.W., Lind, C.D. (1982a). Burro Series Data Report LLNL/NWC 1980 LNG Spill Tests. Lawrence Livermore National Laboratory, UCID-19075, Volume 1.

Koopman, R.P, Baker, J., Cederwall, R.T., Goldwire, H.C., Hogan, W.J., Kamppinen, L.M., Kiefer, R.D., McClure, J.W., McRae, T.G., Morgan, D.L., Morris, L.K., Spann, M.W., Lind, C.D. (1982b). Burro Series Data Report LLNL/NWC 1980 LNG Spill Tests, The Appendices. Lawrence Livermore National Laboratory, UCID-19075, Volume 2.

Koopman, R.P, Cederwall, R.T., Ermak, D.L., Goldwire, H.C., Hogan, W.J., McClure, J.W., McRae, T.G., Morgan, D.L., Rodean, H.C., Shinn, J.H. (1982c). Analysis of Burro Series 40-m3 LNG Spill Experiments. Journal of Hazardous Materials, Vol 6.

Leck, M.J., Lowe, D.J., (1985). Development and Performance of the Gas Sensor System, Hevay Gas Dispersion Trials at Thorney Island, Proceedings of a Symposium held at University of Sheffield, Great Britain, April 3-5, 1984, Elsevier, 1985.

Lofquist, K. (1960), Flow and Stress Near an Interface Between Stratified Liquids. Physics of Fluids, Vol 3. No. 2. March-April 1960.

McQuaid, J. (1976), Some Experiments on the Sztructure of Stably Stratified Shear Flows, Technical Paper P21, Safety in Mine Research Establishment, Sheffield, UK, 1976.

Melton, T.A., Cornwell, J.B. (2009). LNG Trench Dispersion Modeling Using Computational Fluid Dynamics. 12th Annual Symposium, Mary Kay O'Connor Process Safety Center.

Nussey, C., Davies, J.K.W., Mercer, A.,(1985). The Effect of Averaging Time on the Statistical Properties of Sensor Records, Hevay Gas Dispersion Trials at Thorney Island, Proceedings of a Symposium held at University of Sheffield, Great Britain, April 3-5, 1984, Elsevier, 1985.

Pielke, R.A., (2002). Mesoscale Meteorological Modeling, 2nd Edition, Academic Press, New York, 2002.

Pipeline and Hazardous Materials Safety Administration, U.S. Department of Transportation (PHMSA) (2010). Advisory Bulletin ADB-10-07 Liquefied Natural Gas Facilities: Obtaining Approval of Alternative Vapor-Gas Dispersion Models. Federal Register 75 (August 31, 2010): 53371-53374.

Puttock, J.S, Colenbrander, G.W., (1980) Maplin Sands Experiments 1980: Interpretation and Modeling of Liquefied Gas Spills onto the Sea. IUTAM Symposium on Atmosphere Dispersion of Heavy Gases and Small Particles, Delft, West Germany, August/September 1983, Springer-Verlag, Berlin, West Germany.

Puttock, J.S., Blackmore, D.R., Colenbrander, G.W., Davies, P.T., Evans, A., Homer, J.B., Redfearn, J.J., Vant Sant, W.C., Wilson, R.P. (1984). Spill Tests of LNG and Refrigerated Liquid Propane on the Sea, Maplin Sands, 1980: Experimental Details of the Dispersion Tests. Shell Research Limited, TNER.84.046.

Puttock, J. (1987). The Development and Use of HEGABOX/HEGADIS Dispersion Models for Hazard Analysis. Proceedings, International Conference on Vapour Cloud Modeling, pp. 317-341.

Research and Special Programs Administration (RSPA) (1997). Direct Final Rule: Liquefied Natural Gas Regulations - Miscellaneous Amendments. Federal Register 62 (February 25, 1997): 8403-8404.

Spicer, T.O., Havens, J., (1989). User's Guide for the DEGADIS 2.1 Dense Gas Dispersion Model, EPA-450/4-89-019, Environmental Protection Agency, Research Triangle Park, NC, November 1989.

Zeman, O. Tennekes, H. (1977), Parameterization of the Turbulent Energy Budget at the Top of the Daytime Atmospheric Boundary Layer, Journal of the Atmospheric Sciences, January 1977.

APPENDIX C: LIST OF PREPARERS

LIST OF PREPARERS

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B.S., Fire Protection Engineering, 2006, University of Maryland