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Air Quality Monitoring and Surveillance Program Botswana

Mission 3 Report 5-16 May 1997

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Summary

Mission 3 to Botswana was performed 5-16 May 1997 by Tone Bekkestad and Svein Knudsen. Data storage systems, data bases, quality control of data, modelling of air pollution and passive sampling of SO_2 and NO_2 was the main tasks for this mission.

This report describes briefly the various topics covered during the two weeks period, and gives an introduction to the above subjects. For convenience the report is divided in two main subjects is described below.

Mission 3 to Botswana comprised of two major parts:

1. Quality control of the measured air pollution data, the structure of the data storage system, reporting procedures for the measured air quality data, and training in use of air pollution dispersion models. The NILU dispersion models CONCX and CONDEP were introduced to DoM personnel. The BCL smelter in Selebi Phikwe was used for a modelling exercise. The estimated ground level concentrations of SO_2 exceeds the World Health Organisation level air quality guidelines, both for health and vegetation. This is described in chapter 2 through 8.

2. The purpose, location and analysis results of the passive sampling performed in Botswana 13-29 May 1997. Passive samplers were installed in Lobatse, Mosopa, Moropule, Selebi Phikwe, Sua Pan and Maun. This is described in chapter 9. The passive samplers were exposed for approximately 2 weeks.

Passive sampling performed at the five sites mentions above showed on average low two week average concentrations both for SO_2 and NO_2. The highest concentrations were measured around the Railway Track and the Railway Station in Selebi-Phikwe. The passive samplers in Selebi-Phikwe were exposed for 24 h. Daily average SO_2 concentrations of approximately 20 $\mu g/m^3$ were recorded at the Railway Track. At Sua Pan, 2-week average SO_2 concentrations of 45–47 $\mu g/m^3$ were recorded. These measurements indicate that hourly average concentrations of approximately 200–250 $\mu g/m^3$ may occur under normal wind and stability conditions.

The four sites; Lobatse, Mosopa, Moropule, Sua Pan that should have been impacted by industrial activity showed concentrations similar to the concentrations measured at the background station in Maun. Reasons for this may be unfavourable wind direction, samplers damaged by heavy rain fall or reduced emissions from the industry during the sampling period.

From this measurement campaign it is, hence, difficult to draw any conclusions on siting of future monitoring stations. The location of monitoring stations should therefor be based on information on major sources, dominating wind directions and results from dispersion modelling.

Heavy rain over the week-end in between the two sampling weeks may have destroyed the passives samplers which were not installed under a roof (or equivalent). The analysis results for these locations should be presented with precautions. The analysis results are presented in a table in Appendix C.

The next phase in the project is a visit by two persons from DoM to NILU for long-term training and for Mr. Matale to come to NILU to discuss the activities and budgets for 1998.

Air Quality Monitoring and Surveillance Program Botswana

Mission 3 Report
5-16 May 1997

1. Introduction

Mission 3 to Botswana was performed by Tone Bekkestad and Svein Knudsen 5-16 May 1997.

Svein Knudsen introduced the DoM personnel to different types of NILU models for calculation of ground level concentrations of air pollutants as a result of emission from single or multiple sources. The models introduced (CONCX and CONDEP) calculate maximum one hour ground level concentrations, and annual average concentrations for i.e. SO_2, NO_2, PM_{10}.

Tone Bekkestad performed passive sampling of sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) at four different locations in Botswana during a two week period. The installation of passive samplers were performed together with DoM personnel. In addition, DoM personnel installed passive samplers at the two locations of Selebi Phikwe and Gaborone. The passive samplers were brought back to NILU for analysis after the two week sampling period.

The mission report is divided in two;

- Quality control of measured data, the structure of the storage system, reporting procedures of measured data, and training in use of air pollution dispersion models. One week was dedicated to each of the above tasks. These subjects are reported in chapter 2 through 8.
- The purpose, location and analysis results of the passive sampling performed in Botswana during the period 13-29 May 1997. This is described in chapter 9.

The next step in the project now is for two persons from DoM to come to NILU for long-term training and for Mr. Matale to come to Norway to plan next years activities and budgets (1998).

2. Quality control of measured data

Firstly, a status on the work performed since the last visit. The status can be summarised in the following points:

- Procedures for retrieval of data have been elaborated. This includes all stations (OR 13/97).
- The data have been put into the preliminary data storage and stored as monthly files. A full data quality control have not been conducted.

To be able to approve the data a thorough quality control have to be conducted. This quality control is aimed to understand if the measured data have logical explanations and to take out or correct data that is clearly wrong. The quality control contains the following tasks:

1. Quality control at the station.
2. Technical control at the laboratory.
3. Logical control before the data is put into the final data storage.

The two first points will be handled by different parts of the project and will only be partially covered here. The main goal will be to look at the data to see if there are some peculiarities that are not taken out in the two first controls. It will also be the last control before the data are put into the final data storage.

2.1 Quality control at the station

This control is to see if the instruments are working properly. The station holder has to check that there are data on the files that are collected.

This is the first control that will evaluate if the instruments are working properly.

Training in this part of the QA/QC procedures will be covered at a later stage of the project. The procedures for QA/QC at the station is also described in the report/seminar compendium Air Quality Monitoring Systems and Applications (Draft Report, NILU).

2.2 Technical control at the laboratory

Technical control at the laboratory is used to see if there has been any malfunction of the instrument in the measuring period. This is a control of the data and the calibration of the instrument (zero drift, span check, etc.). The next step is to correct the data according to the findings. The data are now ready for preliminary data storage. The original data must however be kept in its original form and stored separately.

Training in this part of the QA/QC procedures will be covered at a later stage of the project. The procedures for technical control at the laboratory is also described in the report/seminar compendium Air Quality Monitoring Systems and Applications (Draft Report, NILU).

2.3 Logical control before the data is put into the final storage

This part of the quality control is mainly based on experience. The techniques that are used are described in the following. The data are plotted in time series. The time series are analysed for the average values and for maximum values. The peculiarities are evaluated by looking at earlier measurements and experiences with this specific station and parameter. The second part is to compare different parameters. This could be SO_2, NO_x, CO and O_3 to see if the relations are logical. The data should also be compared to meteorological parameters and other relevant parameters that are available for comparison. Then the different stations should be compared to see that the relationship is in accordance with the representativity of

the stations. When this is done the data that have been classified as wrong must be replaced by the code for missing data. The data can then be transferred to final storing.

The logical control of the data should consist of monthly time plots. The process contains three stages:

1. A visual control of each parameter. The visual control includes evaluation of diurnal patterns, and if the measurements have logical explanations. This is to detect strange measurements that are potentially wrong. Peculiarities should be flagged so that the data can be evaluated later.
2. The different parameters should also be compared with each other to check that the relative concentration contributions for different parameters, as a result of emissions from the same source, are in agreement. This step should include the available meteorological measurements. Meteorological measurements can be used to "explain" the air pollution measurements and can be used to locate the emission sources.
3. Parameters measured at one station should then be compared to parameters measured at an other station. This procedure is used to evaluate the correlation between parameters. If otherwise equal stations have different values, a calibration of the instruments might be necessary.

This quality control will end up in a understanding of the data and an explanation of why they are as they are. In general, the data should not be taken out if they are not clearly wrong. The code for missing data is set to -9999.

3. Data storage

The data storage system at DoM is based on files in EXCEL format. One file for each station and one spreadsheet for each month. This format is chosen for convenience, because the data on this format are easily available for statistical treatment in EXCEL. DoM have three data bases; one with the raw data, one with preliminary data and one for final data. The raw data are transferred to the preliminary data base as monthly files and plotted. After the QA/QC procedures described above are completed and wrong data substituted with -9999, the data are transferred to a final data storage. The data should then be plotted and to check if the corrections described above are performed. The plots should be kept in a binder for later use.

These files should be write protected. Only the persons that are authorised should be able to edit the files. To make sure that the data are protected in the final data storage the files should only be available as READ ONLY. This means that the data can be read by everyone that have access to the computer network but can only be changed by authorised personnel. This is to avoid that the data are changed accidentally or by purpose. If changes are to be made it is necessary to go through a procedure to make sure that this is done correctly.

4. Quality control of programs (MACROS)

DoM have prepared MACRO's in EXCEL. These MACRO's have to undergo a quality control and an official version of the MACRO must be available for personnel that needs the MACRO. The MACROS must have a short description. The MACROS will probably go through several phases with changes. Hence a system for version numbering or convention should be included.

5. Log on the data/stations

It is necessary to keep a log for the stations which shows the data availability and at which stage of the quality control procedure the data are in.

A simple log could look like this:

Table 1: Data availability in % of possible measurements.

Station	Parameter		January 1997	February 1997	March 1997
Civic center	SO_2	Test data	30	90	
Civic center	SO_2	Final data	29	78	
Civic center	CO	Test data			
Civic center	CO	Final data			
Serowe	CO	Test data			
Serowe	CO	Final data			

This table will be the reference to the availability and the representativity of statistical analysis, and should be included in the data report. A table like this is helpful when the data for some reason are needed at a later stage.

6. Statistical treatment of data

Before the air quality- and meteorological data are report they should be treated statistically. To evaluate the statistics it is necessary to know the data availability. The information on data availability will indicate to what extent the data are statistically valid. Statistical treatment of meteorology always require a wind rose. Air quality measurements always require mean and maximum values.

A list with some of the statistics that might be useful for evaluation of dispersion conditions and air quality measurements is presented below.

6.1 Meteorology

- Wind roses
  - long term wind roses
  - wind roses for specified hours

- Mean and maximum wind speed
  - diurnal variations
  - directional variations
- Temperature
  - mean and maximum
  - time for maximum
- Vertical temperature difference
  - Joint frequency distribution (including 12 wind sectors, four wind speed classes, and four stability classes. This will result in a matrix of 12*16 boxes and will give a good overview of the dispersion conditions. The data can also be split in day and night-time conditions and time of the year.

6.2 Air quality

- Mean and maximum concentrations and time for max.
  - monthly
  - 6 months
  - year
- Occurrence over certain limits including air quality guidelines
- Mean/max./standard deviation of diurnal concentration distribution
- Scatter plots. Scatter plots describe dependence in-between parameters and can be used to find the impact from different sources.

6.3 Combination of meteorology and air quality measurements

- Joint frequency distribution matrix combined with concentration
  - Mean concentration for each wind direction
  - Maximum concentration for each wind direction
  - Mean concentrations for different wind speed classes
  - Concentration distribution for each stability class
- Scatter plots. The scatter plots will be used to see the correlation between concentrations and meteorology. This is important for analysing the high concentrations and if these are caused by emission rates or poor dispersion conditions.

7. Reporting of data

The data can be reported in two standard reports; monthly and annual reports. The contents and structure of the following reports were discussed:

- Monthly report
- Annual report
- Reports on impacts from industrial sources.

Further descriptions of these reports are in Appendix A.

These are the basics for reporting of measurements. Depending on the purpose of the report additional statistical treatment of the data could be necessary. Some of these statistics are shown in Appendix B.

A test was given on the contents of the different reports and the scores were 15 and 12 out of 16. This was considered a good result.

8. Training in dispersion modelling

The personnel at DoM have little experience in dispersion modelling. The aim of this task was therefor to introduce two simple steady state Gaussian models. The models presented were the NILU models CONCX AND CONDEP. The models run under DOS and are written in FORTRAN. The model CONCX calculates hourly ground level concentrations as a function of distance from the emission source, and CONDEP calculates long term ground level concentrations and dry deposition from industrial sources. The models have been briefly introduced to personnel from DoM at the first seminar and in the second mission in January and February 1997.

8.1 Modelling of short term concentrations

The model CONCX was introduced. The input parameters were explained and a practical example was calculated. The example given was the emissions from the tall stack of the BCL smelter in Selebi Phikwe. The contents of the parameters were explained. The input parameters were changed to see the impact on ground level concentrations as a result of change in the different input parameters.

The BCL smelter in Selebi Phikwe was chosen for a modelling exercise. Calculations of emissions from the main stack, the drier plant and the diffuse emissions have been performed. The exercise included most of the different features for representing the ground level concentrations through a model. The last part of the exercise was performed by the DoM personnel. The results were discussed afterwards.

8.2 Modelling of long term concentrations

The steady state Gaussian model CONDEP was also introduced. This models use a joint frequency distribution matrix to calculate long time average ground level concentrations. The joint frequency distribution is a statistical summary of the dispersion conditions at the site for a given period. The meteorological parameters in the joint frequency distribution matrix are as follows:

- Wind direction
- Wind speed
- Atmospheric stability

The wind direction is divided into twelve 30° wind sectors, 4 wind speed classes and four stability classes (atmospheric stability). The matrix contains 12 rows and 16 columns. Each position in the matrix is represented by the occurrence of meteorological condition within this box.

There are no measurements of parameters that can be used for a classification of stability in Botswana today. This means that the joint frequency distribution matrix for these calculations had to be estimated from the wind rose, wind speeds and an understanding of the distribution of atmospheric stability.

A joint frequency distribution matrix was estimated for the BCL smelter. The results have to be used with care but will give some idea of the long time averages from the BCL smelter.

The CONDEP model was introduced and the estimated long time concentrations were calculated using the estimated joint frequency distribution matrix.

The persons trained were given a test after the basic theory was presented and the example was run to ensure that the basic theory was remembered. The results were excellent.

The results from the practical exercises will be reported by DoM in collaboration with NILU.

9. Passive sampling

Passive sampling of SO_2 and NO_2 was performed in the period 13 May to 29 May 1997 at four locations in Botswana. The locations were selected and the passive sampling was performed to get an overview of the concentrations of the two air pollution components SO_2 and NO_2. The locations surveyed were Lobatse (66 km SSW of Gaborone), Moropule (262 km NNE of Gaborone and 23 km WNW of Palapye), Sowa Pan (448 km N of Gaborone and 169 km WNW of Francistown), Moshopa (47 km WSW of Gaborone) and Maun (563 km WNW of Gaborone and 436 WNW of Francistown). In addition, passive samplers were installed at different locations close to the BCL smelter in Selebi Phikwe.

The passive samplers were collected after a two week sampling period. A Geographical Information System (GPS) was used to collect the co-ordinates of the respective sampling sites.

The purpose of the passive sampling was somewhat different for the different locations. Hence, the purpose and the results of the passive sampling will be explained in more detail in the following chapters for each of the locations surveyed. A description of the purpose and the results will, however, be given below.

9.1 Lobatse

The passive sampling in Lobatse was performed to get an overall view of the concentration levels of the two air pollution components SO_2 and NO_2 as a result of emissions from the three main sources in the region; the Botswana Meat Commission (BMC), the Lobatse Tannery and the Botswana Brewery.

DoM have performed measurements of sulphur dioxide and particles close to the bus station for several years with values of SO_2 well below the Air Quality Guidelines.

Passive samplers were installed at different distances from the emission sources in the main wind directions. The samplers were installed at the distances most likely to get the highest ground level air pollution concentrations. The selection of sampler locations was based on a subjective view of the dispersion conditions of the emissions from the stack and air pollution modelling results.

Two passive samplers (SO_2 and NO_2) were installed at a residential home in the BMC residential area close to the BMC factory. Parts of this area seemed to be in one of the main wind direction of emissions from the BMC stack at the time when the installation of the passive samplers around the BMC was performed. The smell of H_2S at this location was distinct and annoying.

The results from the passive sampling in Lobatse show SO_2 concentrations of approximately 3 µg/m³ as a two week average approximately 500 m south of the Lobatse Tannery.

The samplers installed at the BMC house close to the emission sources were removed after one week, and hence not brought back to NILU for analysis. The overall SO_2 concentration levels range from 1.0 to 3.0 µg/m³ as a two week average.

The NO_2 concentrations range from 2.5-10.5 µg/m³. The maximum was recorded 250 m north of the Lobatse Tannery.

Table 2: Analysis results from passive sampling of SO_2 in Lobatse 13–27 May 1997.

Sampling site	Site location	Sample no.	Co-ordinates x	Co-ordinates y	No. of days	SO_4-S µg/ml	SO_4-S µg/m³	SO_2 µg/m³
Lobatse	Boteti Street	SO_2 – 1	166669.9	7205617.0	13.8	0.05	0.47	0.95
Lobatse	Gov. Revenue.Office	SO_2 –2	166535.6	7205089.8	13.8	0.14	1.33	2.65
Lobatse	DoM Meas. Station	SO_2 – 3	164819.3	7205801.7	13.8	0.13	1.23	2.46
Lobatse	Tech. Train. College	SO_2 – 4	164398.5	7205655.3	13.8	0.16	1.52	3.04
Lobatse	BMC House # 1	SO_2 – 6	164986.9	7207359.6	13.8	0.11	1.05	2.09

Table 3: Analysis results from passive sampling of NO_2 in Lobatse 13–27 May 1997.

Sampling site	Site location	Sample no.	Co-ordinates x	Co-ordinates y	No. of days	NO_2-N µg/ml	NO_2-N µg/m³	NO_2 µg/m³
Lobatse	Boteti Street	NO_2 – 1	166669.9	7205617.0	13.8	0.40	3.19	10.47
Lobatse	Gov. Revenue.Office	NO_2 –2	166535.6	7205089.8	13.8	0.33	2.62	8.61
Lobatse	DoM Meas. Station	NO_2 – 3	164819.3	7205801.7	13.8	0.10	0.76	2.48
Lobatse	Tech. Train. College	NO_2 – 4	164398.5	7205655.3	13.8	0.08	0.59	1.95
Lobatse	BMC House # 1	NO_2 – 6	164986.9	7207359.6	13.8	0.31	2.47	8.10

9.2 Mosopa

Only two locations were selected for passive sampling in the Mosopa area. Mosopa has been selected as the background station for Gaborone. The Diratsame CJSS school property outside Mosopa is found to be a suitable location for the future monitoring station. Passive samplers for SO_2 and NO_2 were therefore installed at the Diratsame CJSS and on a tree approximately 10 km from the school in a non-polluted area to see whether the school could be characterised as a non-polluted area. The analysis results of the passive samplers show that the concentration levels recorded at Diratsame CJSS is somewhat higher than those recorded in the non-polluted area outside Mosopa both for SO_2 and NO_2. However, because of the heavy rain showers during the sampling period and the fact that the samplers fell down, this might be the reason why the concentrations for the two sites differ.

Table 4: Analysis results from passive sampling of SO_2 in Mosopa 13–27 May 1997.

Sampling site	Site location	Sample no.	Co-ordinates x	Co-ordinates y	No. of days	SO_4-S µg/ml	SO_4-S µg/m^3	SO_2 µg/m^3
Mosopa	School (u/roof)	SO_2 – 7	138525.4	7257271.6	13.8	0.20	1.90	3.80
Mosopa	On tree (destroyed)	SO_2 – 8	147679.9	7263000.8	13.8	0.06	0.57	1.14

Table 5: Analysis results from passive sampling of NO_2 in Mosopa 13–27 May 1997.

Sampling site	Site location	Sample no.	Co-ordinates x	Co-ordinates y	No. of days	NO_2-N µg/ml	NO_2-N µg/m^3	NO_2 µg/m^3
Mosopa	School (u/roof)	NO_2 – 7	138525.4	7257271.6	13.8	0.08	0.59	1.95
Mosopa	Tree (fell down)	NO_2 – 8	147679.9	7263000.8	13.8	0.01	<0.01	<0.01

9.3 Moropule

There is a coal fired Power Plant approximately 6.2 km west of Palapye on the road to Serowe. In Mission 2 Report average emissions of sulphur dioxide from the Power Plant were given as 549.3 g/s (or 1977 kg/h). Wrong emission numbers were reported. The correct emission numbers are supposed to be 2/3 of what was reported in the Mission 2 Report. Hence, Average emissions of sulphur dioxide from the Power Plant are 366.2 g/s (1318 kg/h).

Estimates show that the ground level concentrations of SO_2 can amount to approximately 400 µg/m^3 on a 1-hour average 2-3 km from the plant. This is above the WHO Air Quality Guidelines, which has a limit of 350 µg/m^3 as a hourly average. It has therefor been decided that continuous monitoring of the Power Plant needs to be performed. Passive samplers were therefor installed in the area around the Power Plant and exposed during a two week period.

The main wind direction for the area is to the west. However, at the time of the installation of the passive samplers the wind direction was towards east. Passive

samplers were, however, installed west of the Power Plant at approximately 2.5 km distance from the plant. Mr. Sereetsi and Mr. Mukuwa in Selebi-Phikwe were instructed to install additional passive samplers east of the plant if the wind continued to be in an easterly direction.

Because of dense vegetation in the area west of the Power Plant, installation of passive samplers were not as straight forward as first expected. However, 11 passive samplers were installed at the approximate same distance from the plant forming and arch. The passive sampler installed at the Old DoM Station and the sampler installed at the Corner of the Fence were inside the Power Plan properties and within 500 m from the emission source. The samplers were installed with 200 m spacing. An additional two samplers were installed at the Power Plant properties. The samplers were installed on a fence approximately 1.5 km from the emission source.

The results from the passive sampling around the Power Plant is shown in Table 6 below. The results show that the 2 week average SO_2 ranged from 0.4 to 3.6 µg/m^3.

According to the results from the passive sampling a monitoring station will be recommended installed at a distance of 2-4 km from the Power Plant in an angle that coincide with the samplers SO_2-18 and SO_2-19.

However, the sampler may have been exposed to heavy rain a couple of days during the sampling period. The analysis results may therefor not be correct.

Table 6: Analysis results from passive sampling of SO_2 in Moropule 14–28 May 1997.

Sampling site	Site location	Sample no.	Co-ordinates x	Co-ordinates y	No. of days	SO_4-S µg/ml	SO_4-S µg/m^3	SO_2 µg/m^3
Moropule Mine	Old DoM station	SO_2 – 9	996570.4	7509082.0	14.0	0.19	1.78	3.55
Moropule Mine	Fence (corner)	SO_2 – 10	296808.1	7508789.7	14.0	0.15	1.40	2.80
Moropule Mine	Fence W of Mines	SO_2 – 12	296172.7	7508973.8	14.0	0.04	0.37	0.75
Moropule Mine	"	SO_2 – 13	296112.5	7508784.3	14.0	0.04	0.37	0.75
Moropule Mine	"	SO_2 – 14	296047.9	7508580.7	14.0	0.10	0.94	1.87
Moropule Mine	"	SO_2 – 17	295699.6	7508105.3	14.0	0.02	0.19	0.37
Moropule Mine	"	SO_2 – 18	295542.1	7507975.6	14.0	0.15	1.40	2.80
Moropule Mine	"	SO_2 – 19	295574.4	7507868.9	14.0	0.13	1.21	2.43
Moropule Mine	"	SO_2 – 20	295941.0	7507758.6	14.0	0.02	0.19	0.37
Moropule Mine	"	SO_2 – 21	295943.0	7507650.2	14.0	0.08	0.75	1.49

9.4 Sua Pan

Sua Pan is a small town in the easternmost section of the Makgadikgadi Depression of northern Botswana. The town is built to house the Soda Ash Botswana (SAB) employees and their families. The Soda Ash Plant is situated 17 km east of Sua Pan in an almost flat area of saline sands, which supports little vegetation and is periodically flooded in the wet season. Soda Ash Botswana is built to produce soda ash and salt which is exported to South Africa. Soda Ash

(sodium carbonate – Na_2CO_3) is used in glass manufacture, metallurgical applications and the detergent industry. SAB produces about 650 000 tons of salt per year which, except for the relatively small salt usage in Botswana, is exported to South Africa.

The average SO_2 emissions from SAB is 90.3 g/s (325 kg/h). The emission data for SAB were wrongly reported to be 180.6 g/s in Mission 1 Report (or 650 kg/h). The stack is 50 m tall. Concentration calculations of ground level SO_2 concentrations as a result of emissions from Soda Ash Botswana (SAB) have shown that concentrations of approximately 300-320 µg/m^3 can occur 1-2 km from SAB during unstable and neutral atmospheric conditions.

SAB performs monitoring of meteorology (FF, DD, gust, T, RH, evaporation, etc.). The wind data for the passive sampling period was made available to us by Mr. Eltis at SAB. According to SAB the prevailing wind direction is north-south. In the winter time, however, the wind may change to a more easterly direction. This is in accordance with the measurements performed during the passive sampling period. During the sampling period wind recordings show that winds from ESE, NNE and NE are prevailing. Wind recordings in Francistown show that east and south east winds are prevailing in the Francistown area (55 %).

Passive samplers were installed at approximately 1-2 km distance from SAB forming a 360 degree circle. Mr. Colin Eltis (Site Manager at SAB) was very helpful during this work. The vegetation around SAB is, as mentioned above, scarce. Hence, the passive samplers had to be installed on whatever was available on the sites.

The results from the passive sampling performed around SAB in Sua Pan show that 2-week average SO_2 concentrations of 45-47 µg/m^3 may occur approximately 1–2 km from SAB. Under normal wind and stability conditions hourly average concentrations of 200–250 µg/m^3 may occur as a result of this.

The highest concentrations recorded were measured 1–2 km south/south-east of SAB. This indicates that the main wind direction has been winds from north and north-east (approximately 53% of the time). This coincide with Mr. Eltis' description of the general wind distribution for the area. Calm winds were recorded 17% of the time.

Installation of monitoring equipment for continuous monitoring of sulphur dioxide in the Sua Pan area is therefore recommended 1.5–2 km south/south-east of SAB.

Table 7: Analysis results from passive sampling of SO_2 in Sua Pan 14–28 May 1997.

Sampling site	Site location	Sample no.	Co-ordinates x	Co-ordinates y	No. of days	SO_4-S µg/ml	SO_4-S µg/m^3	SO_2 µg/m^3
Sua Pan	Bitterns Line Pole	SO_2 - 42	192306.4	7724770.3	14.0	2,54	23,73	47,46
Sua Pan	Tree west of pole	SO_2 - 43	191800.3	7725245.0	14.0	2,41	22,52	45,03
Sua Pan	Sign by road to W	SO_2 - 44	191097.6	7726747.7	14.0	0,12	1,12	2,24
Sua Pan	Entr. to W well (sign)	SO_2 - 45	191420.3	7727786.0	14.0	0,25	2,34	4,67
Sua Pan	Inlet Box	SO_2 - 46	193655.1	7730689.9	14.0	*	*	*
Sua Pan	Gap Boom	SO_2 - 47	194963.8	7730499.8	14.0	0,26	2,43	4,86
Sua Pan	Light pole - Tango	SO_2 - 48	200187.3	7727017.3	14.0	0,27	2,52	5,05
Sua Pan	..sign on tar road	SO_2 - 49	200316.9	7723424.9	14.0	0,10	0,93	1,87
Sua Pan	Airport sign	SO_2 - 50	198163.1	7723492.1	14.0	0,33	3,08	6,17
Sua Pan	.....	SO_2 - 51	196473.0	7723568.5	14.0	0,17	1,59	3,18
Sua Pan	Pole shoreline S of spit	SO_2 - 52	195002.8	7722913.7	14.0	0,41	3,83	7,66
Sua Pan	N corner pole of site	SO_2 - 53	194533.9	7723983.8	14.0	0,30	2,80	5,61

* = destroyed

9.5 Maun

Maun has been selected as the background station for Botswana in the national air quality monitoring program. Maun is a small village 563 km NNW of Gaborone in the south eastern part of the Okavango Delta. The population of the village is approximately 13 000, and it has the second busiest airport in southern Africa during the high season for tourism (winter).

In a park 3 km from Maun centre is Okavango Research Centre. The properties of ORC has been picked out as possibly the best location for a background station in the Maun area. The background station will comprise of continuous monitoring of ozone and precipitation. In addition, SO_2 and NO_2 will probably be monitored using passive samplers (two week averages). Passive sampling in Maun was performed to decide which type of instruments to use to measure the different parameters at the background station. The results from the passive sampling will also be used to decide the location of the future monitoring site. Using passive samplers for SO_2 and NO_2 would be cost effective and it would reduce the need for maintenance.

Passive samplers of SO_2 and NO_2 were installed at three different locations at the properties of ORC. In addition, passive samplers were installed at Sedie CJSS (Community Junior Secondary School) 3 km from Maun centre, and in a typical non-polluted "bush-site" approximately 9 km from Maun centre. The passive samplers at Sedie CJSS and the "bush-site" were installed to compare the concentrations of the passive samplers at ORC.

Tone Bekkestad had been in contact with Professor Lars Ramberg, whom is the director of ORC. Professor Ramberg has addressed his interest in helping out with the monitoring at the background station in exchange of analysis results from the analysis of the precipitation sampling at the background station in Maun.

The results from the sampling indicate that Sedie CJSS had the highest average background SO_2 and NO_2 concentrations of 3.2 and 2.0 µg/m³, respectively, as a two week averages. The range of the concentrations were 0.6-3.2 µg/m³ for SO_2 and 0.1-2.0 µg/m³ for NO_2. The passive samplers NO_2-12, NO_2-13 and NO_2-14 had fallen down because of the heavy rain and the results may therefor not be correct.

The two week average concentrations recorded at Sedie CJSS were higher than the ones recorded at ORC. This coincides with the fact that Sedie CJSS is located in an area with more traffic compared to ORC which is a park away from any major pollution sources. ORC seems to be a suitable place to install a background station in the Maun area, and co-operation with ORC would be helpful and interesting.

Table 8: Analysis results from passive sampling of SO_2 in Maun 16–29 May 1997.

Sampling site	Site location	Sample no.	Co-ordinates x	Co-ordinates y	No. of days	SO_4-S µg/ml	SO_4-S µg/m³	SO_2 µg/m³
Maun	Sedie CJSS	SO_2 – 60	-290112.7	7775868.5	13.2	0.16	1.59	3.17
Maun	On tree (destroyed)	SO_2 – 61	-281869.9	7775867.9	13.0	0.12	1.21	2.41
Maun	ORC (u/roof)	SO_2 – 62	-290984.6	7773221.8	13.2	0.05	0.50	0.99
Maun	ORC - fell down	SO_2 – 63	-291021.4	7773203.8	13.2	0.09	0.89	1.78
Maun	"	SO_2 – 64	-291109.9	7773171.6	13.2	0.12	1.19	2.38
Maun	"	SO_2 – 65	-294340.5	7774153.9	13.1	0.03	0.30	0.60

Table 9: Analysis results from passive sampling of NO_2 in Maun 16–29 May 1997.

Sampling site	Site location	Sample no.	Co-ordinates x	Co-ordinates y	No. of days	NO_2-N µg/ml	NO_2-N µg/m³	NO_2 µg/m³
Maun	Sedie CJSS	NO_2 – 9	-290112.7	7775868.5	13.2	0.08	0.62	2.04
Maun	ORC (u/roof)	NO_2 – 11	-290984.6	7773221.8	13.2	0.07	0.53	1.76
Maun	ORC - fell down	NO_2 – 12	-291021.4	7773203.8	13.2	0.01	0.03	0.08
Maun	"	NO_2 – 13	-291109.9	7773171.6	13.2	0.07	0.53	1.76
Maun	"	NO_2 – 14	-294340.5	7774153.9	13.1	0.08	0.62	2.04

9.6 Selebi Phikwe

Passive sampling in Selebi-Phikwe was performed to get an overall idea of the concentrations levels of SO_2 as a result of emissions from the BCL smelter. The sampling periods were 1 and 4 days.

The highest concentrations were measured around the Railway Track and the Railway Station in Selebi-Phikwe. Daily average SO_2 concentrations of approximately 20 µg/m³ were recorded at the Railway Track. However, wind direction measurements for the same period are necessary to evaluate if these concentrations are caused by emissions from the BCL smelter, or if these concentration levels are caused by some other type of activity.

The results of the passive sampling of SO_2 at the BCL smelter is show in the Table 10.

Table 10: Analysis results from passive sampling of SO_2 in Selebi-Phikwe 15–29 May 1997.

Sampling site	Site location	Sample no.	Co-ordinates x	Co-ordinates y	No. of days	SO_4-S µg/ml	SO_4-S µg/m^3	SO_2 µg/m^3
Selebi Phikwe	Railway track	SO_2 – 22	378454.9	7572145.8	1.0	0.03	3,92	7,85
Selebi Phikwe	N of Railw. track	SO_2 – 23			1.0	0.08	10,46	20,93
Selebi Phikwe	Railway station	SO_2 – 24	378062.1	7570988.6	1.0	0,04	5,23	10,46
Selebi Phikwe	Railway track	SO_2 – 25	378454.9	7572145.8	4.0	0,07	2,29	4,58
Selebi Phikwe	N of Railw. track	SO_2 – 26			4.0	0,06	1,96	3,92
Selebi Phikwe	Railway station	SO_2 – 27	378062.1	7570988.6	4.0	0,10	3,27	6,54
Selebi Phikwe	Railway track	SO_2 – 28	378454.9	7572145.8	1.0	0,07	9,16	18,31
Selebi Phikwe	N of Railw. track	SO_2 – 29			1.0	0,03	3,92	7,85
Selebi Phikwe	Railway station	SO_2 – 30	378062.1	7570988.6	1.0	0,04	5,23	10,46

Appendix A

Passive sampling – analysis results

Report date: 13/6/97
Report page: 1

Analysis report for measurements of SO_2 in air using passive samplers.

Analysis report NILU-U-52

Sampling site	Site location	Sample no.	Co-ordinates x	y	No. of days	SO_4-S µg/ml	SO_4-S µg/m3	SO_2 µg/m3
Lobatse	Boteti Street	SO_2 - 1	166669.9	7205617.0	13.8	0.05	0.47	0.95
Lobatse	Gov.Revenue.Office	SO_2 - 2	166535.6	7205089.8	13.8	0.14	1.33	2.65
Lobatse	DoM Meas.Station	SO_2 - 3	164819.3	7205801.7	13.8	0.13	1.23	2.46
Lobatse	Tech.Train.College	SO_2 - 4	164398.5	7205655.3	13.8	0.16	1.52	3.04
Lobatse	BMC House # 1	SO_2 - 6	164986.9	7207359.6	13.8	0.11	1.05	2.09
Sampling site	Site location	Sample no.	Co-ordinates x	y	No. of days	SO_4-S µg/ml	SO_4-S µg/m3	SO_2 µg/m3
Mosopa	School (u/roof)	SO_2 - 7	138525.4	7257271.6	13.8	0.20	1.90	3.80
Mosopa	On tree (destroyed)	SO_2 - 8	147679.9	7263000.8	13.8	0.06	0.57	1.14
Sampling site	Site location	Sample no.	Co-ordinates x	y	No. of days	SO_4-S µg/ml	SO_4-S µg/m3	SO_2 µg/m3
Moropule Mine	Old DoM station	SO_2 - 9	996570.4	7509082.0	14.0	0.19	1.78	3.55
Moropule Mine	Fence (corner)	SO_2 - 10	296808.1	7508789.7	14.0	0.15	1.40	2.80
Moropule Mine	Fence W of Mines	SO_2 - 12	296172.7	7508973.8	14.0	0.04	0.37	0.75
Moropule Mine	"	SO_2 - 13	296112.5	7508784.3	14.0	0.04	0.37	0.75
Moropule Mine	"	SO_2 - 14	296047.9	7508580.7	14.0	0.10	0.94	1.87
Moropule Mine	"	SO_2 - 17	295699.6	7508105.3	14.0	0.02	0.19	0.37
Moropule Mine	"	SO_2 - 18	295542.1	7507975.6	14.0	0.15	1.40	2.80
Moropule Mine	"	SO_2 - 19	295574.4	7507868.9	14.0	0.13	1.21	2.43
Moropule Mine	"	SO_2 - 20	295941.0	7507758.6	14.0	0.02	0.19	0.37
Moropule Mine	"	SO_2 - 21	295943.0	7507650.2	14.0	0.08	0.75	1.49
Sampling site	Site location	Sample no.	Co-ordinates x	y	No. of days	SO_4-S µg/ml	SO_4-S µg/m3	SO_2 µg/m3
Selebi Phikwe	Railway track	SO_2 - 22	378454.9	7572145.8	1.0	0.03	3.92	7.85
Selebi Phikwe	N of Railw. track	SO_2 - 23			1.0	0.08	10.46	20.93
Selebi Phikwe	Railway station	SO_2 - 24	378062.1	7570988.6	1.0	0.04	5.23	10.46
Selebi Phikwe	Railway track	SO_2 - 25	378454.9	7572145.8	4.0	0.07	2.29	4.58
Selebi Phikwe	N of Railw. track	SO_2 - 26			4.0	0.06	1.96	3.92
Selebi Phikwe	Railway station	SO_2 - 27	378062.1	7570988.6	4.0	0.10	3.27	6.54
Selebi Phikwe	Railway track	SO_2 - 28	378454.9	7572145.8	1.0	0.07	9.16	18.31
Selebi Phikwe	N of Railw. track	SO_2 - 29			1.0	0.03	3.92	7.85
Selebi Phikwe	Railway station	SO_2 - 30	378062.1	7570988.6	1.0	0.04	5.23	10.46
Sampling site	Site location	Sample no.	Co-ordinates x	y	No. of days	SO_4-S µg/ml	SO_4-S µg/m3	SO_2 µg/m3
Sua Pan	Bitterns Line Pole	SO_2 - 42	192306.4	7724770.3	14.0	2,54	23,73	47,46
Sua Pan	Tree west of pole	SO_2 - 43	191800.3	7725245.0	14.0	2,41	22,52	45,03
Sua Pan	Sign by road to W	SO_2 - 44	191097.6	7726747.7	14.0	0,12	1,12	2,24
Sua Pan	Entr. to W well (sign)	SO_2 - 45	191420.3	7727786.0	14.0	0,25	2,34	4,67
Sua Pan	Inlet Box	SO_2 - 46	193655.1	7730689.9	14.0	*	*	*
Sua Pan	Gap Boom	SO_2 - 47	194963.8	7730499.8	14.0	0,26	2,43	4,86
Sua Pan	Light pole - Tango	SO_2 - 48	200187.3	7727017.3	14.0	0,27	2,52	5,05
Sua Pan	sign on tar road	SO_2 - 49	200316.9	7723424.9	14.0	0,10	0,93	1,87
Sua Pan	Airport sign	SO_2 - 50	198163.1	7723492.1	14.0	0,33	3,08	6,17
Sua Pan		SO_2 - 51	196473.0	7723568.5	14.0	0,17	1,59	3,18
Sua Pan	Pole shoreline S of spit	SO_2 - 52	195002.8	7722913.7	14.0	0,41	3,83	7,66
Sua Pan	N corner pole of ... site	SO_2 - 53	194533.9	7723983.8	14.0	0,30	2,80	5,61

* = destroyed

Report date: 13/6/97
Report page: 2

Analysis report for measurements of SO_2 in air using passive samplers.

Analysis report NILU-U-52

Sampling site	Site location	Sample no.	Co-ordinates x	Co-ordinates y	No. of days	SO_4-S µg/ml	SO_4-S µg/m3	SO_2 µg/m3
Maun	Sedie CJSS	SO_2 - 60	-290112.7	7775868.5	13.2	0.16	1.59	3.17
Maun	On tree (destroyed)	SO_2 - 61	-281869.9	7775867.9	13.0	0.12	1.21	2.41
Maun	ORC (u/roof)	SO_2 - 62	-290984.6	7773221.8	13.2	0.05	0.50	0.99
Maun	ORC - fell down	SO_2 - 63	-291021.4	7773203.8	13.2	0.09	0.89	1.78
Maun	"	SO_2 - 64	-291109.9	7773171.6	13.2	0.12	1.19	2.38
Maun	"	SO_2 - 65	-294340.5	7774153.0	13.1	0.03	0.30	0.60

Report date: 13/6/97
Report page: 1

Analysis report for measurements of NO_2 in air using passive samplers.

Analysis report NILU-U-52

Sampling site	Site location	Sample no.	Co-ordinates x	y	No. of days	NO_2-N µg/ml	NO_2-N µg/m3	NO_2 µg/m3
Lobatse	Boteti Street	NO_2 - 1	166669.9	7205617.0	13.8	0.40	3.19	10.47
Lobatse	Gov. Revenue Office	NO_2 - 2	166535.6	7205089.8	13.8	0.33	2.62	8.61
Lobatse	DoM Meas. Station	NO_2 - 3	164819.3	7205801.7	13.8	0.10	0.76	2.48
Lobatse	Tech. Train. College	NO_2 - 4	164398.5	7205655.3	13.8	0.08	0.59	1.95
Lobatse	BMC House # 1	NO_2 - 6	164986.9	7207359.6	13.8	0.31	2.47	8.10
Sampling site	Site location	Sample no.	Co-ordinates x	y	No. of days	NO_2-N µg/ml	NO_2-N µg/m3	NO_2 µg/m3
Mosopa	School (u/roof)	NO_2 - 7	138525.4	7257271.6	13.8	0.08	0.59	1.95
Mosopa	Tree (fell down)	NO_2 - 8	147679.9	7263000.8	13.8	0.01	< 0.01	< 0.01
Sampling site	Site location	Sample no.	Co-ordinates x	y	No. of days	NO_2-N µg/ml	NO_2-N µg/m3	NO_2 µg/m3
Maun	Sedie CJSS	NO_2 - 9	-290112.7	7775868.5	13.2	0.08	0.62	2.04
Maun	ORC (u/roof)	NO_2 - 11	-290984.6	7773221.8	13.2	0.07	0.53	1.76
Maun	ORC - fell down	NO_2 - 12	-291021.4	7773203.8	13.2	0.01	0.03	0.08
Maun	"	NO_2 - 13	-291109.9	7773171.6	13.2	0.07	0.53	1.76
Maun	"	NO_2 - 14	-294340.5	7774153.0	13.1	0.08	0.62	2.04

Appendix B

Soda Ash Botswana – pictures

Soda Ash Botswana

16 May 1997

10:00 AM

On the road from Sua Pan town towards the Soda Ash Plant.

16 May 1997

10:00 AM

Office buildings at Soda Ash Botswana

Vegetation on, and just outside SAB-properties.

The vegetation and the ground is covered with a thick layer of dust.

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BOTSWANA

ABSTRACT
Mission 3 to Botswana comprised of two major parts:
1. Quality control of the measured air pollution data, the structure of the data storage system, reporting procedures for the measured air quality data, and training in use of air pollution dispersion models. The dispersion models introduced to the DoM personnel were the NILU models CONCX and CONDEP. The BCL smelter in Selebi Phikwe was used for a modelling exercise.
2. The purpose, location and analysis results of the passive sampling performed in Botswana 13-29 May 1997. Passive samplers were installed in Lobatse, Mosopa, Moropule, Selebi Phikwe, Sua Pan and Maun. The passive samplers were exposed for approximately 2 weeks.

NORWEGIAN TITLE

KEYWORDS		
Data bases	Dispersion modelling	Passive sampling

ABSTRACT (in Norwegian)

** Classification*
A Unclassified (can be ordered from NILU)
B Restricted distribution
C Classified (not to be distributed)