Pan American Health Organization
World Health Organization
REGIONAL OFFICE FOR THE Americas

Representation of The Bahamas
& Turks and Caicos Islands

IN REPLY REFER TO: BAH-PHE-81.1 – 2017

11 December 2017

Mrs. Janice Miller
Permanent Secretary
Ministry of Environment and Housing
Charlotte House
Charlotte Street
Nassau, New Providence
The Bahamas

Dear Madam Permanent Secretary,

Re: Final Report – Environmental Health Risk Assessment for Pinder's Point, Lewis Yard and surrounding area, Grand Bahama

In response to a recent telephone request from the Office of The Honourable Romauld Ferreira, Minister of Environment and Housing, I am pleased to enclose a copy of the above referenced report.

Your assistance is hereby solicited with ensuring that the same is brought to the immediate attention of the Honourable Minister.

Thank you most kindly for your attention.

Please accept renewed assurances of the highest consideration of this Office.

Yours sincerely,

Sherlin Brown

p.p. Dr. Esther de Gourville
PAHO/WHO Representative
The Bahamas and The Turks and Caicos Islands

EMd/cvm

Enclosure: As stated

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ENVIRONMENTAL HEALTH RISK ASSESSMENT FOR PINDER'S POINT, LEWIS YARD, AND SURROUNDING AREA

- FINAL REPORT -

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Acknowledgements

The project management team of Institute for Risk Assessment Sciences (IRAS) would like to take this opportunity to acknowledge and thank those who made this work possible. We note that this document is the result of the collective effort and expertise from multiple individuals both directly and indirectly involved in the research.

To the Pan American Health Organization/World Health (PAHO/WHO) Organization Country Office to The Bahamas and Turks and Caicos, under whom this report was commissioned, thank-you for your support and coordination efforts. Particularly, to Dr. Gerry Eijkemans, PAHO/WHO representative to The Bahamas and Turks and Caicos Islands: Your understanding and knowledge of environmental health issues, and support for this project have been invaluable. We would also like to thank Ms. Kelly Kavanagh Salmond, project manager, and the staff who both accompanied consultants into the field, and supported the processes of data collection and coordination. We extend our sincerest thanks and gratitude for your diligent efforts and support. With a special note of thanks to project support, Ms. Abigail Pedican. Your on-the-ground project support, effort, and expertise aided in the final report from the beginning to the end.

To the Minister for Grand Bahama, the Hon. Dr. Michael Darville, who requested this assistance of PAHO/WHO in this Environmental Health Risk Assessment for the areas of Pinder's Point, Lewis Yard, and Surrounding Areas. Thank you for your foresight and initiative that requested the support of PAHO/WHO, and ultimately saw this report to fruition. Additional and notable thanks to the Permanent Secretary of the Ministry for Grand Bahama, Melvin Seymour, who developed a Memorandum of Understanding, and supported the administrative needs to the project. Additional thanks to Ministry staff, Ms. Leslie Dorsett for your time and commitment to the development of the most comprehensive report possible. Your diligence in building bridges with local organizations and institutions for the gathering of information was invaluable.

A special thanks to the technical experts that leant their expertise to the process and finalization of the final report and recommendations going forward: Dr. Danny Davis, Dr. Rik van de Weerdt, and Jolanda Willems. Your support and partnership on the process, and finalization was insightful and poignant.

Additionally, we would like to acknowledge the many agencies and individuals that took time out of their busy schedules to meet with us to discuss the past and current environmental health situation is the aforementioned communities. Notable thanks to the local and national authorities that have provided support and information along the way: The Department of Statistics for Grand Bahama, the RAND Memorial Hospital, the Department of Environmental Health Services, and the Grand Bahama Port Authority Environmental Monitoring Unit. Additional thanks to Mr. Joseph Darville, Mr. Maurice Moore, Mr. Bert Pinder and Mr. Michael Wallace, who were especially interested in the pursuit of this assessment. Thank you for your time, dedication, and effort.

Finally, but not least, the team would like to acknowledge and thank the residents in the community for their dedication, support, hospitality, and active involvement in the sampling and data collection. Without this instrumental collaboration with the project team, this report would not have been possible. We thank you and your families for all of your efforts to see this report to its fruition.

Executive Summary

The Environmental health risks associated with the industrial park located near the communities of Pinder's Point, Lewis Yard, Hunters, and Hawksbill; Grand Bahama have long been a source of citizen, activist, and leadership concern.

At the request of the Minister for Grand Bahama, the Pan American Health Organization (PAHO) engaged the Institute for Risk Assessment Sciences (IRAS) of Utrecht University, the Netherlands to conduct an environmental health risk assessment, more specifically, to:

1. independently evaluate empirical environmental and health data to identify harmful exposures that have occurred, or are currently occurring;
2. report potential health effects associated with chemical exposures;
3. recommend actions to protect the public.

It was agreed that an independent assessment, which would not be altered in any substantive way by either PAHO or the Government, was crucial to fully understand any potential risk and maintain trust with the affected communities.

Community Risk Perception

Environmental health concern among residents in the affected communities is very high. There is a strong belief among many that the environmental health impacts of living so close to the industrial area have been, and indeed still are, significant.

Although outside the scope of this assessment, the existing risk perception is important to acknowledge and better understand. Experience has shown that moving forward in addressing environmental health risk depends on the support and cooperation of the communities affected.

The environmental health risk assessment formally started December 4, 2014 and ended November 30, 2015. The project had several dimensions, including:

1. A detailed review and evaluation of existing studies, including "Chemical Health Study, Phase 1" (Wallace, 2014)", and "Grand Bahamas Environmental Health Assessment" (Pedican, 2014);
2. Onsite data collection in the affected communities to gather additional information on emissions, exposures, and health status;
3. Assessment of the current health status of residents due to historical exposures, in particular by taking into account (i) cancer cases and (ii) respiratory disorders and skin and eye irritations;
4. Current chemical exposure was assessed by international experts and using the state of the art analysis facilities at Utrecht University.

Environmental Health Risk Assessment Conclusions*

1. During the monitoring period, and based on air and water sampling, no evidence was found of harmful chemical exposure on a day to day basis in the affected residential areas. There is, however, a potential health risk associated with incidental, or periodic releases of chemicals from the industrial area, such as venting of storage tanks.
2. Based on an analysis of health records extending back over 25 years, no evidence has been found that cancer rates are higher in the studied population than in other areas of Grand Bahama.
3. Based on the analysis of health records extending back over 25 years, there is a downward trend in hospital visits related to respiratory disorders.
4. Overall, the conclusions of the environmental health risk assessment are consistent with the two other previously completed studies, Wallace, 2014, and Pedican, 2014;
5. There is a potential safety risk for the people living in Pinder's Point and Lewis Yard being located close to the industrial area. Fire, for example in the large oil storage bunkers, is the more obvious threat, however, not likely the only risk.
6. There is no independent environmental monitoring system in place, which means that warning systems may be unreliable and that available data on the environmental health risk is incomplete.

*** Acknowledging the Limitations of Environmental Health Risk Assessments**

All complex environmental health risk assessments are based on evidence that may be limited or incomplete in various ways. Although this study was conducted consistent with international best practice, it is important to acknowledge these limitations, including:

- The historical data on cancer cases, for example, may not capture individuals who went to private clinics in The Bahamas or abroad.
- The levels of chemical exposure in the air may be significantly different during other times of the year, for example, when the prevailing winds shift.
- Access to all available data, for example records of complaints maintained by BORCO, was at times difficult to secure.
- Assessing historic risk factors, especially if conditions may have changed over time, is difficult to confirm.

Environmental Health Risk Recommendations

1. An independently run and year-round environmental monitoring system should be established, led by the Government of Grand Bahama and involving the residential community.
2. A professional safety assessment related the potential threat of fires, quakes, hurricanes, and explosions to people living in Pinder's Point and Lewis Yard should be performed.

Statement

The Pan American Health Organization/World Health Organization (PAHO/WHO) country office to the Bahamas and Turks and Caicos Islands was approached by the Ministry for Grand Bahama to carry out an independent assessment on the potential of health effects related to industrial activities in the residential areas located in the Freeport Industrial Park, Grand Bahama. The overall goal of the assessment was to carry out a study that focuses on health effects resulting from current exposure to hazardous chemicals, in the aforementioned area on Grand Bahama.

PAHO/WHO engaged the Institute for Risk Assessment Sciences (IRAS) of Utrecht University, the Netherlands, a WHO Collaborating Centre, to evaluate empirical environmental and health data from the herein defined residential area on the island of Grand Bahama, to identify harmful exposures that have occurred or are currently occurring, to report potential health effects associated with chemical exposures, and to recommend actions to protect public. The project formally started December 4, 2014 and ended November 30, 2015.

The Utrecht University Institute for Risk Assessment Sciences has no ties with the government, industries, or residents of Grand Bahama, and can work fully independently.

The project and preliminary results were discussed during an expert meeting, which took place October 5-7, 2015, in Freeport, Grand Bahama. The meeting was attended by the following experts (in addition to the authors of this report):

- Kelly Kavanagh Salmond, M.A., Project Manager, PAHO/WHO Country Office to The Bahamas and Turks and Caicos
- Abigail Pedican, MPH, project sub-contractor
- Danny Davis, PhD; College of the Bahamas
- John Rainford, MPA; Carleton University, Ottawa and the Warning Project, Canada
- Jolanda Willems, MSc MBA; PreventPartner, the Netherlands
- Rik van de Weerdt, MD, MPH, Toxicologist (ERT); Public Health Authority Gelderland-Midden, The Netherlands

The final report has been reviewed by Danny Davis, John Rainford, Jolanda Willems, and Rik van de Weerdt.

December 7, 2015

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1. Introduction and background

1.1. Introduction and study approach

In the Southern part of Grand Bahama, an industrial park is located, which is bordered by the residential areas Pinder's Point, Lewis Yard, Hunters, and Hawksbill. The proximity of industry to these residential areas has been a source of health and safety concerns by the inhabitants of these areas. Anecdotal information on health and safety issues relates to incidents dating back to the 1980s. At that time, industrial emissions led to visible contamination of the area, and to acute health effects, such as respiratory disorders and skin and eye irritations. The most memorable incident occurred in the late 1980s, when an entire school had to be evacuated and several students were brought to the hospital. Eventually, this incident led to the relocation of the school.

Even though over the years the situation has improved, residents living close to the industrial park still have the impression that their health is severely, adversely being affected by industrial emissions, that the number of cancer cases is higher than on other parts of the island, and that they suffer more from respiratory disorders, and skin and eye irritations.

In the past, a number of studies have been carried out aiming to assess the health impact of living close to the industrial park. These studies were performed by several stakeholders in the area, including individual industries, groups representing the residents, and the Grand Bahama Port Authority. The information on these studies is limited and their results appear hard to find, or are not accessible or publicly available. Hence, in 2014 a new project was initiated by the Ministry for Grand Bahama.

The overall objective of the 2014 project was to carry out a study that:

- focused on health effects resulting from current exposure to hazardous chemicals in the residential areas near the industrial park in Grand Bahama, and;
- provides recommendations for the future.

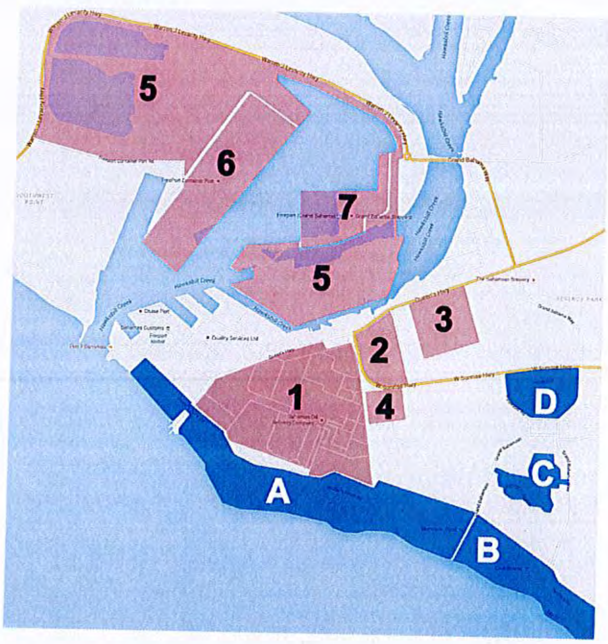
The project, as described in the present report, is unique in the sense that it is the first to attempt collating existing, anecdotal, and new (experimental) information on exposure and health effects, and making the results available to the public.

The approach of the overall project was stepwise and as follows:

1. Available information was collected from local experts, which resulted in two reports: "Chemical Health Study, Phase 1" (Wallace, 2014)", and "Grand Bahama Environmental Health Assessment" (Pedican, 2014);
2. International experts visited Grand Bahama several times to collect additional information on emissions, exposures, and health status;
3. The current health status of residents due to historical exposures was assessed, in particular by taking into account (i) cancer cases and (ii) respiratory disorders and skin and eye irritations;
4. Current chemical exposure was assessed by experimental field measurements;
5. Based on data resulting from the previous steps, recommendations are provided.

1.2. Current industrial activities and chemical emissions in the Industrial Park

The Freeport Industrial Park is located on the West side of the city of Freeport, next to the Grand Bahama harbor. It is about 6 km^2 in size and harbors both chemical industry and nautical and 'geo' activities. A map of the area is presented in Figure 1.1. Pinder's Point and Lewis Yard are residential areas located on the South side of the Industrial Park. The areas are enclosed by the Freeport Harbor on the West side, the North Atlantic Ocean on the South side, and the BORCO oil storage and blending facility on the North side. On the South side (in the ocean), jetties for loading and unloading oil products for/from the BORCO facility are present. Other residential areas under study in the current project are Hawksbill and Wellington, located in between Freeport and the Industrial Park (East of the park).



1. BORCO
2. GB Power Company
3. Polymers International
4. PharmaChem Technologies Ltd.
5. Bahama Rock
6. Freeport Container Port
7. GB Shipyard

A. Pinder's Point & Lewis Yard
B. Hunter's
C. Wellington
D. Hawksbill

Figure 1.1. Map of the Freeport Industrial Park and its surrounding residential areas.

All residential areas are located in close or very close proximity of the various industrial activities in the Park. These activities are represented by seven main industries:

1. Bahamas Oil Refining Company (BORCO). This is the largest petroleum (oil) storage/transshipment and blending facility for refined and crude oils in the Caribbean.
2. Grand Bahama Power Company. This power plant generates electricity by combusting heavy oil.
3. Polymers International; a company producing polystyrene products.
4. PharmaChem Technologies Ltd.; a pharmaceutical company currently producing active ingredients for anti-HIV drugs.
5. Bahama Rock. This company mines limestone in the Industrial Park, by blasting and excavating the geological material.
6. Freeport Container Port (transshipment of containers).
7. Grand Bahama Shipyard (ship-building and repair).

1.3. Population size

In the early phase of the project, and in the project description, it was assumed that the total population living in the residential communities surrounding the industrial park involved approximately 5000 people. In May 2015, however, the Grand Bahama Bureau of Statistics provided the 2010 census data. Population size at that time appeared to be lower, 3076 people. The distribution over the four communities was as follows:

- Pinder's Point 311
- Lewis Yard 934
- Hunters 1108
- Hawksbill 723

2015 census data and data from before 2010 are not available at this moment. A more detailed description of characteristics of the population can be found in Annex A.

2. Historical health information

2.1. Formal and informal sources of information

Those familiar with the history of the affected communities have noted that over the last 35 years, health has been a significant and ongoing concern for the residents in the communities located close to the industrial park. Scientific reports addressing these concerns are, however, limited. In 1986, Mahmood et al. presented the results of *"An investigation on the effects of industrial pollution around a combined industrial complex on the island of Grand Bahama, Bahamas"*. In this extensive study, the impact of industrial pollution on four distinct groups of people was investigated. Students, teachers, workers, and residents who had been studying, teaching, working, or living within a 5 mile radius around the industrial activities for at least 5 years were included in the study. No significant effects on their eyes, ears, respiratory function, skin, respiratory, blood, liver, and kidney function were found.

In 2007, Brathwaite et al. published an epidemiological profile of Grand Bahama over the period 1988-2002. They reported an approximate age-standardized annual cancer incidence rate of 167.7 per 100,000 for the entire Grand Bahama population. For both sexes this rate is lower than the averaged cancer rate for the Caribbean, which measures 185.4 per 100,000 (http://globocan.iarc.fr/Pages/fact_sheets_cancer.aspx). It should be noted that this rate applies to the entire Grand Bahama population, not just to the population living close to the industrial park.

As part of the project, meetings were held with representatives of the residential communities. During two of these town hall meetings, in April and May 2015, people were invited to come forward and share their health concerns. A wide range of health complaints were mentioned. Concerns about breast cancer clusters and respiratory disorders were most widespread. Further, health complaints that were frequently mentioned were reproductive problems, eye and skin irritations, nausea, and headaches.

In order to obtain more quantitative information on the health status of the residents living in the proximity of the industrial park, two official sources of health data were made available for this project by the Grand Bahama Health Services. The Rand Memorial Hospital provided information on cancer cases, reproductive and respiratory disorders and birth defects. The Hawksbill Clinic provided information on respiratory, skin, and eye disorders.

2.2. Data on cancer cases

Even though the project focused on the current exposure situation, health effects caused by exposures in the past may still play a role at present. This is most relevant for cancer cases. Unfortunately, on Grand Bahama no official cancer registry is available. Therefore, an alternative type of cancer registration was used to better understand cancer prevalence. The Medical Records Department/Health Information Unit of the Rand Memorial Hospital provided patient information from the period 1989-2013. All hospital visits related to cancer for the entire island were shared. A total number of 1222 records were made available, of which 103 records were of patients living in one of the communities under study. A wide range of cancer types were recorded.

Since all cases had been recorded by the same procedures and protocols, this data set provides a reliable comparison between the residents living close to the Freeport Industrial Park and the entire population of Grand Bahama. Still, this alternative registry does have its limitations: people (having cancer) may go to private clinics, on Grand Bahama or Nassau, or abroad. Since the information provided was anonymized, it was not possible to determine whether all records available refer to unique individual cases. Records of people returning to the hospital for follow up visits could not be discerned from new cases.

The distribution of cancer types and the relative number of cancer cases are comparable for both the total Grand Bahama population and the subgroup of residents living close to the industrial park. For both populations, five cancer types account for 60% of all cancer cases: breast cancer, prostate cancer, cervix cancer, lung cancer, and stomach cancer. Breast cancer and prostate cancer are the most common diagnoses when all cancer types are considered for both populations. The percentage of breast cancer cases in entire Grand Bahama (25%) and the study population (22%) are similar. Further, the mean age of the women diagnosed with breast cancer is 52 years for both populations. No statistically significant differences between both populations can be discerned. Moreover, these data are also similar to the distributions for the entire Caribbean region. For this region, the most common types of cancer are breast, cervix uteri, colorectum, lung, and corpus uteri cancer (in women), and prostate, lung, colorectum, stomach, and bladder cancer (in men).

Based on an analysis of the available data, no increased cancer risk for residents living in close proximity of the industrial park could be detected. A more detailed discussion and description of the underlying data can be found in Annex A.

2.3. Data on acute disorders

Information on hospital/clinic visits by the study population related to respiratory, skin, and eye disorders were provided by both the Rand Memorial Hospital (1989 - 2014) and the local Hawksbill clinic (October 2008 - April 2011). Some of the respiratory disorders, like asthma and upper respiratory tract infections (URI), occurred frequently, whereas others like lung edema and emphysema occurred only once in the 25 year period. Diagnoses were mainly related to respiratory tract infections. Annex A provides a more elaborate discussion on these health data.

Over the 25 year period, a statistically significant downward trend in hospital visits related to respiratory disorders can be observed. Even though during informal meetings residents have noted that the environmental situation has improved over the years, citizens still link their acute health concerns to (incidental) emissions by companies in the industrial park. Acute health effects due to incidental emissions from industrial parks in other parts of the world have been described in the scientific literature (Delfino, 2002; EPA 2002; Alwahaibi & Zeka, 2015; Tanyanont & Vichit-Vadakan, 2013). More information on both long term and incidental short term emissions is needed to verify this correlation for the Grand Bahama Industrial Park.

3. Current exposure situation

3.1. Chemical emissions and exposure routes

Based on informal reports, personal observations, and interviews with residents and experts, an inventory of emission sources and chemicals has been made (see Annex B.1-2). No formal information on chemical emissions, for example provided by the various industrial parties, was available. The most important chemicals that are being emitted in the Freeport Industrial Park include:

- Volatile organic chemicals (VOCs). This chemical group includes benzene, toluene, ethylbenzene, and xylenes (collectively referred to as BTEX), as well as other volatile, low-molecular-weight alkanes and aromatics emitted by both petrochemical and combustion activities into the air. The most important sources of these chemicals are BORCO, the Power Company, the harbor, and traffic (both regular and industrial). BORCO is said to emit VOCs at a rather constant, yet background level, but also at frequent peak levels, most likely during bunker venting activities. Finally, PharmaChem incidentally releases solvents, which are also VOCs.
- Hydrogen sulfide (H_2S). This gas, having a characteristic 'rotten eggs' smell, evaporates into the air from high-sulfur crude oils handled by BORCO.
- Polycyclic aromatic hydrocarbons (PAHs). These chemicals are produced during combustion processes and as such most likely are being emitted by the Power Company (combusting oil), PharmaChem (combusting waste), shipping activities in the harbor, and traffic (both regular and industrial). Furthermore, these chemicals

are constituents of petroleum products and may thus be emitted by BORCO and the Power Company in the case free product (oil) is accidentally released, and by bilge water spills in the harbor.

- Petroleum (oil) as free product. Substantial emissions of oil occur incidentally in the ocean during oil transshipment at BORCO's jetties and may occur on the BORCO and Power Plant properties in the case of oil leaks. As a result of past leaks, the subsurface system underneath the BORCO property is reported to hold about 1.5 million gallons of free product, floating on top of the ground water table (Shaw Consultants International, 2010).

Not all the chemicals emitted in the Freeport Industrial Park are likely to reach the residential areas. Chemical fate (the lifecycle of a given compound) determines whether the emitted compounds can end up in Pinder's Point, Lewis Yard, Hunters, Wellington, and Hawksbill; with chemical fate being driven by the compounds' physico-chemical properties, the environmental conditions (e.g., wind direction, temperature), and the environmental compartment where the emission takes place. Annex B.3 explains in detail that the environmental compartments air and water can be considered the major vectors for exposure of the residents in the study areas to specific industrial chemicals. Exposure routes for the residents thereby involve (1) inhalation of contaminated air, potentially containing VOCs and H_2S; and (2) drinking/contact with contaminated water, as extracted from ground water wells being present in the Pinder's Point and Lewis Yard areas, and potentially containing petrochemicals.

3.2. Sampling strategy

In the past, several small-scale monitoring activities have taken place. These activities, however, were often linked to specific industrial activities or sites and limited in their (chemical) scope. Moreover, the limited existing monitoring information obviously does not adjudicate the current situation and exposure of residents. Therefore, the project involved environmental monitoring to map the current state of residential exposure. Based on the above exposure route considerations (see also Annex B), this monitoring included:

- Sampling of water from seven ground water wells and one city water tap in Pinder's Point and Lewis Yard and chemical analysis of the water for the presence of BTEX as indicator compounds for petrochemical contamination.
- Sampling of air at seventeen locations throughout the residential areas during the first week of June 2015. A passive sampling approach was applied and (background) VOC concentrations were quantified. Additionally, in the period of July to November 30, 2015, active air sampling pumps were stationed at four locations in Pinder's Point and Lewis Yard. With these pumps it was hoped to capture the higher concentrations of VOCs occurring during venting events (i.e., episodes of high odor intensity that are caused by specific activities at the BORCO site, probably the venting of tanks).

Maps indicating the air and water sampling locations are presented in Annex C.

3.3. Chemical exposure assessment

Chemical analyses of the water samples did not reveal the presence of BTEX (see Annex C1). Concentrations of these compounds were below the limits of detection of the instruments and methods used and thereby at least a factor of 170 to 17,000 below the Maximum Contaminant Levels (MCL) for these compounds, as set for drinking water by the United States Environmental Protection Agency (USEPA). Hence, the ground water system from which water is being pumped up by the residents does not seem to contain substantial or hazardous concentrations of BTEX and the substantial presence of other petrochemicals is thereby also highly unlikely.

The air monitoring program in June 2015, during which air was passively sampled for up to 6 days, did demonstrate the presence of a range of VOCs. These included BTEX, but also alkanes and other substituted aromatics (see Annex C2). The quantified concentrations were, however, low, which agreed with the absence of the anticipated 'petroleum odor' during the sampling period. Concentrations of BTEX were below the existing USEPA Reference Concentrations (RfCs), implying that adverse health effects are not likely to occur even in case residents were to be exposed to these concentrations for a lifetime period. Similarly, according to USEPA standards, continuously breathing the sampled air would result in not greater than a one-in-a-10,000 to 100,000 increased chance of developing cancer. Considering a population in the residential areas amounting to about 3000, increased cancer rates are thus not to be expected under these conditions. During winter, however, when the winds predominantly are from the Northeast and directed towards the residential communities of Pinder's Point and Lewis Yard, VOC concentrations in these residential areas may be higher than those detected in June 2015, also considering the reports of a constant smell of petroleum by the residents. Hence, it cannot be excluded that concentrations during other times of year may exceed the RfCs. The project planning did not allow sampling during winter and the accompanying exposure concentrations thus could not be quantified.

Although the contribution of traffic and petrochemical/combustion activities to the VOC concentrations cannot be distinguished, BORCO appears to be a clear source of the compounds, since VOC concentrations declined along a transect moving away from a high-activity (pumping) area on the BORCO property.

Despite the fact that residents have complained about frequent episodes of peak petroleum concentrations that give rise to acute health effects (most probably caused by BORCO venting events during which oil fumes are released), these did not occur during the period of July – November 30, 2015, the period during which active air sampling occurred (see Annex C3). Consequently, peak VOC and H_2S concentrations to which residents are potentially being exposed could not be quantified. The absence of venting events corresponds with the absence of reported odor nuisance and health effects in this period (see Annex D).

3.4. Safety assessment

In addition to chemical exposure, several safety issues play a role in the risk to residents. These are all linked to the close proximity of the residential areas to the industrial properties.

- Pinder's Point and Lewis Yard are located exceptionally close to BORCO. In the case of an emergency, impact on the residents seems inevitable. Examples of emergency situations include bunker fires caused by lightning strike, hurricanes, and explosions. In August 2015, a bunker fire occurred.
- The Bahama Rock Company applies blasting for limestone mining purposes. The resulting quakes have been registered in the Hawksbill, and also in the Pinder's Point area. It is unclear whether the bunkers and pipelines on the BORCO property, being located close to the Bahama Rock Company and the residential areas, are fully quake-resistant, also considering the reported low stability and fragile nature of the underground (Eclipse Environmental and Engineering, Inc., 2009).

A professional safety assessment based on the above issues requires specific approaches and/or models, about which the authors of this report have insufficient knowledge. According to, for example, Dutch guidelines, the minimal distance between a residential area and petrochemical activities is recommended to be at least 90 m. Several homes in Pinder's Point and Lewis Yard do not meet this standard.

4. Conclusions and recommendations

Based on the analysis of hospital records extending back over 25 years, it can be concluded that cancer rates and those of other, acute, disorders in the population living in the residential areas close to the Freeport Industrial Park, are not higher than in other areas of the island of Grand Bahama. Furthermore, exposure measurements indicated that concentrations of probable contaminants in water and air were below levels of concern during the test period. As such, no evidence was found of significant chemical exposure on a day to day basis. Yet, based on information from the residents, there seems to be a health risk associated with incidental, or periodic releases of chemicals from the industrial area, even though these releases could not be captured during the sampling period. Additionally, there is a potential safety risk of people living in close proximity of, in particular, the large oil storage bunkers on the BORCO property.

Since residents in the study area still express concerns about their health and safety, mainly related to the above-mentioned incidental emissions of chemicals, more information on the accompanying (short term) exposures is required. Because the timings of the incidental emissions are unpredictable, we recommend the implementation of a continuous air monitoring system for example "*e*-noses", which could provide such information. A similar system may also function as an early warning system in case of a chemical emergency. We recommend the system to be implemented and led by the Government, but to involve the community and, if possible, the industry, in a transparent way. Also, we recommend a professional safety assessment related the potential, sequential impact of quakes, hurricanes, and explosions on the industrial parties and the residential communities.

ANNEX A

Epidemiological and demographic review

A1. Population under study

A1.1. Size of population

This study focused on the communities situated close to the Grand Bahama Industrial Park. The population of concern consists of the residents of the communities located south and east of the industrial park. The communities considered were:

- Pinder's point
- Lewis Yard
- Hunter's
- Hawksbill.

In the early phase of the study and in the project description it was stated that the total population of all these communities combined would be around 5000 people. In May 2015, the Grand Bahama Bureau of Statistics provided the 2010 census data. Population size at that time turned out to be lower, around 3000 people.

The distribution of the population over area codes is given in Table A1.

Table A1. 2010 Census data on Pinder's Point and surrounding communities (Grand Bahama Bureau of Statistics, May 2015).

Area code	Number of inhabitants
270801 Pinder's Point	311
271401 Bartlett Hill/ Lewis Yard	303
271501 Lewis Yard	300
271601 Hawksbill	342
271701 Hawksbill	381
272001 Hunters Town	427
272101 Hunters Town/ Mack Town	393
272401 Lewis Yard	331
272701 Mack Town/ Lewis Yard/ Hunters	288
Total	**3076**

Based on remarks during interviews with residents, it can be assumed that the number of people living in the area has decreased over the years. Information on earlier and 2015 census data is not available at this moment. For the assessments performed in this report, the 2010 data as mentioned in Table A1 will be used.

The codes mentioned in the table refer to specific areas within the communities. Codes referring to the same communities (e.g. 271601 Hawksbill and 271701 Hawksbill) have been combined to provide an overview of the population size of the communities, as they are commonly used. The population sizes per community that will be used in this report are given in Table A2.

Table A2. Combined number of inhabitants for Pinder's Point and surrounding communities.

Community	Number of inhabitants
Pinder's Point	311
Lewis Yard	934
Hunters Town	1108
Hawksbill	723
Total	3076

The population size of the Pinder's Point community is considerably smaller than that of the other communities. Pinder's Point is a distinct community, since most of its area borders directly to one of the main industries of the Freeport industrial park.

The division into these four communities is chosen, because it can be connected to the health information data provided. Information on hospital and health clinic visits is provided anonymously, but with address information; the address level being one of the four categories mentioned above.

A1.2. Information on population

The 2010 census data provide, among others, information on income situation per household, access to health insurance, education level, and nationality of the residents. Table A3 lists this information.

Table A3. Information on income, health insurance, level of education, and nationality among the residents.

Community	Households income 25,000 max	No access to health insurance	Highest level of education: secondary school	Bahamian nationality
Pinder's Point	53%	62%	89%	87%
Lewis Yard	72%	77%	90%	65%
Hunters Town	53%	61%	83%	88%
Hawksbill	43%	71%	87%	87%
Total	48%	69%	87%	80%

In general, access to health insurance is low in all four communities. The level of education is comparable for the residents in the four communities. Differences can be found in the percentage of households with an income up to 25,000 dollars. This percentage is distinctly higher in Lewis Yard. Lewis Yard is also the community with a relatively low percentage of residents with Bahamian nationality. For this community, the percentage of people with a Haitian nationality is 35%, whereas in the other three communities 13% of the people have a Haitian background.

A1.3. Previous studies on health effects related to the Grand Bahama industrial park

Since the 1950s, Grand Bahama, being the northern-most island in the Bahamas, has been a site with many industrial activities. Current and past industries at Grand Bahama consist of oil storage, refining and shipment, pharmaceutical and polymer companies, a power plant, and cement industry. These industries and their potential emissions are described in detail in Annex B.

Residential settlements are located nearby these activities, i.e., Pinder's Point, Hawksbill, Hunter's, Lewis Yard, and Mack Town. Several researchers have expressed their concerns about the safety of the residents in these communities, because of the nearby industrial activities. Pedican (2014), in preparation for this project, collected a number of the reports locally available on the health concerns. Dr. Cooper was one of the first researchers, who performed a study on Grand Bahama (date unknown). He mentioned that health effects on Grand Bahama were caused by high levels of e.g. mercaptans, sulphur-containing compounds, and particulate matter. These compounds are released through air by different industrial parties, amongst others the oil refining industry. Dr. Cooper also registered increases in health effects during the winter months, when winds blew from northwest, suggesting air pollution to be the cause of the health effects.

In 1985, the Grand Bahama Environmental Task (GBET) studied the health complaints of the residents in Hawksbill, Lewis Yard, Pinder's Point, and Hunter's by a house to house survey. The researchers found that 15% of the citizens complained about dizziness, 32% about headaches, 6% of the citizens noticed skin rashes, 12% eye irritation, and 18% nauseous feelings.

In 1986, Mahmood et al. presented the results of "An investigation on the effects of industrial pollution around a combined industrial complex on the island of Grand Bahama, Bahamas". In this extensive study, the impact of industrial pollution in four distinct groups of people was studied. Students, teachers, workers and residents; studying, teaching, working, or living in a 5 miles radius around the industry for at least 5 years were included in the study. No significant effects on their eyes, ears, respiratory function, skin, respiratory, blood, liver, and kidney function were found.

In 2007, Brathwaite et al. published an epidemiological profile of Grand Bahama over the period 1988-2002. They reported an approximate age-standardized annual cancer incidence rate of 167.7 per 100,000 for the entire Grand Bahama population. For both sexes this rate is lower than the averaged cancer rate for the Caribbean, which is 185.4 per 100,000 (http://globocan.iarc.fr/Pages/fact_sheets_cancer.aspx). It should be noted that this rate applies to the entire Grand Bahama population, not just to the population living close to the

industrial park. In a recent discussion with dr. Brathwaite, he added that no significant differences were found between the various communities at Grand Bahama.
In 2011, another resident study was performed by community activists. They found that 10% of the 155 citizens complained about having cancer and 13% reported respiratory effects.

For both the study from Cooper and the GBET, no additional information was available about confounding factors, like age, gender, living distance from industrial activities, job, etc. Therefore, the epidemiological quality of these studies should be considered low, but the results do raise questions about the health effects of citizens living nearby the industrial activities.

A2. Health data

A2.1. Informal information on health concerns

Health is a big concern for the residents living in the communities close to the industrial park. As part of the project, meetings were held with representatives of the communities. During two town hall meetings, in April and May 2015, people were invited to share their health concerns. Furthermore, during the preparations for the sampling and during the actual sampling of water and air, in support of this project, residents expressed their worries and shared health information.
A wide range of health complaints were mentioned. Within the communities, concerns about (breast) cancer clusters and respiratory disorders are most widespread. Further, health complaints frequently mentioned are reproductive problems, eye and skin irritations, nausea, and headaches.
People occasionally also remark that the number of health issues was higher in the past. An often heard remark was that the present project started 2-30 years too late to study the real problems. A lot of people referred to the incidents in the late 1980s, which led to relocating schools.

Considering both the data from earlier reports and the health aspects mentioned by the residents, the focus in this project was on the following health issues: respiratory disorders, cancer, reproductive disorders, and eye and skin irritation.

A2.2. Quantitative data on health

Two sources of health data were made available for this project by the Grand Bahama Health Services. Grand Bahama Health Services is an institution of the Public Hospitals Authority located on the Island of Grand Bahama. It is a local healthcare system comprised of the Rand Memorial Hospital and ten satellite Community Health Clinics. For this project, data were provided by both the Rand Memorial Hospital and the Hawksbill Clinic. Rand Memorial Hospital is the only public hospital on the island, providing services in a wide range of medical specialisms, including oncology, ear, nose and throat, and gynecology; all being of relevance for the project.

Hawksbill clinic is the Community Health Clinic located in the center of the area of concern. The Community Health Clinics provide a range of primary health care services. http://gbhs.phabahamas.org/about/historical-overview/

A2.3. Rand Memorial Hospital

The Medical Records Department/Health Information Unit of the Rand Memorial Hospital provided in patient information from the period 1989-2013.

The following types of disorders were recorded:

- Cancers, types of cancers occurring
  - Bladder, breast, bronchus/lung, cervix, colon, kidney, larynx, multiple myeloma, ovary, pancreas, prostate, pleura, rectum, secondary brain, and stomach
- Reproductive disorders, types occurring
  - Abortion, blighted ovum, ectotopic pregnancy, excessive menstruation, female infertility, menstrual disorders, abortions, other abnormalities of the uterus, tubal pregnancy
- Respiratory disorders, types occurring
  - Asthma, bronchitis, chronic airway obstruction, (chronic) tonsillitis, COPD, bronchopneunomia, pneumococcal pneumonia, upper respiratory tract infection (URTI)
- Births defects, types occurring
  - Accessory of toes, brachial cleft abnormalities, congenital heart abnormalities, congenital hydrocephalus, congenital pyloric stenosis, Hirschsprungs disease, malformation of Aqueduct of Sylvius, other congenital malformations of limbs, polydactyly, spina bifida, syndactyly, undescended testicle

For the 25 year period (1989-2013), the Medical Records Department checked their files for patients living in the concerned communities. All data were provided anonymously. Information provided per record included:

- Visit date (day, month, year)
- Age of patient (in years)
- Sex of patient
- Address (Pinder's Point, Lewis Yard, Hunter's Town, Hawksbill)
- Diagnosis

Over the 25 year period for the entire population the following numbers of records were made available:

- 103 records concerning all types of cancers
- 278 records concerning all types of reproductive disorders
- 236 records concerning all types of respiratory disorders
- 14 records concerning all types of birth defects

Since the information provided was anonymized, it was not possible to determine whether all records available refer to unique individual cases. Records of people returning to the hospital for follow up visits could not be discerned from new cases.

A2.4. Hawksbill clinic

The Hawksbill Clinic is located in the vicinity of the communities of concern.

Personnel from the Hawksbill Clinic provided an overview of the visits to their clinic in the period October 2008 through April 2011, in total 31 months.

The Information provided per record included:

- Visit date (day, month , year)
- Age of patient (in years)
- Sex of patient
- Address (Pinder's Point, Lewis Yard, Hunter's Town, Hawksbill)
- Diagnosis

The following types of disorders and numbers were recorded during the 31 months period:

- Respiratory disorders, 99 records
- Sore throat, 105 records
- Skin rashes, 55 records
- Eye irritation, 12 records
- Headaches, 8 records
- Unexplained vomiting, 26 records

A2.5. Limitations of data

Even though a large number of data have been made available, providing information on the health status of a large number of people over a long period, it should be noted that the actual, total number of health issues might be higher. The information acquired relates to two public healthcare facilities. It is known that not all people visit these clinics in case of health problems. Some people visit private hospitals, either on Grand Bahama, or in Nassau or in the United Stated. Also, in some cases, employers provide health care for their workers in company-owned or US clinics. Hence, the number of hospital visits reported herein may be an underestimation of the total number of health problems that occurred over the years.

A3. Rand Memorial Hospital

A3.1. Cancer cases

The Medical Records Department/Health Information Unit of the Rand Memorial Hospital provided in patient information from the period 1989-2013. These records only related to patients living in one of the communities under study.

In a later stage (November 2015), all visits related to cancer for the entire island were shared. A total number of 1222 records were made available, of which 103 records were of patients living in one of the communities under study.
The distribution of records over the different types of cancer for the communities is given in Figure A1.

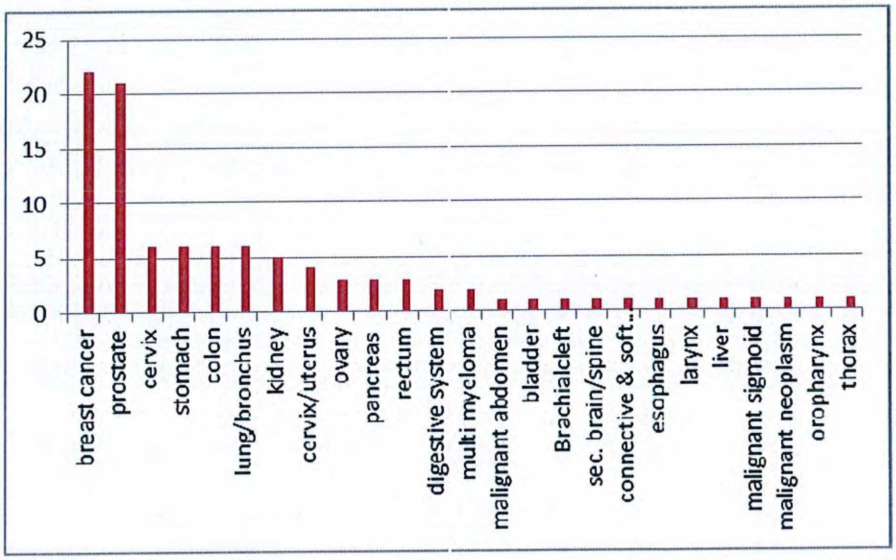


Figure A1. Number of hospital records related to specific cancer types for the entire study population.

Breast cancer and prostate cancer are the most common diagnoses when all cancer types within the four communities are considered. The percentage of breast cancer cases within all women diagnosed with cancer is 36.6%, for prostate cancer in men this percentage is 51%.
When all cancer cases are split over the four communities, breast cancer and prostate cancer remain the two types most commonly occurring. The absolute numbers for the specific types of cancer are low and similar for the four communities.

For the Caribbean region, the most common types of cancer are breast, cervix uteri, colorectum, lung and corpus uteri cancer (in women); and prostate, lung, colorectum, stomach and bladder cancer (in men).
The rate for breast cancer is 26.6%; for prostate cancer it is 38.7%. The age-standardized rates for breast cancer and prostate cancer are 46.1 and 79.8, respectively http://globocan.iarc.fr/Pages/fact_sheets_population.aspx.

A3.2. Comparison with the entire Grand Bahama population

The distribution over cancer types and the number of cancer cases is similar for both the total Grand Bahama population and the subgroup of residents living close to the industrial park. For both populations, 60% of all cancer cases are caused by 5 types of cancer: breast cancer, prostate cancer, cervix cancer, lung cancer, and stomach cancer. Breast cancer and prostate cancer are the most common diagnoses when all cancer types are being considered for both populations. The percentage of breast cancer cases in entire Grand Bahama (25%) and the study population (22%) are similar. The mean age of the women diagnosed with breast cancer is 52 years for both populations. Hence, no statistically significant differences between both populations can be discerned.

A4. Respiratory disorders

A4.1. Types of respiratory disorders

A wide range of respiratory disorders was found in the records of the Rand Memorial Hospital. Some of these disorders, like asthma and upper respiratory tract infection (URI) occurred frequently, whereas others, like lung edema and emphysema, occurred only once in the 25 years period. Figure A2 gives an overview of different types of respiratory disorders recorded and the number of records found related to each disorder.

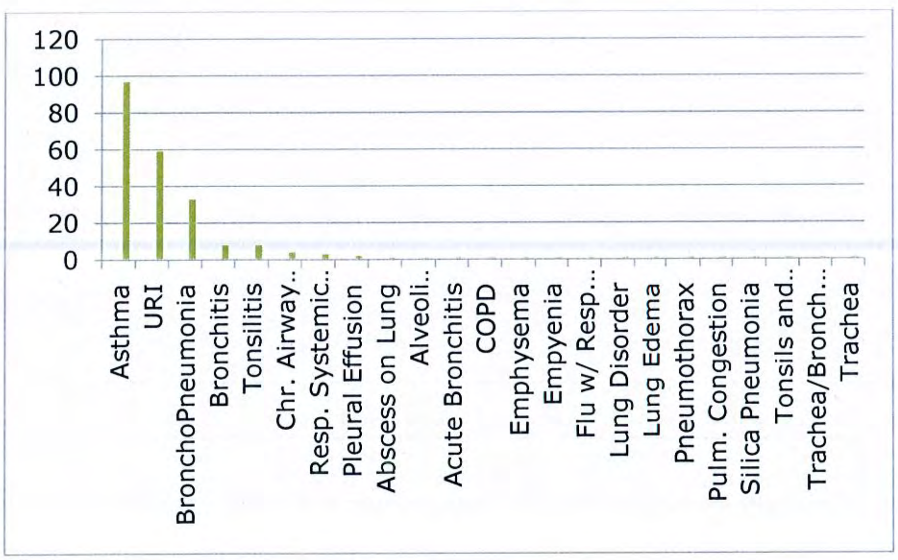


Figure A2. Number of hospital records related to respiratory disorders in the entire study population.

Asthma and URI are by far the respiratory disorders occurring most. (Bronco) pneumonia holds place number three. The same distribution can be found in all four distinctive communities.

A4.2. Seasonal influence

Wind directions change over the year on Grand Bahama (see http://www.windfinder.com/windstatistics/freeport grand bahama). In the period April-September, the wind is predominantly south-east, while in the period October-March it is predominantly north-east.

Since the communities are located south, south-east, and east of the industrial park, this annual change in wind direction may affect the frequency of acute health complaints directly linked to industrial emissions. Residents from the communities have mentioned a variety in the number and severity of respiratory complaints over the year.

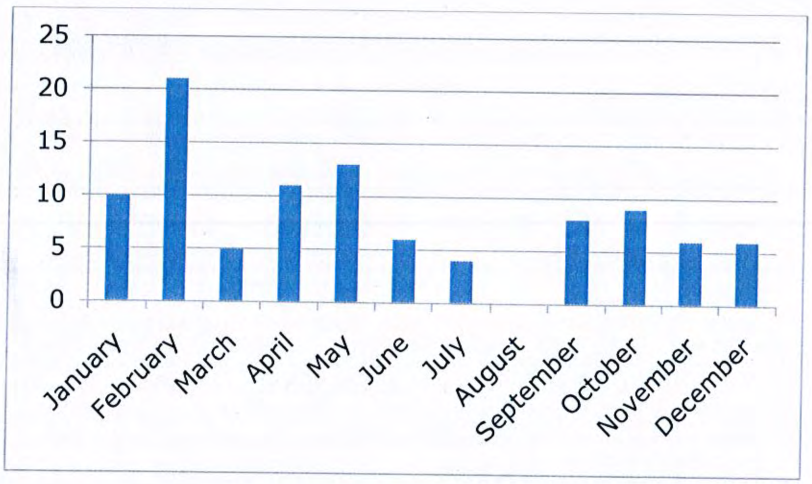


Figure A3. Monthly fluctuation of asthma hospital records for the entire study population.

For all communities, a dip in hospital records appears to be present in the summer months, with the prevailing wind coming from the south-east. Statistical analyses however showed that the differences in asthma hospital visits during the months with winds coming predominantly from the south-west were not significantly different from those during the months with winds coming predominantly from the south-east.

The same overview is composed for the frequency of URI records over the year in Figure A4.

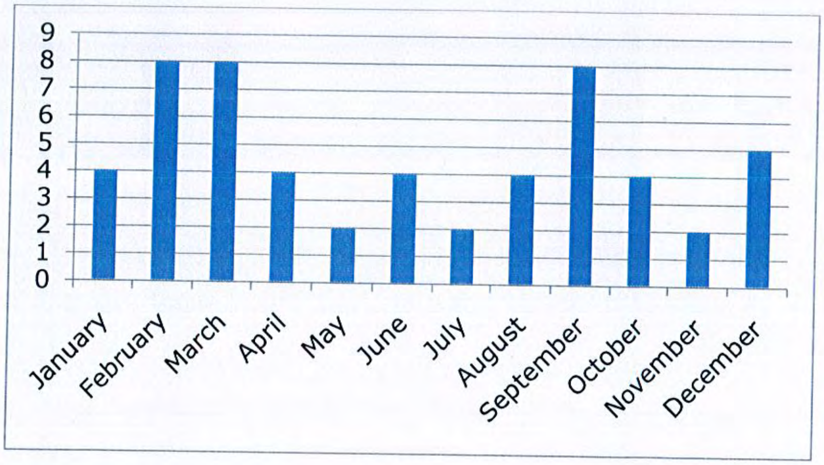


Figure A4. Monthly fluctuation of upper respiratory infections (URI) hospital records for the entire study population.

Also in this case, differences were not statistically different.

A4.3. Trends in hospital visits for respiratory disorders

During conversations with representatives of the communities and during direct meetings with residents, a downward trend in health issues, especially with respect to respiratory disorders was mentioned. In figure A5, the number of hospital records per year over the period 1989-2008 is shown.

Figure A5. Number of hospital records related to respiratory disorders over the period 1989-2008 for all communities.

For the entire population and for the four specific communities, a statistically significant downward trend in hospital visits can be observed. After 2008, no more files were added, or made available.

A5. Reproductive disorders and birth defects

A5.1. Reproductive disorders

The reproductive disorders found in the Rand Memorial records fall in 11 different categories of diagnosis (see Figure A6). Abortion is by far the largest category. The definition of abortion used in this case is not known. Usually spontaneous abortion is defined as natural death of a fetus within 20 weeks of gestation. Among women who know they are pregnant, the miscarriage rate is roughly 10 to 20%, whereas rates among all conceptions are around 30 to 50% (http://www.nichd.nih.gov/).

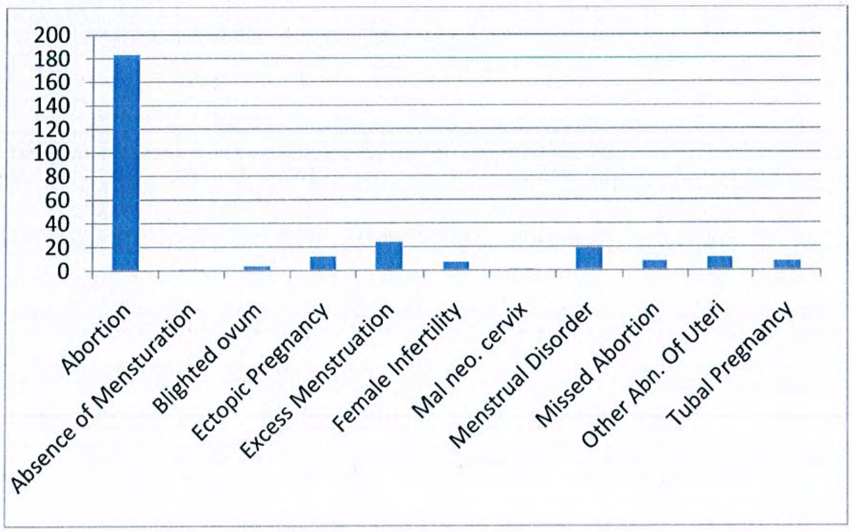


Figure A6. Number of hospital records related to reproductive disorders during the period 1989-2008.

A5.2. Birth defects

Over the period 1989-2013, in total 14 hospital visits were related to birth defects. 13 different types of birth defects were described in the records (Figure A7).

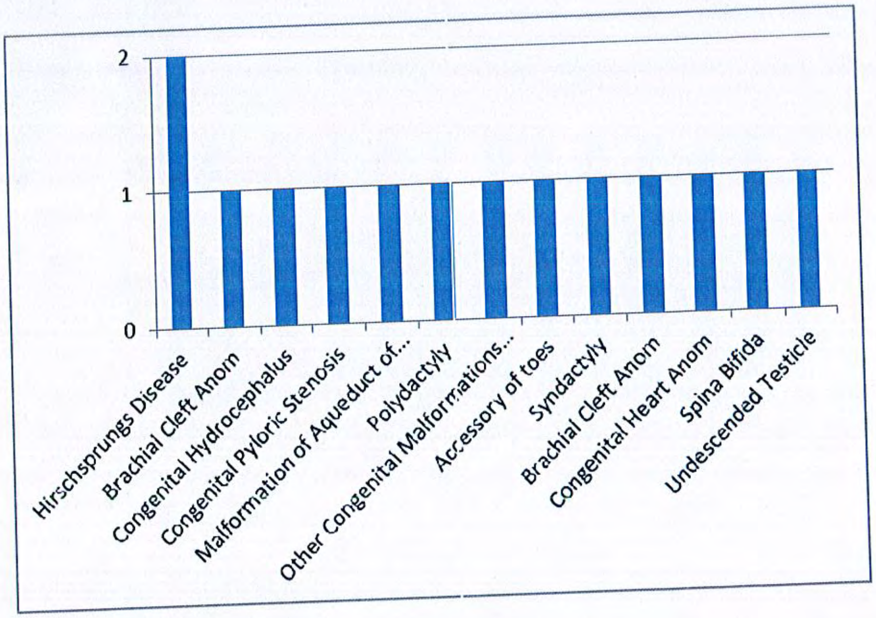


Figure A7. Number of hospital visits related to birth defects in the entire population (1989-2013).

A6. Hawksbill Health Clinic data

A6.1. Respiratory disorders

The information provided by the Hawksbill clinic refers to the period October 2008 till April 2011. In this period, 99 records on respiratory disorders were available. Diagnoses were mainly related to respiratory tract infections, in most cases this was specified to upper respiratory tract infections. As compared to the Rand Memorial hospital, a much smaller number of asthma cases were reported. This could be due to differences in expertise in lung disorders between the two clinics.

Again, the distribution over the different types of respiratory disorders is similar for all four communities.

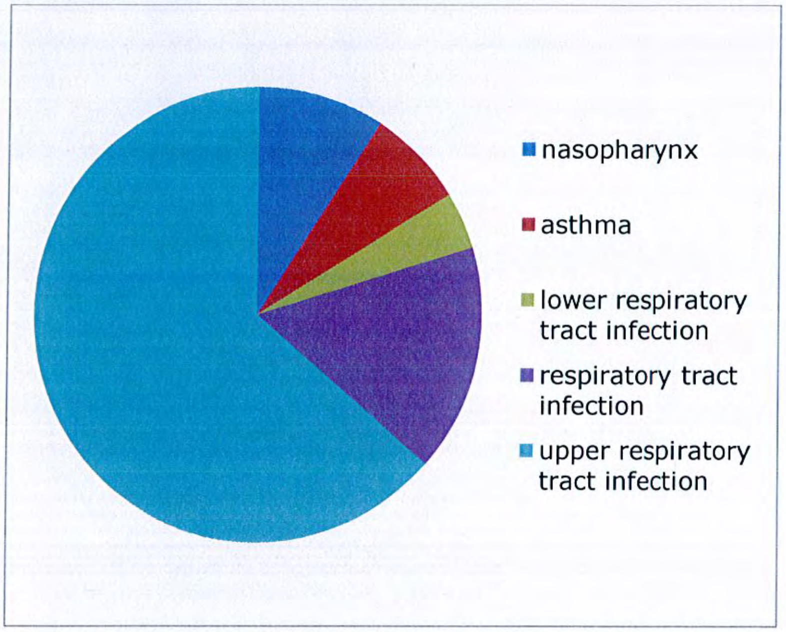


Figure A8. Distribution of respiratory disorders in the entire population (2008-2011).

A6.2. Persistent Runny or Irritated Eyes

Based on remarks by the residents and based on the 1986 study by Mahmood et al., special attention was paid to records on eye disorders. Over the 31 month period, in total 12 clinic visits concerning eye problems were recorded (Figure A9). No specific eye disorder stood out in this overview. The increased number of cases of conjunctivitis, which was mentioned in the Mahmood report, was not present in the 2008-2011 records of the Hawksbill clinic.

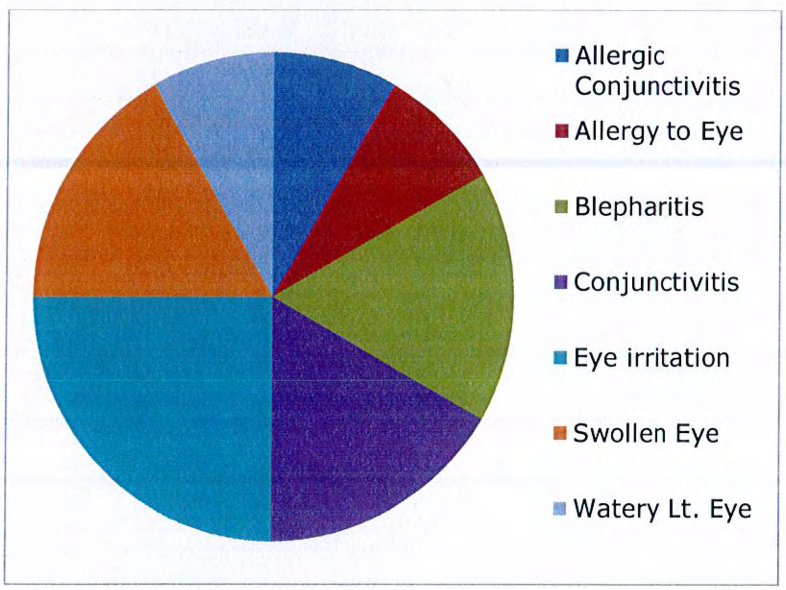


Figure A9. Distribution of eye disorders over categories for the entire population.

A6.3. Skin disorders

In total 55 clinic records referring to skin disorders were found. The most common diagnosis was dermatitis (70% of all records), followed by rash in 22% of the cases (Figure A10).

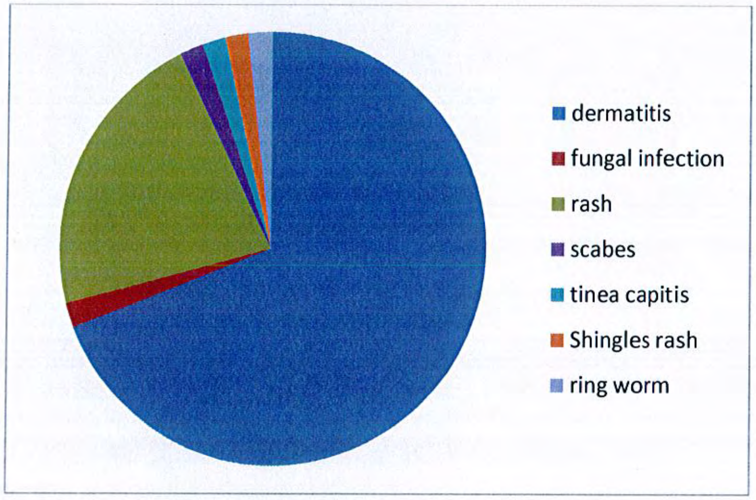


Figure A10. Distribution of skin disorders over categories for the entire population.

A6.4. Headaches and unexplained vomiting

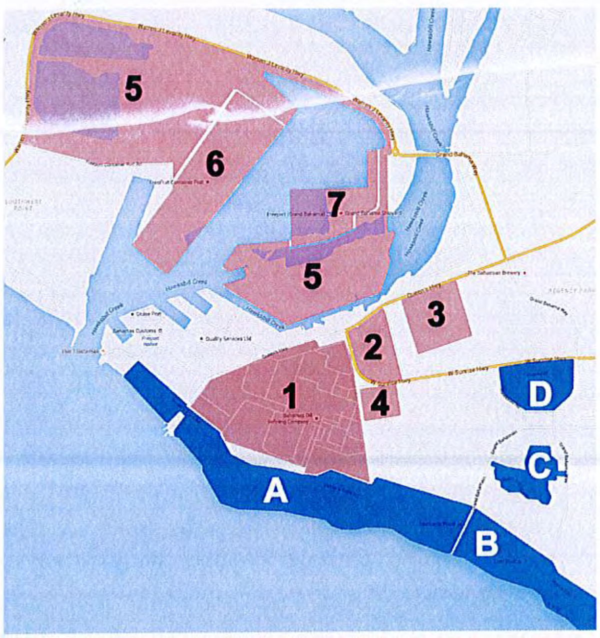
Again based on conversations with residents, high occurrences of clinic records related to headaches and vomiting were expected. However, these complaints do not show up in the records provided. In total 10 visits related to headaches were reported, of which 5 were classified as migraine. Twenty-six cases of "unexplained vomiting" were recorded between October 2008 and April 2011.

ANNEX B

Chemical source inventory, qualitative exposure assessment, and sampling strategy

B1. Past and current industrial activities in the Freeport Industrial Park

The Freeport Industrial Park is located on the West side of the city of Freeport, next to the Grand Bahama harbor. It is about 6 km^2 in size and harbors both chemical industry and nautical and 'geo' activities. A map of the area is presented in Figure B1. Pinder's Point and Lewis Yard are residential areas located on the South side of the Industrial Park. The areas are enclosed by the Freeport Harbor on the West side, the North Atlantic Ocean on the South side, and the BORCO oil storage and blending facility on the North side. On the South side (in the ocean), jetties for loading and unloading oil products for/from the BORCO facility are present. Other residential areas under study in the current project are Hawksbill and Wellington, located in between Freeport and the Industrial Park (East of the park).



1. BORCO
2. GB Power Company
3. Polymers International
4. PharmaChem Technologies Ltd.
5. Bahama Rock
6. Freeport Container Port
7. GB Shipyard

A. Pinder's Point & Lewis Yard
B. Hunter's
C. Wellington
D. Hawksbill

Figure B1. Map of the Freeport Industrial Park and its surrounding residential areas.

The current industrial activities in the Freeport Industrial Park include the following:

- Petroleum (oil) storage/transshipment and blending by the **Bahamas Oil Refining Company** (BORCO; EST 1958). BORCO is the largest oil storing company in the Caribbean and in terms of area coverage it is also one of the largest companies in the Freeport Industrial Park (it occupies about a quarter to one third of the park area).

Although the company name suggests otherwise, there are no current refining activities. The refining unit has been demolished in 2009. Petroleum products (both crude and refined) are imported from overseas and unloaded at the jetties in the ocean on the South side of the island and pumped through offshore pipelines onto land, into bunkers, of which there are about 84 on the BORCO property. Blending occurs on site and both bended and unblended products find their way back to the jetties, where they are loaded for transport to other locations. Crude oils processed include both sweet and sour oils, i.e., both sulfur-poor and -rich ones.

- Generation of electricity by the **Grand Bahama Power Company** (EST 1967). The power company generates electricity by combusting a heavy oil product (Bunker C), which is stored on site in bunkers. Combustion gases are emitted through about 5 chimneys located on the property.
- Production of polymers by **Polymers International** (EST 1994). This company produces polystyrene products (beads, pellets, lids, etc).
- Production of bulk pharmaceutical ingredients and registered intermediates by **PharmaChem Technologies Limited** (EST 2006). The plant on the 62-acre large site currently produces tenofovir disoproxil fumarate, the active ingredient in HIV/AIDS drugs.
- Mining of limestone by the **Bahama Rock** company. This company applies blasting to produce rock material. Mega-cranes and large trucks are operational on the site for excavation and transporting activities.
- Transshipment and handling of containers in the **Freeport container Port** (EST 1996).
- Ship-building and repair in the **Grand Bahama Shipyard** (EST 1999).

Past industrial activities, in addition to the above, have included:

- Refining petroleum products. The refining activities took place on the current BORCO property.
- Previous owners of the PharmaChem pharmaceutical company have produced naproxen and steroid products.
- Other previous pharmaceutical companies have produced antioxidants (Uniroyal; 1991-2001), cimetidine (Franklin Chemicals; 1981 - 1986), and Ceflosporine antibiotic (Gist-Brocades; 1987 - 1990).

B2. Chemical source/emission inventory

Personal observations, interviews with residents and experts, and literature (report) research has led to the following list of emission sources and specific chemicals emitted by the different industrial parties.

- BORCO acts as a source of **petroleum** and **petrochemicals**, as well as of hydrogen sulfide (**H_2S**), a gas with a distinct 'rotten egg' smell. First, the handling of the products at the jetties causes petroleum fumes and incidental oil spills in the ocean, which have been reported to strand on the shore and pollute the coast. Second, the activities on site cause a 'background' but distinct petroleum smell, which can be observed most frequently and clear on the North and West side of the property, but depending on the wind direction (thus, the time of year) may also be detected at the other borders and surrounding areas. Third, specific activities event-wise result in strong petroleum fumes that have been reported to cause acute health complaints by residents. Both the background and fume events concern emissions to the air and will contain volatile petroleum hydrocarbons, including, but not limited to, **benzene, toluene, ethylbenzene, xylenes** (generally collectively referred to as **BTEX**), low molecular weight **alkanes** and **(alkylated) aromatics**. The events may be accompanied by H_2S emissions, in case sour crude oils are concerned. Fourth, a previous report (Shaw Consultants International, 2010) describes the existence of a huge petroleum phase (estimated volume of about 1.5 million gallons in 2009) underneath the current BORCO property, floating on top of the ground water table. This non-aqueous phase liquid (NAPL) would find its origin in past activities and/or leaks and may cause contamination of the ground water. Fifth, past and ongoing activities have caused petroleum contamination of the soil on site, but as far as the authors know, not off site.
- The Grand Bahama Power Company emits gasses and particulate matter produced by the combustion of Bunker C oil. This oil is known to be very rich in toxic organic chemicals (Vrabie et al., 2009; 2010) and may also contain sulfur compounds and heavy metals. The combustion gasses have frequently been observed to be yellowish/brownish. This may suggest the presence of toxic **sulfur compounds** (like SO_x). Combustion of Bunker C oil will also result in the formation of **polycyclic aromatic hydrocarbons (PAHs)**, which are well-known toxic (carcinogenic) compounds. The combustion gasses are emitted into the air through 5 chimneys. The company applies ground water for cooling purposes, which is rich in sulfur. The process water is discharged into the Hawksbill Creek and may contain H_2S. Accidental spills by e.g., leaking pipelines could cause the emission of **Bunker C oil** into soil on site.
- Polymers International. In terms of emissions, there is not much information available on this company. Operational emissions of styrene (the basic material)

might be expected, but cannot be confirmed. Information has been found that the company disposes aqueous streams to deep injection wells, or has been doing so in the past.

- PharmaChem Technologies Ltd. uses different chemicals in their production processes. It is not completely clear what happens with the company's waste. At least part of it is combusted in an incinerator located on site. The combustion products have been observed to consist of black smoke, indicating incomplete combustion and the formation of **PAHs**. The chimney is blackened and has a limited height. Whether or not other waste is dumped on site or transported and dumped off site is unknown. Also for this company, information has been found that aqueous streams might be disposed to deep injection wells. In the vicinity of the company, different **solvent**-like odors (including ether-like) have been observed.
- The Bahama Rock Company does not emit chemicals; the blasting however produces quakes and fine particulate matter (geodust).
- The container Port and the Grand Bahama Shipyard will emit chemicals related to regular shipping activities, such as bilge water (**oil**) and paint waste. Chemicals contained in these streams occur in many harbors worldwide and will include **PAHs**.
- Past industrial activities may have cause chemical emissions to air, soil, ground water, and surface water (i.e. the Hawksbill Creek). Examples of such emissions are refinery emissions to the air, oil contamination of the soil and ground water (see above), and emissions by former pharmaceutical companies.

B3. Qualitative exposure assessment for Pinder's Point, Lewis Yard, and surrounding areas

Exposure of the residents of Pinder's Point, Lewis Yard and adjacent areas to chemicals produced by the different industrial parties can occur via inhaling contaminated air, ingesting contaminated soil and food, and using contaminated water (drinking and cleaning/bathing applications). The likelihood of each exposure route for the chemicals generated by the different industrial activities is discussed below.

- Exposure to chemicals via the **air** is possible for volatile chemicals emitted at present. The petrochemicals emitted by BORCO are volatile and are present in air (after all, one can smell them); hence, these are readily available for uptake through inhalation. The likelihood of exposure to these chemicals is high, as the residential areas are located in very close proximity of BORCO and the smell (i.e., the occurrence of the chemicals) has been reported and observed in the areas very frequently. Exposure via the air to chemicals that are not volatile and/or are emitted in the past is not possible. Exception is exposure to non-volatile chemicals that are bound to aerosols that may be inhaled, such as PAHs in smoke. This may occur for the chemicals from the Power Company emissions. However, it should be noted that these chemicals are emitted through the company's chimneys and will generally be diluted right away in the air and transported away from the island by the Bahamian winds. According to previous reports/memos, in wintertime, deposition of the emissions in the residential areas may however potentially occur. Still, because of the height of the chimneys, the distance of the sources to the residential areas, the prevailing winds, and the open location of the residential areas, generally, PAH concentrations in the residential areas are expected to be lower than those in the city, where PAH levels are often high due to traffic. This applies to PAHs in general, also those emitted by PharmaChem (combustion), although this company is situated somewhat closer to the study area and its chimney is lower. Also important to realize is that PAHs are also produced by the residents themselves through traffic, fires, and smoking. Hence, any exposure assessment could not be linked to the industrial sources. Finally, it should be mentioned that the bioavailability of PAHs is generally very low, since they are bound very tightly to their carrier (smoke, soot) particles (Jonker and Koelmans, 2002; Cornelissen et al., 2005). Inhalation of particles containing PAHs thus does not imply health effects related to the presence of these chemicals per se.

- Exposure to chemicals through contaminated **soil** is not very likely because of the following reasons: (i) severe soil pollution may only be present at certain 'hot spots' (e.g., oil pollution at the BORCO and Power Company property, specific chemicals at the PharmaChem property). The study area residents do not have access to these sites and thus cannot be exposed to any chemicals present at these hot spots; (ii) soils in the residential areas may only receive chemicals from diffuse sources instead, and therefore potentially contain only low concentrations of chemicals; (iii) these chemicals (e.g., petrochemicals from BORCO or chemicals produced by combustion) would be introduced via the air. The petrochemicals would be volatile chemicals that do not tend to accumulate in soil. In particular at the high temperatures occurring in Freeport throughout the year, these chemicals will accumulate in the air and not in soil. In case petrochemicals end up in soil anyway (e.g., though spilling whole product), the volatile fraction will evaporate readily and the remaining fraction may be expected to degrade relatively rapidly, again considering the high temperatures. Only non-volatile and very persistent chemicals (i.e., chemicals that hardly do degrade) would accumulate in soil. An example would be for instance DDT, but similar chemicals are not being intentionally produced in the Freeport Industrial Park. Some chemicals formed during incomplete combustion at the Power Company or PharmaChem's incinerator (e.g., PAHs) are persistent in soil, but as described above, these are not very likely to settle to and accumulate in soils of the residential areas to a large extent. It should also be noted that these chemicals also find their origin in any other combustion process, such as traffic and open fires. Both are present/occurring in the areas to a relatively large extent (there are many cars in the areas and residents have been observed to burn waste), just like in any other residential area. Any of the chemicals that would be detected thus could not easily be linked to a specific source. Furthermore, it should be noted that in particular chemicals formed during incomplete combustion are generally very strongly bound to their carrier material (soot), which strongly reduces their availability for biological uptake (Jonker and Koelmans, 2002; Cornelissen et al., 2005); (iv) the ingestion of soil by humans is low. There are only very few gardens in the areas in which residents grow vegetables (ingestion of soil may come through vegetables). Combined with the presumed low concentrations of chemicals and the low bioavailability of any combustion-derived chemicals, soil is therefore not considered an important source.

- Likewise, **food** is not a likely source of chemicals from the Industrial Park for similar reasons: (i) only few residents of Pinder's Point have trees with coconuts, mangos and other fruit, which are being consumed. Other types of food are not being cultivated in the area, at least not to a considerable extent. As such, food cannot be considered a generic exposure route for chemicals produced in the Industrial Park. It could only play a role for specific residents; (ii) however, as described for soil above, airborne, volatile chemicals do not tend to accumulate in this food at the high temperatures. Uptake of chemicals from soil and accumulation in the fruit is not very likely, as concentrations in soil can be expected to be low and fruit is not a preferable medium for hydrophobic chemicals (those that potentially could accumulate in soil) to accumulate in. Considering the presence of the BORCO jetties in the ocean and the reported oil spills at sea, fish could be a source of hydrophobic petroleum hydrocarbons, as these chemicals tend to accumulate in fish. However, according to the residents from Pinder's Point, there is no/hardly any fishing activity along the coast anymore, since they believe that the fish is polluted. Few individuals may do some fishing next to the lighthouse in Pinder's Point, but it is unclear if they consume what they catch. Also of note, fish migrate and it will be impossible to link any accumulated chemicals to a specific source in the industrial park (they might also have accumulated the chemicals in the open ocean or in another harbor, where petrochemicals will also occur through shipping activities - bunkering, bilge water spills). In summary, food is not considered an important or unambiguous source of chemicals from the Industrial Park.
- Residents may be exposed to chemicals through **water**, either by drinking, washing/cleaning, or recreational activities. The majority of residents in Pinder's Point and Lewis Yard, and presumably all residents of Hawksbill and Wellington, use city water or bottled water for drinking purposes. This water may be assumed free of chemicals from the Industrial Park, although it cannot be ruled out that water pipes carrying the city water may be in contact with contamination in soil at very specific locations (e.g., free petroleum product close to the BORCO property). The pipes in Pinder's Point and Lewis Yard seem to be made of plastic, which basically is

penetrable by, for instance, petrochemicals. In Pinder's Point and Lewis Yard, about 10 water wells exist, which are being used by residents for collecting water for cleaning and bathing purposes. At least one individual has admitted to drink the well water. It is unknown from which depth water is being collected, but obviously it concerns ground water. Considering the close proximity of the BORCO property, underneath which a huge NAPL phase is said to be present, the well water may be contaminated with petroleum hydrocarbons, such as BTEX. Although most probably only very few people drink the water, cleaning, bathing, and washing may be a route of exposure to these chemicals. Finally, it is unlikely that residents of the study area will be exposed to the industrial chemicals during recreational activities in water, since they do neither swim in the ocean adjacent to the study area (because of fear for sharks and oil pollution, according to representatives), nor in the Hawksbill Creek (too far and too industrialized).

B4. Sampling strategy

Based on the above, both air and water are considered potential exposure compartments of chemicals emitted in the Freeport Industrial Park for the residents of Pinder's Point, Lewis Yard and adjacent areas; whereas soil and food are not. The sampling activities in the present project were therefore focused on air and water.

- Water samples were taken from the water wells in Pinder's Point and Lewis Yard. They were analyzed for BTEX. Results were compared to USEPA thresholds for drinking water. A map showing the water sampling locations is shown in Figure C1.
- Airborne chemicals were sampled in June 2015 by a passive sampling methodology utilizing activated charcoal samplers. Seventeen samplers were placed for up to 6 days in the Pinder's Point, Lewis Yard, Hunter's, Wellington, and Hawksbill areas; around the BORCO property and next to the Power Company. A map showing the locations of the samplers is shown in Figure C2.

  The samples were analyzed for volatile organic chemicals (VOCs), including, but not limited to BTEX. Based on these measurements, 'background' concentrations were obtained, which were compared with safety thresholds (USEPA standards) for the chemicals of concern. Second, in the period of July to November 2015, it was attempted to perform active air sampling at 4 locations in Pinder's Point and Lewis Yard, with sampling pumps and sorbent cartridges, during BORCO venting events (i.e., periods of high odor intensity that are caused by specific activities at the BORCO site, probably venting tanks. Residents have specifically complained about these).

ANNEX C

Quantitative exposure assessment

C1. Water analyses

C1.1. Methodology

Water samples were taken from 7 water wells located in Pinder's Point and Lewis Yard. A map showing the locations is presented in Figure C1. In addition, a tap (city) water sample was taken from the tap in one of the homes located at the upper West part of Pinder's Point, i.e., West of the location at which the petroleum pipelines enter land (and cross the city water pipelines. This location (W-8) was selected, because information exists that the soil underneath the pipes is contaminated with oil. If the city water pipes would be in contact with this soil, petroleum hydrocarbons could be present in the water at the selected location. Finally, a procedural blank sample (purified water) was included.

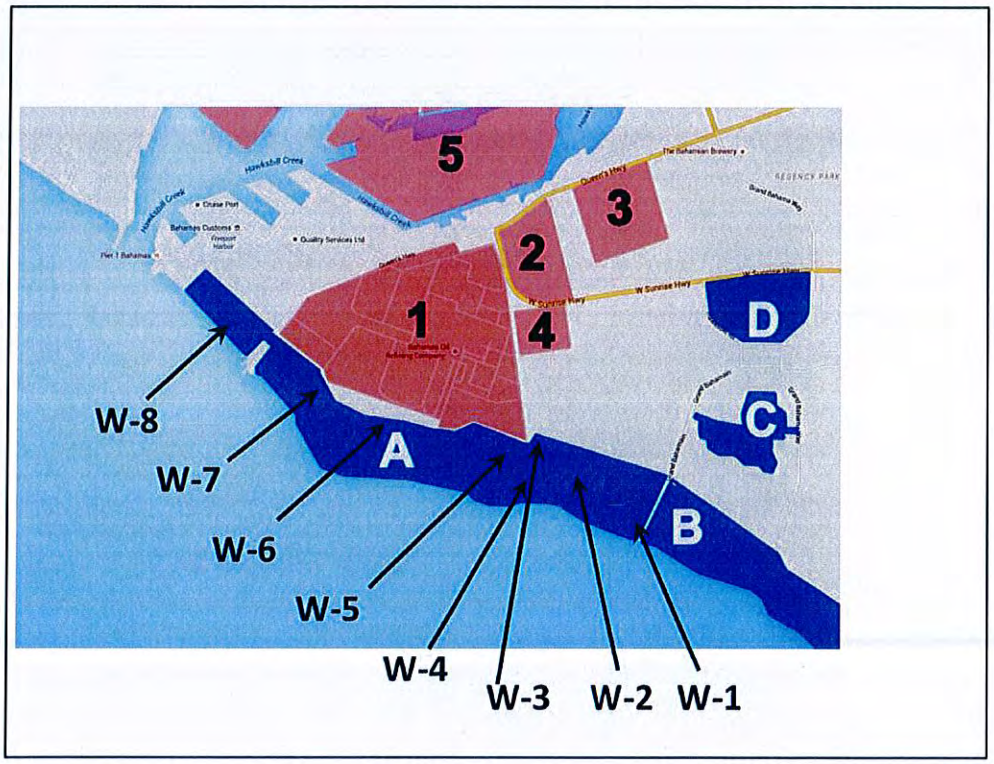


Figure C1. Map of Pinder's Point and Lewis Yard, showing the water sampling locations.

All samples were taken in duplicate in amber-colored 500 mL bottles that had successively been cleaned in a dishwasher, rinsed twice with ultrapure acetone (Pesti-S grade; Biosolve, the Netherlands), and air-dried in a fume hood, prior to shipping them to Freeport. All bottles contained 250 mg of sodium azide (Merck, Germany) as a biocide to prevent any microbiological degradation of the target compounds in sampled water during transport. Just before filling the bottles with a water sample, a sampling cartridge consisting of a stainless steel mesh cylinder (100 mesh; 5.8 mm diameter) filled with activated carbon (30-

50 mesh) (Sigma-Aldrich) was conditioned in purified water (displacing any gas in the cartridge, thereby preventing gas formation during sampling and the possibility of purging out any BTEX) and added to the bottles with tweezers. Water was pumped from the wells and the first 5-10 L was discarded. Then, the bottles were filled with freshly pumped water flowing straight from the tap, minimizing turbulence of water in the bottles. The bottles were all filled up to the top, leaving no headspace, and immediately spiked with 50 µL of a 20 mg/L cocktail solution of benzene-D6, toluene-D8, ethylbenzene-D10, and *p*-xylene-D10 in acetone. This resulted in concentrations of all deuterated compounds of 2 ug/L water. i.e., concentrations 2.5 times below the USEPA maximum contaminant level for benzene, which measures 5 ug/L. Following the spiking, the bottles were swiftly closed with an aluminum foil septum and a Teflon-lined polypropylene cap. Finally, the bottles were homogenized by gentle tumbling and shipped to the Netherlands.

In the Utrecht lab, the bottles were placed on a roller coach for 24 h, at 60 rpm. This duration and speed is sufficient to adsorb BTEX from a 500 mL solution. Subsequently, the bottles were opened; the cartridges were harvested, dried on a tissue, and placed in 2 mL glass tubes, to which 1.7 mL of dichloromethane (DCM) was added. The cartridges were then extracted for 30 min in a sonication bath, after which they were removed from the tubes. Any water in the tubes was removed with a pipette and the remaining DCM was transferred to an autosampler vial.

Concentrations of the BTEX and deuterated BTEX were quantified on an Agilent 5977 high resolution gas chromatograph, equipped with a mass selective detector (MSD) and an Agilent 7650 autosampler. Two µL aliquots of the samples were injected at 175 °C in the split mode (split ratio 20) on a SGE HT-8 column (50m x 0.22mm x 0.25 µm) with Helium as carrier gas at a constant flow of 1 mL/min. The oven temperature was as follows: 40 °C for 2 min; ramp with 10 °C/min to 125 °C; hold for 3 min. The MSD operated in the SIR mode with one quantifier and two qualifier ion masses selected for each target component. The source temperature was 230 °C and the quad temperature 150 °C. Data processing was performed with MassHunter software and all peaks were integrated manually. Calibration was performed based on a 6-point calibration curve of BTEX and deuterated BTEX in DCM, of which the standards were run in fivefold.

C1.2. Results of the water analyses

The results of the BTEX analyses of the water samples are presented in Table C1. In all of the samples, BTEX concentrations were below the limits of detection (LOD), being 0.03 µg/L for benzene; 1.2 µg/L for toluene; 0.05 µg/L for ethylbenzene; 0.25 µg/L for *p+m*-xylene; and 0.57 µg/L for *o*-xylene. A comparison of the LODs and the USEPA maximum contaminant levels (MCL) for drinking water, as also included in Table C1, shows that none of the chemicals in any of the samples exceeds the limits. This was already evident from the GC-MS output, since the BTEX peaks were all below the deuterated BTEX peaks, representing concentrations all well below the MCL for benzene in drinking water (actually, no BTEX peaks were visible, as they were all below the LOD). Concentrations of the BTEX compounds are thus at least 170 (benzene) to 17,000 (xylenes) times below the drinking water limits. These results indicate that there is no demonstrable petroleum contamination in the groundwater reservoir from which water is pumped up by the residents, since BTEX are indicator compounds for petroleum contamination in, amongst others, groundwater (Irwin, 1997).

Table C1. BTEX concentrations (µg/L) in water from 7 ground water wells and a city water sample.

	Benzene	Toluene	Ethylbenzene	*p+m*-Xylene	*o*-Xylene
USEPA MCL [1]	5	1,000	700	10,000 (sum Xylenes)	
Well 1	< 0.03	< 1.2	< 0.05	< 0.25	< 0.57
Well 2	< 0.03	< 1.2	< 0.05	< 0.25	< 0.57
Well 3	< 0.03	< 1.2	< 0.05	< 0.25	< 0.57
Well 4	< 0.03	< 1.2	< 0.05	< 0.25	< 0.57
Well 5	< 0.03	< 1.2	< 0.05	< 0.25	< 0.57
Well 6	< 0.03	< 1.2	< 0.05	< 0.25	< 0.57
Well 7	< 0.03	< 1.2	< 0.05	< 0.25	< 0.57
Tap water	< 0.03	< 1.2	< 0.05	< 0.25	< 0.57

[1] USEPA MCL: the maximum contaminant level (µg/L) for drinking water as set by the United States Environmental Protection Agency.

C2. Passive air sampling

C2.1. Methodology

Air was passively sampled at 17 locations, distributed over the residential areas and the Industrial Park. In Figure C2, the locations and sampling codes are shown.

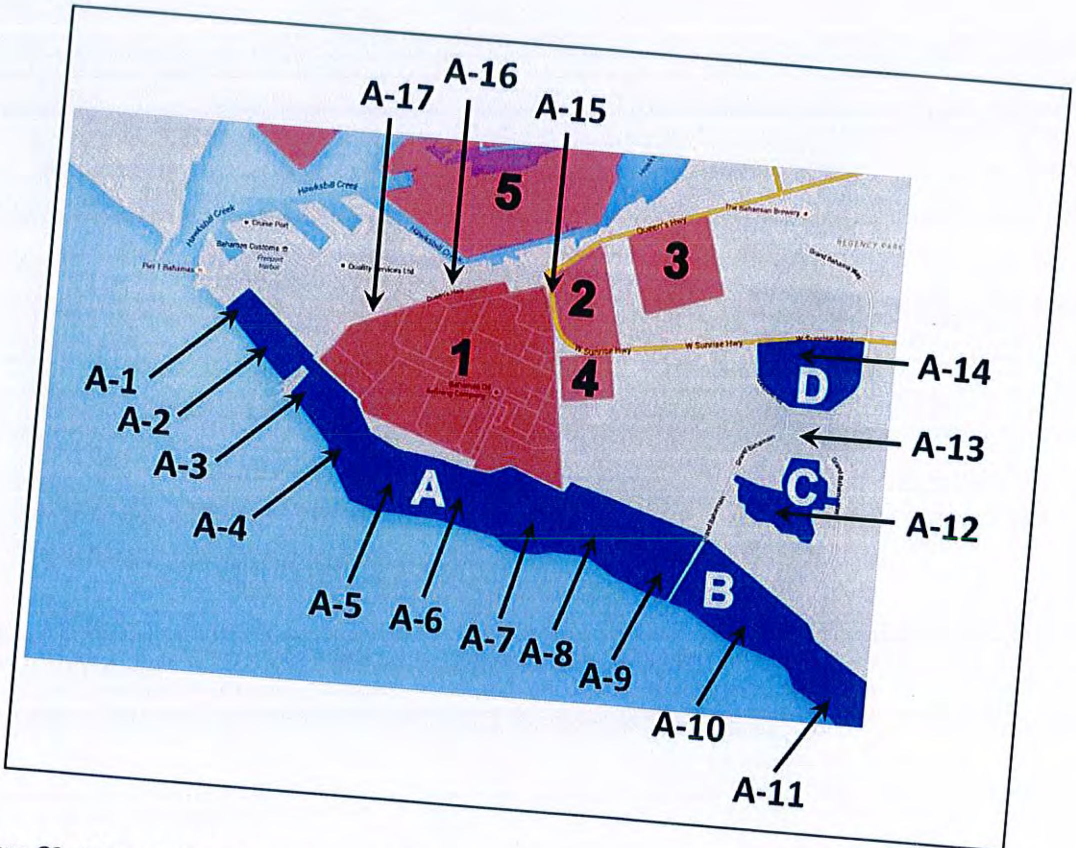


Figure C2. Map of the Freeport Industrial Park, showing the passive air sampling locations.

Sampling was performed according to the standard Radiello protocol for VOC sampling (see: http://www.radiello.com/english/cov_chim_en.htm), using sampling cartridges for solvent desorption (RAD130; Supelco). Just prior to starting the sampling, the cartridge housing was unsealed, the cap was removed and without touching the cartridges, they were placed in diffusive bodies. These bodies were mounted on top of vertical adapters, which subsequently were connected to triangular supporting plates that were hung inside shelters. The shelters protected the samplers from direct sunlight and showers. They were attached to electricity poles owned by the Grand Bahama Utility Company at a height of 3 m. Although the preferred exposure height is 1.5 m, 3 m was applied to prevent vandalism or people simply touching the samplers. In order to cover a wide range of adsorbed chemical masses (to increase the chance of analytical success), each shelter housed three samplers. Based on received information about the exposure (noticeable petroleum odor would be present all of the time), initially it was planned to expose the samplers for either 2, 4, or 6 days, i.e., it was planned to sample one of the samplers in each shelter after 2 days, another one after 4 days, and the last one after 6 days. During the sampling period, the distinct petroleum odor was hardly present, and it was decided to exposure the samplers for 4, 5, and 6 days. As specified in the Radiello protocol for outdoor sampling, depending on the concentrations the Radiello sampling cartridges can be exposed for 8 h to 30 days, with 7 days being the ideal exposure duration.

The samplers were checked daily during the 6-day exposure period, and the temperature was measured. When harvesting a sampler, it was removed from the shelter, opened, and without touching it the cartridge was transferred to its coded 2 mL glass tube. The tube was closed with the accompanying cap and sealed in the original, matching plastic bag, which was carefully closed with tape. Once all samplers had been collected, they were packed in 3 packages, each sealed in an additional two plastic bags, and shipped to the Netherlands. Three procedural blanks were included. These involved three cartridges that were not exposed, but simply opened, closed, and shipped.

In the lab, the samplers were stored as shipped in a clean and dedicated fridge for 3 months until analysis. Stored in this manner, the cartridges maintain their content unaltered for at least 6 months (http://www.radiello.com/english/cov_chim_en.htm). The cartridges were then extracted according to the standard Radiello protocol, with some minor modifications. First, 1.8 mL of carbon disulfide (CS_2; ReagentPlus; low benzene; Sigma-Aldrich) was added to the glass tubes containing the cartridges, followed by the addition of 200 µL of internal standard solution (2.0 mg 2-fluorotoluene/L CS_2). The tubes containing the cartridges were then sonicated for 15 min, after which they were left for another 15 min, while tumbling them regularly. The tubes were opened, the cartridges were discarded with the help of tweezers, and the remaining CS_2 was transferred to amber autosampler vials.

The extracts were all analyzed for a series of 21 VOCs, being typical petrochemical compounds and compounds formed during combustion. The analyses were performed on an Agilent 5977 high resolution gas chromatograph, equipped with a mass selective detector (MSD) and an Agilent 7650 autosampler. Two µL aliquots of the samples were injected at 175 °C in the splitless mode (splitless time 120 sec) on a SGE HT-8 column (50m x 0.22mm x 0.25 µm) with Helium as carrier gas at a constant flow of 1 mL/min. The oven temperature was as follows: 35 °C for 2 min; ramp with 10 °C/min to 100 °C; ramp with 5 °C/min to 200 °C; ramp with 15 °C/min to 280 °C; hold for 8 min. The MSD operated in the SIR mode with one quantifier and two qualifier ion masses selected for each target component. The source temperature was 230 °C and the quad temperature 150 °C. Data processing was performed with MassHunter software and all peaks were integrated manually. Calibration was performed based on a 7-point calibration curve (run in at least triplicate) of which the standards had been contacted with Radiello cartridges to correct for extraction recoveries (see Radiello protocol). The quantified chemical masses were translated to concentrations in air based on sampling rates as specified by Radiello and the exposure duration of the respective sampler.

C2.2. Passive air sampling results

The concentrations of the target chemicals in air at the 17 locations, as determined with the passive sampling approach, are listed in Table C2. The concentrations resulting from the 3 exposure durations were averaged. Although the measurements concern pseudo replicates, the resulting standard deviations were such that pooling the data per location seems justified. In general, the standard deviations are small; the averaged overall standard deviation of the monitoring program (all locations and pseudo replicates) measures 8 %, which can be considered low for this type of measurements, in particular in light of the very low concentrations that were detected.

The results in Table C2 demonstrate the general presence of VOCs in the air of the residential areas and the Industrial Park. Out of the 21 target compounds, 19 were quantified in all (except two) extracts. In particular in the extracts from samplers exposed at locations A-3 and A-17 (i.e., those locations with the highest target VOC concentrations), many more substantial peaks were detected. These concerned different alkylated benzenes (mostly diethyl-methyl benzene isomers; identification based on MS spectra and NIST library). Quantification was not performed, but the presence of all these compounds points to a complex mixture of VOCs. Note that location A-3 is situated next to the point where the offshore pipes from the jetties enter land and split into a network distributing the oil on the BORCO property. Location A-17 is the location at which a subtle but distinct petroleum odor could be detected during some of the sampling days.

One target compound (dodecane) could not be quantified, due to identification issues (qualifier ion ratios did not meet the criteria). Therefore, this compound was omitted from Table C2.

Table C2. VOC concentrations (µg/m^3; ± standard deviation; n=3) in air passively sampled at 17 locations in the residential areas and the Freeport Industrial Park during the period 2-8 June 2015.

Location →	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9
benzene [a]	0.30 ± 0.00	1.14 ± 0.07	4.27 ± 0.86	0.67 ± 0.21	-	-	-	-	-
toluene	4.72 ± 0.24	8.53 ± 0.38	22.2 ± 1.96	8.05 ± 0.39	3.43 ± 0.15	4.01 ± 0.42	3.16 ± 0.21	2.06 ± 0.12	2.19 ± 0.07
ethylbenzene	1.44 ± 0.05	2.18 ± 0.06	4.10 ± 0.31	1.93 ± 0.09	0.96 ± 0.10	0.74 ± 0.10	0.55 ± 0.02	0.46 ± 0.02	0.50 ± 0.02
o-xylene	1.76 ± 0.08	2.82 ± 0.08	5.06 ± 0.50	2.36 ± 0.11	1.22 ± 0.12	0.92 ± 0.13	0.65 ± 0.04	0.51 ± 0.02	0.58 ± 0.02
m+p-xylene	4.58 ± 0.20	7.24 ± 0.24	13.0 ± 1.15	6.00 ± 0.27	3.10 ± 0.34	2.33 ± 0.34	1.62 ± 0.10	1.25 ± 0.06	1.41 ± 0.06
1,2,4-trimethylbenzene	1.63 ± 0.07	3.19 ± 0.25	6.21 ± 1.16	3.15 ± 0.20	1.36 ± 0.09	0.84 ± 0.09	0.77 ± 0.03	0.60 ± 0.03	0.65 ± 0.02
1,3,5-trimethylbenzene	0.54 ± 0.02	1.02 ± 0.07	1.96 ± 0.30	1.08 ± 0.04	0.49 ± 0.03	0.31 ± 0.03	0.27 ± 0.01	0.21 ± 0.01	0.23 ± 0.00
1,2,3-trimethylbenzene	0.55 ± 0.03	1.07 ± 0.07	2.11 ± 0.38	1.39 ± 0.10	0.47 ± 0.04	0.29 ± 0.04	0.23 ± 0.01	0.16 ± 0.01	0.17 ± 0.01
1,3-diethylbenzene	0.13 ± 0.00	0.24 ± 0.02	0.50 ± 0.13	0.24 ± 0.02	0.09 ± 0.01	0.05 ± 0.01	0.03 ± 0.00	0.02 ± 0.00	0.02 ± 0.00
1,4-diethylbenzene	0.05 ± 0.00	0.07 ± 0.01	0.16 ± 0.05	0.08 ± 0.01	0.03 ± 0.00	0.02 ± 0.00	0.14 ± 0.01	0.11 ± 0.03	0.10 ± 0.01
n-propylbenzene	0.27 ± 0.01	0.47 ± 0.04	0.96 ± 0.13	0.53 ± 0.03	0.24 ± 0.02	0.15 ± 0.02	0.11 ± 0.01	0.09 ± 0.01	0.10 ± 0.00
isopropylbenzene	0.10 ± 0.00	0.19 ± 0.01	0.35 ± 0.04	0.25 ± 0.02	0.09 ± 0.01	0.05 ± 0.01	0.05 ± 0.00	0.03 ± 0.00	0.03 ± 0.00
1,2,4,5-tetramethylbenzene	0.13 ± 0.01	0.24 ± 0.03	0.50 ± 0.14	0.24 ± 0.02	0.10 ± 0.00	0.06 ± 0.00	0.04 ± 0.00	0.03 ± 0.00	0.03 ± 0.00
octane	1.05 ± 0.05	1.90 ± 0.12	4.22 ± 0.52	2.27 ± 0.19	0.91 ± 0.04	0.71 ± 0.03	0.30 ± 0.04	0.20 ± 0.02	0.16 ± 0.01
nonane	1.50 ± 0.17	1.80 ± 0.14	4.19 ± 0.71	2.24 ± 0.21	0.80 ± 0.05	0.50 ± 0.05	0.24 ± 0.04	0.20 ± 0.03	0.16 ± 0.02
decane	1.53 ± 0.15	1.47 ± 0.13	3.48 ± 0.70	2.06 ± 0.08	0.89 ± 0.05	0.58 ± 0.06	0.41 ± 0.06	0.36 ± 0.03	0.34 ± 0.03
undecane	1.61 ± 0.15	1.67 ± 0.01	3.42 ± 0.54	2.09 ± 0.02	1.25 ± 0.07	0.82 ± 0.15	0.58 ± 0.06	0.51 ± 0.10	0.52 ± 0.05
naphthalene	0.31 ± 0.02	0.57 ± 0.06	1.13 ± 0.25	0.53 ± 0.07	0.25 ± 0.01	0.16 ± 0.01	0.61 ± 0.12	0.39 ± 0.03	0.13 ± 0.01
2-methylnaphthalene	0.35 ± 0.01	0.57 ± 0.06	1.16 ± 0.27	0.55 ± 0.14	0.34 ± 0.05	0.18 ± 0.02	1.40 ± 0.26	n.d.	n.d.

[a] Due to a high solvent background, benzene could not be quantified in most samples. See text for explanation.
n.d.: not detected.

Table C2. Continued

Location →	A-10	A-11	A-12	A-13	A-14	A-15	A-16	A-17
benzene [a]	-	-	-	-	-	-	0.20 ± 0.00	0.76 ± 0.26
toluene	1.76 ± 0.11	2.40 ± 0.18	2.28 ± 0.38	3.34 ± 0.24	4.46 ± 0.20	1.83 ± 0.06	6.60 ± 0.08	12.3 ± 1.12
ethylbenzene	0.41 ± 0.02	0.58 ± 0.05	0.44 ± 0.02	0.74 ± 0.05	1.05 ± 0.05	0.56 ± 0.03	1.51 ± 0.04	7.85 ± 0.27
o-xylene	0.48 ± 0.03	0.64 ± 0.05	0.55 ± 0.03	1.31 ± 0.08	1.16 ± 0.05	0.69 ± 0.03	1.98 ± 0.08	10.5 ± 0.42
m+p-xylene	1.14 ± 0.07	1.54 ± 0.10	1.28 ± 0.06	2.71 ± 0.16	2.77 ± 0.11	1.65 ± 0.10	5.09 ± 0.17	27.2 ± 1.05
1,2,4-trimethylbenzene	0.54 ± 0.03	0.78 ± 0.07	0.58 ± 0.03	1.14 ± 0.08	1.25 ± 0.06	0.72 ± 0.00	3.09 ± 0.11	8.02 ± 0.82
1,3,5-trimethylbenzene	0.20 ± 0.01	0.27 ± 0.03	0.23 ± 0.01	0.51 ± 0.03	0.49 ± 0.01	0.31 ± 0.02	1.00 ± 0.04	2.48 ± 0.27
1,2,3-trimethylbenzene	0.14 ± 0.01	0.18 ± 0.01	0.16 ± 0.01	0.37 ± 0.02	0.31 ± 0.01	0.23 ± 0.00	1.07 ± 0.05	2.75 ± 0.29
1,3-diethylbenzene	0.01 ± 0.00	0.02 ± 0.00	0.02 ± 0.00	0.05 ± 0.01	0.03 ± 0.00	0.04 ± 0.00	0.28 ± 0.01	0.78 ± 0.07
1,4-diethylbenzene	0.08 ± 0.01	0.10 ± 0.01	0.10 ± 0.00	0.21 ± 0.01	0.15 ± 0.00	0.15 ± 0.00	0.07 ± 0.01	0.26 ± 0.02
n-propylbenzene	0.08 ± 0.00	0.11 ± 0.01	0.08 ± 0.00	0.14 ± 0.01	0.19 ± 0.01	0.14 ± 0.00	0.43 ± 0.02	1.09 ± 0.12
isopropylbenzene	0.02 ± 0.00	0.03 ± 0.00	0.03 ± 0.00	0.06 ± 0.00	0.06 ± 0.01	0.05 ± 0.00	0.15 ± 0.00	0.44 ± 0.05
1,2,4,5-tetramethylbenzene	0.03 ± 0.00	0.03 ± 0.00	0.03 ± 0.00	0.08 ± 0.00	0.05 ± 0.00	0.05 ± 0.00	0.29 ± 0.01	0.94 ± 0.08
octane	0.11 ± 0.01	0.12 ± 0.01	0.11 ± 0.01	0.26 ± 0.01	0.19 ± 0.01	0.37 ± 0.00	1.82 ± 0.05	5.44 ± 0.79
nonane	0.12 ± 0.02	0.12 ± 0.00	0.13 ± 0.01	0.24 ± 0.01	0.15 ± 0.00	0.43 ± 0.01	1.98 ± 0.08	6.22 ± 0.82
decane	0.29 ± 0.01	0.28 ± 0.05	0.31 ± 0.04	0.47 ± 0.01	0.30 ± 0.01	0.65 ± 0.05	1.96 ± 0.03	5.64 ± 0.73
undecane	0.47 ± 0.07	0.45 ± 0.06	0.45 ± 0.06	1.13 ± 0.12	0.73 ± 0.09	1.17 ± 0.17	2.46 ± 0.17	6.01 ± 0.81
naphthalene	0.21 ± 0.01	0.14 ± 0.00	0.13 ± 0.01	0.19 ± 0.02	0.14 ± 0.02	0.14 ± 0.01	0.55 ± 0.05	1.95 ± 0.08
2-methylnaphthalene	0.43 ± 0.01	0.24 ± 0.01	0.16 ± 0.04	0.41 ± 0.05	0.17 ± 0.05	0.21 ± 0.03	0.84 ± 0.06	2.22 ± 0.09

[a] Due to a high solvent background, benzene could not be quantified in most samples. See text for explanation.

Analytical problems also occurred for benzene. This compound could not be quantified in most extracts due to a high background in the extraction solvent (CS_2) used. Although this solvent concerned a certified 'low-benzene' product and the lot number received had been approved in the IRAS laboratory by quantifying benzene in one of the bottles, another individual bottle (of the same lot number) later on appeared to be contaminated with elevated levels of benzene. Exactly this bottle was used for the extraction work and thereby caused high benzene levels in all extracts. An official claim has been filed at the producing company (Sigma), who has meanwhile admitted that there were problems related to the benzene background in this solvent batch, but this obviously does not restore the benzene results. BTEX compounds are however known to occur in air in more or less fixed ratios, depending on their source (Liu et al., 2008). For instance, toluene/benzene (T/B) ratios are in the range of 1-12 (Liu et al., 2008; Khoder, 2007; Hsieh et al., 2006; Kerchich and Kerbachi, 2012). This implies that benzene concentrations are at most equal to those of toluene, but generally lower by up to a factor of 12. Note that the benzene concentrations quantified at locations A-2 through A-4 are consistent with this ratio range, but that those quantified at locations A-1, A-16, and A-17 are lower than what would be expected based on these general BTEX ratios. Most probably this is due to the larger error associated with subtracting the high background values (resulting in an underestimation of actual benzene levels). Combining the knowledge about BTEX ratios with the results in Table C2, one can roughly estimate the benzene concentrations in the samples. In all cases, the estimates are below 20 $\mu g/m^3$ and thus well below the Reference Concentration (RfC) for benzene in air, as set by the USEPA, which measures 30 $\mu g/m^3$. Benzene concentrations at or below the RfC are not likely to cause adverse health effects, according to the USEPA. The same applies to toluene and ethylbenzene, compounds for which the RfCs measure 5000 and 1000 $\mu g/m^3$, respectively. For benzene, being a carcinogenic compound, the detected/estimated concentrations (being below USEPA cancer thresholds 4.5 and certainly 45 $\mu g/m^3$) would result in not greater than a one-in-a-10,000 to 100,000 increased chance of developing cancer upon continuously breathing the air (http://www3.epa.gov/airtoxics). As the population in the residential areas amounts to about 3000, increased cancer rates thus are not to be expected under the detected exposure conditions. The same conclusion follows from the reverse calculation: The increase in the lifetime risk of an individual who is continuously exposed to 1 $\mu g/m^3$ of benzene in the air over his lifetime is 2.2×10^{-6} to 7.8×10^{-6}, according to the USEPA. This implies that at an exposure concentration of benzene of 1 $\mu g/m^3$, 2 to 8 additional cases of cancer would be expected in a population of a million people, being continuously exposed to this concentration over the entire lifetime. In the residential areas, holding about 3000 inhabitants, a constant, lifetime exposure benzene concentration of about 700-2600 $\mu g/m^3$ would therefore be required to cause the additional cancer risk. This concentration range is orders of magnitude above the detected/estimated benzene concentrations.

Based on the above and because for none of the other VOCs RfCs are available, the VOC concentrations that were detected in the air of the residential areas and the Freeport

Industrial Park in the week of 2-8 June 2015, are not expected to cause adverse health effects. This conclusion matches with the absence of the usually prevailing and general 'petroleum smell' during that week. Important to note however is that during wintertime, when the winds predominantly are from the Northeast and directed towards the residential communities, VOC concentrations in Pinder's Point, Lewis Yard, and Hunter's may be higher than those reported in Table C2, also considering the reported constant petroleum smell by the residents. It cannot be excluded that VOC, and in particular, BTEX concentrations during this period may exceed the RfCs. The project planning did not allow sampling during wintertime and the accompanying exposure concentrations thus could not be quantified.

Although the contribution of different sources, i.e., petrochemical activities, traffic, and combustion activities, to the VOC concentrations cannot be distinguished, BORCO seems to be a likely and important source of the compounds. This follows from two observations: (1) at location A-17, the highest VOC concentrations were detected. This location receives similar VOC input from traffic as location A-15 and A-16, but at location A-17, VOC compounds could actually be smelled (petroleum); (2) VOC concentrations declined alongside a two-way transect moving away from a high-activity (pumping) area on the BORCO property, situated next to location A-3. VOC concentrations were relatively high at location 3 and decreased when going both West (towards location 1) and East. Residents have also reported that the petroleum smell can most frequently and most clearly be detected in the area between location A-3 and A-17.

C3. Active air sampling

C3.1. Methodology

The passive air sampling was performed to quantify the background levels of VOCs in the residential areas and the Industrial Park. Residents, however, also have complained about episodes characterized by a very strong oil odor, giving rise to acute health effects. Concentrations of VOCs during such episodes are expected to largely exceed background levels, and considering the reported health effects it was deemed crucial to sample VOCs during these episodes as well. As the episodes were reported to last for a few hours at most, the preferred sampling approach involved active air sampling, pumping a relatively large volume of air through a sorbent cartridge for a short duration.

Pumps (Gilian GilAir-5) were therefore installed at 4 locations in Pinder's Point/Lewis Yard and carefully-selected residents were trained to operate the pumps in the case of venting episodes, according to a simple protocol. Note that the timing of the episodes is unpredictable and the episodes are reported to usually occur at night, so that sampling by the authors of this report was not feasible. The approach involved opening and connecting activated charcoal tubes (ORBO^{TM}-32; Supelco) to the pump via original Gilian tubing and tube holders; and operating the pump, which was pre-programmed to pump at 1.0 L/min at a constant flow. After ending the sampling (1-2 hours), the ORBO tubes should be closed by accompanying caps, packed in matching plastic bags, and shipped to the Netherlands by the local project assistant.

As particular concern has also been raised by the residents about H_2S exposure, additionally dedicated H_2S monitors (Honeywell; GasAlert MicroClip XL multi gas monitors) were installed and the residents that were trained to operate the active air sampling pumps were asked to operate these monitors as well. Operation of the monitors was performed according to a simple protocol that was provided. It involved switching on and off the monitor during episodes characterized by a distinct rotten-egg odor. The data were logged by the monitor and could be retrieved by connecting the monitors to a laptop on which the accompanying software (Fleet Manager II, v. 2.6.4) was installed.

C3.2. Active air sampling results

The active air sampling equipment was installed mid July 2015 and stayed in the residential area until the end of November 2015. During this period however, no venting events were observed by the residents, and as a result, no active air sampling was performed. Exposures to H_2S and peak concentrations of VOCs thus could not be quantified. The fact that no episodes took place is considered remarkable by the residents, based on the frequency of the episodes in the past. The general opinion exists among the residents that BORCO changed its operation strategy as of mid 2015. As can be seen in the odor nuisance reporting by the residents (Annex D1.4), there has only been one odor report by one resident since the end of June 2015. This episode was not picked up by the residents operating the active air sampling equipment, most probably because the venting activity was very local (thus small-scale).

D1. Anecdotal information

During the duration of the project, researchers were onsite in Pinder's Point and the adjacent communities. Contact was established with many residents and especially during sampling events, many residents contacted the authors of this report, sharing information about chemical emissions, health effects, and industrial (primarily BORCO) activities. Below, an overview of the information gained from the residents is listed. Also, as log files from official stakeholders, such as BORCO, are not easily accessible, in June 2015 it was decided to distribute a file to selected residents in which they could fill in their complaints about e.g. air quality. The compiled data base is provided at the end of this annex.

D1.1. Chemical sources

- There appear to be frequent oil spills on the coast, originating from the jetties or the ships connecting to the jetties. In 2014, about 4 spills were observed by the residents. The spills were cleaned by people in white protective suits. Some of the spills appear on the news, but others are not officially reported. In September 2015, oil stranded ashore in Eight Mile Rock; this oil spill appeared in the local media.
- Many residents complain about venting events at BORCO, which usually take place at night. A very strong oil odor is noted that wakes up the people and gives rise to acute health effects (see below).
- Other complaints about BORCO concern a constant oil odor, predominantly noticeable at the NW side of the property.
- The bunkers at the BORCO property undergo regular sandblasting. This produces dust/particles that settle down in the communities and causes concern. The dust is visible on for instance cars.
- The general impression among the residents is that the frequency of the BORCO venting events has recently declined substantially.
- There are frequent complaints about the city water. The water sometimes appears to be whitish or contains brown material. As the first disappears after some time and the second settles down, this most probably is caused by maintenance of the piping network (causing air and biofilm, respectively in the water). According to the Utility Company, the pipe material in part is iron, so the brown particulate material may very well also concern rust.
- Residents have reported that at the same time BORCO is venting (which causes a very strong petroleum odor), the company is spraying a sweet (flower-like) odor. The combination of this odor and that of the oil fumes is considered terrible.
- A few years ago, the alarm of the air quality monitor that was present in the house of a former BORCO worker went off during a venting event, suggesting a high and dangerous indoor concentration of H_2S or VOCs at that time.

- The Power Company is combusting heavy oil (Bunker C) for power generation purposes. Both the raw fuel and the emission gasses are of substantial chemical concern. This way of power generation, as well as the plant itself is clearly outdated. It is recommended to consider and introduce a cleaner and more sustainable way of power generation.

D1.2. Health effects

- Most of the acute health complaints from residents relate to the BORCO venting activities. People report burning eyes, coughing (without being able to stop), asthma, nasal disorders, and one report exists of a child that was vomiting blood after coughing badly.
- People have reported that in 2014, two workers at the jetties became unwell and were transported to the US because of H_2S poisoning. They went into coma and died in a clinic later on.
- Also in 2015, a BORCO worker appears to have suffered from H_2S poisoning (exposed at the jetties), but he recovered and left BORCO.
- End of September 2015, a young (28 years old) and seemingly healthy scrubber at BORCO (cleaning the bunkers) got sick and went to the RAND hospital. He was diagnosed sunstroke, but he died a few days later due to kidney and liver failure.

D1.3. BORCO

- In August 2015, a bunker fire occurred, possibly due to lightning strike. The fire was under control in about an hour, but was very close to several homes in Pinder's Point.
- Residents have reported that BORCO workers were conducting air sampling a couple of weeks before the passive air sampling activities described in this report. They used (similar) sampling cartridges and the sampling took about two days.
- Residents have reported that BORCO workers were taking pictures of the passive sampling equipment used by the authors of this report.
- In case of acute complaints from the residents to the BORCO hotline, BORCO workers tend to come to the area in protective clothing. This suggests knowledge about the risks associated with exposure to the fumes.
- If BORCO is keeping files of the complaints, this would be a valuable source of emission and health effect information.

D1.4. Odor nuisance report/complaint inventory mid June – end November 2015

PINDER'S POINT, LEWIS YARD, HUNTERS, MACK TOWN & HAWKSBILL ODOUR NUISANCE REPORT

#	Name (optional)	Date (dd/mm/yy)	Start Time a.m./p.m.	End Time a.m./p.m.	Scale (1 - 10) 1=low; 10=unbearable	Odour reported to: (Borco, Police, etc.)	Health Effects (coughing, vomiting, headache, etc.)	Hospital visit (ER, etc., include diagnosis, if possible)
. 1	Resident 1	17-Jun-15	5:00 AM	7:00 AM	5			
. 2	Resident 2	17-Jun-15	5:00 AM	7:00 AM	5			
. 3	Resident 3	17-Jun-15	5:00 AM	7:00 AM	5			
. 4	Resident 2	25-Jun-15	7:15 AM	12:00 PM	8		Burning eyes	
. 5								
. 6	Resident 4	17-Jun-15	5:30 AM	5:00 PM	3	Borco	Coughing	
. 7	Resident 5	17-Jun-15	7:24 AM	5:00 PM	5	Borco	Coughing	
. 8	Resident 6	17-Jun-15	3:00 AM	5:00 PM	7	Borco		
. 9	Resident 7	20-Jun-15	6:00 AM	5:00 PM	8	Borco	Went up Town/Left area	Odor Lasted until 22/6
. 10	Resident 5	20-Jun-15	6:00 AM	5:00 PM	8	Borco	Coughing	Odor Lasted until 22/6
. 11	Resident 4	20-Jun-15	6:00 AM	5:00 PM	9	Borco	Upset stomach	Odor Lasted until 22/6
. 12	Resident 8	23-Jun-15	6:30 AM		5	Borco		
. 13	Resident 9	26-Aug-15	9:30 AM	11:00 PM			headache	
. 14	Resident 9	28-Aug-15	3:00 AM	4:00 AM			eye burning	
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ANNEX E

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