GOVERNMENT OF BERMUDA
Ministry of the Environment

Department of Environment and Natural Resources
Pollution Control Section

Glyphosate Monitoring Study

Evaluation of the exposure risks from Glyphosate and associated degradation products from road-side spraying for weed control

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1 Executive Summary

This study was initiated to address the exposure risk from the road-side spraying of the herbicide glyphosate to the public and to the employee of the Government road-side weed control programme.

As a result of a petition from the public and following various stakeholder meetings the Minister of Health, Seniors & Environment decided to suspend the importation of glyphosate products to Bermuda in May 2015. The petition was initiated following the decision by the World Health Organization's (WHO) International Agency for Research on Cancer (IARC) raising the classification of glyphosate, specifically in the Roundup® formulation, from 'Possibly Carcinogenic to Humans' (*i.e.* Group 2B) to 'Probably Carcinogenic to Humans' (*i.e.* Group 2A) due to their assessment of a range of studies. This decision by the IARC raised the health risk for working with glyphosate to that similar to professions such as barbers and fry cooks and raised the health risk to equivalent to exposure from other chemicals that are found in motor oil, soot, exhaust emissions and road runoff.

The European Food Safety Authority (EFSA) report in November 2015 concluded that glyphosate was not considered to be carcinogenic (*i.e.* not genotoxic, damaging to DNA) to humans, an opinion that is also consistent with the US Environmental Protection Agency (EPA). Following the EFSA report in November 2015 the Minister relaxed the importation restriction on *Ready To Use* glyphosate products and maintained the ban on the more concentrated forms of glyphosate, specifically, formulations over 2% concentration.

More recently in May 2016 the Joint Food Agriculture Organization and World Health Organization (FAO/WHO) reported that there was no reason to change the previously reported Acceptable Daily Intake (ADI) limit for glyphosate, stating that glyphosate was "unlikely to pose a carcinogenic risk to humans from exposure through diet", which contradicts the report in November 2015 by the WHO cancer agency IARC.

It is important to note that the IARC does not set maximum permissible exposure limits for carcinogenic compounds because it does not provide a quantitative estimate of the magnitude of the risk resulting from a specified level of exposure. This role is the responsibility of the Regulatory Authorities.

This Government study determined glyphosate and its degradation products in a range of different matrices that could form potential vectors of exposure to the public, herbicide applicator employee and organisms found in Bermuda's environment.

Groundwater used to feed the Ministry of Public Works reverse osmosis potable water treatment system and the resultant potable water generated for public use was shown to be free of glyphosate and degradation products (*i.e.* <10 parts per trillion, nano-grams per litre, ng/l). One of the three groundwater samples and one pond water sample was shown to contain glyphosate only at just above the analytical detection limit (*i.e*. 10.8 ng/l), which was one order of magnitude lower than the most stringent drinking water standard that has been set in the UK and EU. At present groundwater and Government potable water do not therefore pose any risk of glyphosate exposure to the public of Bermuda.

Air samples collected from both inside the cab and at the rear of the herbicide applicator vehicle while spraying demonstrated similar concentrations of glyphosate that ranged from 13.3 to 46.8 ng/l. The herbicide applicator employee was considered to represent the 'Critical Group' with respect to being exposed, through inhalation of glyphosate in water mists, to the highest expected concentrations on a daily basis. Comparison of the worst-case inhalation exposure risk of the herbicide applicator employee, without taking into account the benefits of wearing a half face particle/organic vapour mask, suggested that he was exposed to less than 5% of the maximum permissible OSHA arbitrary limit of 1mg/m^3

glyphosate. In the absence of other occupational inhalation standards a comparison to the known ingestion exposure standards was made as a cross comparison. With the assumption that all inhaled glyphosate was retained by the body the worst-case inhalation rate equated to less than 9% of the most stringent daily ingestion rate of glyphosate that is stipulated by the European Food Safety Agency.

Foodstuffs imported to supermarkets in Bermuda were sampled to provide some scale of the exposure risk to the public and herbicide applicator employee from roadside spraying relative to the potential exposure route from eating generic crop foodstuffs that may have been sprayed with glyphosate and imported to Bermuda. It is acknowledged that any glyphosate present in the foodstuffs selected may result from either the crops being from a Genetically Modified (GM) origin or from the use of glyphosate as a pre-harvest desiccant on non-GM crops. Glyphosate was present in most of the foodstuffs sampled, however, the levels are considered to be safe according to the Acceptable Daily Intake (ADI) stipulated by the World Health Organization (WHO) at 0.3 milligrams per kilogram body weight per day (*i.e.* 0.3 mg/kg bw per day) and the European Food Safety Agency (EFSA) most stringent Acceptable Operator Exposure Level (AOEL) of 0.1 mg/kg bw per day. Quick oats and whole wheat flour were found to have the highest glyphosate concentrations at 1140 and 603 ng/g (*i.e.* parts per billion), respectively. For a typical 60kg person the AOEL limit equated to having to eat more than 5kg of quick oats (*i.e*. *16 kg to exceed the WHO ADI*) and more than 10kg (*i.e*. *30kg to exceed the WHO ADI*) of whole wheat flour per day to exceed the EFSA AOEL. Therefore based on the existing most stringent legislated ADI levels the foodstuffs sampled do not pose a health risk from glyphosate ingestion.

Comparison to the exposure risk through inhalation of the herbicide applicator employee (*i.e*. critical group) suggested that the worst-case inhalation dose of glyphosate, without considering the positive effects of wearing PPE (i.e. half-face particle and organic vapour mask), was equivalent to eating less than half a kilogram of quick oats per day. Based on the current most stringent exposure limits the results from this study highlighted that the risk to human health posed by roadside spraying of glyphosate of Rodeo® for weed control was safe provided that the current standard operating procedures and safety precautions were maintained.

Going forward the Department of Environment and Natural Resources and the Department of Health will monitor the developments in legislation from other developed jurisdictions for potential future changes to these exposure limits. The Departments will also monitor for the potential inclusion into regulatory exposure limits of any new active or non-active ingredients that are present within certain herbicide formulations (*i.e.* Roundup®, Rodeo®, etc). Any new information that is brought to the Departments' attention will be used to update the exposure risk to the applicator or public either based on the existing data collected or, if a subsequent study is required, on any new data generated.

Based on the information presented in this report with respect to the exposure risk to the public, herbicide applicator employee and the environment that have been taken from existing legislation from other jurisdictions the Department of Environment & Natural Resources (DENR) can find no reason to continue the ban on the concentrated glyphosate formulation Rodeo® that is used by the Ministry of Public Works for road-side weed control. Other recommendations are also presented that address training and certification of competent commercial and private pesticide applicators as determined by the Department of Health in addition to requiring a risk assessment process with potential mitigation measures to be considered before opting for more harmful pesticide-based solutions. Finally, before these and other recommendations are implemented it is recommended that a Communication Plan be completed that includes an opportunity for feedback to be received from key stakeholders who were initially consulted in February 2016.

2 Introduction & Background

This study was initiated to address the exposure risk from the road-side spraying of the herbicide glyphosate to the public and to the employee of the Government road-side weed control programme. The strategy behind this study is summarised in Annex A.1.

As a result of a petition from the public and following various stakeholder meetings the Minister of Health, Seniors & Environment (the Minister) decided to suspend the importation of glyphosate to Bermuda in May 2015. The petition was initiated following the decision by the World Health Organization's (WHO) Agency for Research on Cancer (IARC) raising the classification of glyphosate from 'Possibly Carcinogenic to Humans' (*i.e.* Group 2B) to 'Probably Carcinogenic to Humans' (*i.e.* Group 2A) due to their assessment of a range of studies[1].

Subsequent to the IARC report the European Food Safety Agency (EFSA) published its report, which was based on the findings of the German Federal Institute for Risk Assessment (BfR). One of the many studies that were used in the EFSA assessment was an Agricultural Health Study[2] in the US, considered high-exposure individuals who are licenced to apply pesticides (57,311 individuals) and was a collaborative effort with investigators from the National Cancer Institute, the National Institute of Environmental Health Sciences, the EPA, and the National Institute for Occupational Safety and Health. The EFSA report in November 2015 concluded that glyphosate was not considered to be carcinogenic (*i.e.* not genotoxic, damaging to DNA) to humans, an opinion that is also consistent with the US Environmental Protection Agency (EPA)[3] but contradicted the conclusions of the WHO IARC.

There have been a range of reports that have tried to justify the apparently different conclusions made by the IARC and the EFSA. Some of these reports have related to the IARC which focused on the effects from both glyphosate and glyphosate-based formulations whereas others related to the the EFSA which focused solely on the single chemical glyphosate[4, 5, 6]. It is apparent from the reference list of studies considered by the IARC that 34 of them focussed specifically on RoundUp® and two references referred to two of the other 12 trade names of products that contain glyphosate in addition to glyphosate alone[1]. Therefore, there may be some apparent difference in genotoxicity between glyphosate in the Roundup® formulation compared to glyphosate alone. The EFSA[6] concludes by stating that the toxicity of each pesticide formulation, and in particular its genotoxic potential, should be further considered and addressed by Member State authorities while they re-assess uses of glyphosate-based formulations in their own territories[6]. To date the Regulatory Authorities of developed jurisdictions have not set exposure limits for other active or allegedly non-active ("inert") ingredients in glyphosate formulations such as Roundup® or Rodeo®.

[1] International Agency for Research on Cancer (IARC) World Health Organization (WHO). IARC Monographs Volume 112: Evaluation of five organophosphate insecticides and herbicides, 20 March 2015 and supporting information: http://monographs.iarc.fr/ENG/Monographs/vol112/mono112-09.pdf.

[2] De Roos, A.J. et al., (2005) cancer incidence among glyphosate-exposed pesticide applicator in the Agricultural Health Study. Environ. Health Perspect. Jan, 113(1), 49-54.

[3] Glyphosate Issue Paper: Evaluation of Carcinogenic Potential. US EPA's Office of Pesticide programs, September 12, 2016.

[4] Food Safety News. "EFSA Finds glyphosate 'Unlikely to cause cancer in humans". Dan Flynn, Nov 13, 2015.

[5] Science Media Centre. Expert reaction to EFSA's conclusions on glyphosate safety. Dr Peter Jenkinson. Nov 12, 2015.

[6] EFSA Explains Risk Assessment – Glyphosate. https://www.efsa.europa.eu/sites/default/files/corporate_publications/files/efsaexplainsglyphosate151112en.pdf

Following the EFSA report in November 2015, the Minister relaxed the importation restriction somewhat to only apply to the more concentrated forms of glyphosate, specifically, formulations over 2% concentration (*i.e*. the ban on *Ready To Use* glyphosate products was lifted).

More recently in May 2016 the Joint Food Agriculture Organization and World Health Organization (FAO/WHO) meeting[7] on pesticide residues reported that there was no reason to change the previously reported Acceptable Daily Intake (ADI) limit for glyphosate and it was not necessary to establish an 'Acute Reference Dose' (ARfD) for glyphosate. Of most significance within the FAO/WHO report was the statement that glyphosate was "unlikely to pose a carcinogenic risk to humans from exposure through diet", which contradicts the report in November 2015 by the WHO cancer agency IARC.

With respect to the IARC classification of glyphosate it is important to note that exposure to category 'Group 2A' (*i.e.* 'Probably Carcinogenic to Humans') chemicals raises the health risk for working with glyphosate to that similar to professions such as barbers and fry cooks and raises the health risk to equivalent to exposure from other chemicals that are found in motor oil, soot, exhaust emissions and road runoff (See Annex A.2 of this report).

It is also important to note that the IARC does not set maximum permissible exposure limits for carcinogenic compounds because it does not provide a quantitative estimate of the magnitude of the risk resulting from a specified level of exposure. This role is the responsibility of the regulatory authorities. Table A.2.2. of Annex A includes the list of known carcinogenic compounds that can be encountered to some limited extent in most of our daily lives (*i.e.* benzene from fuelling a car, paint and air pollution). However, based on the calculated maximum permissible exposure limits that are set by regulatory authorities these concentrations are not expected to be exceeded through normal behaviour or in occupational settings once suitable personal protective equipment or other precautions are taken into account.

Based on the above discussion it is the opinion of DENR that the exposure risk of glyphosate from the road-side weed control spraying of Rodeo® to the public and the herbicide applicator employee should only be considered with respect to the most stringent exposure limits that are set by regulatory authorities from other developed jurisdictions (*i.e*. UK, US, Canada, etc.). The purpose of this study and the data generated from it will therefore only be related to the stated maximum rates of ingestion or inhalation to the public and herbicide applicator employee and also to any environmental guidelines that may be available for pond water, soils and sediments.

Furthermore, the data from this study will also be able to be used in the future, if and when the regulatory authorities decide if it is necessary to reduce the exposure limits of glyphosate or associated compounds that are in the various herbicide formulations available on the market.

[7] Joint FAO/WHO Meeting on Pesticide Residues (Food and Agriculture Organization of the United Nations), World Health Organization. Geneva, 9-13 May 2016, Summary report issued 16 May 2016. http://www.who.int/foodsafety/jmprsummary2016.pdf

3 Glyphosate in the Environment

Glyphosate currently has the highest global production volume of all herbicides. The largest use worldwide is in agriculture. The agricultural use of glyphosate has increased sharply since the development of crops that have been Genetically Modified (GM) to make them resistant to glyphosate. Glyphosate is applied directly on these crops. Glyphosate is also used as a pre-harvest desiccant for non-GM crops in addition to being used in forestry, urban, and home applications.

In air, glyphosate is not expected to be present as a vapour due to its very low vapour pressure, and due to its high solubility in water it will be expected to be present within the water mists that are generated from road-side spraying for weed control. See Section 5.3 for more details on the spraying technique and controls.

Glyphosate is stable in water but it undergoes rapid ionization causing it to be strongly adsorbed to sediments, suspended particles and soils[9] and has been estimated to have a very short half-life in static water[8] such as ponds. Bio-concentration of the herbicide glyphosate in aquatic organisms is low and glyphosate is not suspected of being an endocrine-disrupting chemical[9]. Glyphosate degrades to natural products such as carbon dioxide and phosphate ions predominantly via microbial processes.

The Department has in the past funded environmental studies with the Bermuda Zoological Society and Fort Laboratories Inc. in Oklahoma that focused on a wide range of pollutants including pesticides and herbicides in sediments and pond water in Bermuda. These studies focused on critical groups of organisms found in ponds in Bermuda, including toads, killifish and terrapins, and found over the 2001 to 2013 period that glyphosate was not present in sediments (*i.e.* <0.5µg/kg, <0.5 ng/g) nor in the water column (*i.e.* <0.05 µg/l, <50 ng/l).

[8] Canadian Water Quality Guidelines and associated Report Rationale – prepared by the Task Force on Water Quality Guidelines of the Canadian Council of Ministers of the Environment, Nov, 2008.

[9] Maycock, D., Crane M, Atkinson, C and Johnson, I (2012) Proposed EQS for Water Framework Directive Annex VIII substances: glyphosate (for consultation). Water Framework Directive, UK Technical Advisory Group (TAG).

4 Human Exposure to Glyphosate

There are a number of potential exposure routes for the Bermuda public and the herbicide applicator employee to be exposed to glyphosate. These glyphosate exposure routes and potential mitigating measures are presented below:

Glyphosate Exposure Route / Mitigation Measure:

1. **Inhalation** of glyphosate within the water mists from road-side spraying for weed control.

   Mitigation measures:

   - Applicator only sprays when sufficient distance away from the public.
   - Applicator does not spray when wind is greater than 10 mph or if gusty at the roadside.
   - Applicator wears a particle/organic vapour half-face mask.
   - Applicator dilutes the glyphosate concentrate down to between 0.53 to 0.56%.
   - Regulatory Authorities provide occupational exposure limits via inhalation.
   - Studies corroborate whether inhalation limits could be exceeded for certain critical groups when glyphosate is applied as per the manufacturer's instructions.

2. **Absorption of herbicide through the skin**

   Mitigation measures:

   - Herbicide applicator shall use suitable gloves, coveralls and goggles when working with glyphosate.
   - Public should follow instructions when using glyphosate products purchased from retail stores.

3. **Ingestion of herbicide by accident, in drinking water or from glyphosate-treated crops**

   Mitigation measures:

   - Herbicide applicator shall not eat on the job without removing PPE and washing hands.
   - Public should follow instructions when using glyphosate products purchased from retail stores.
   - Government analyses potable water for a range of chemicals including glyphosate to ensure that its water is safe to drink.
   - It is illegal in Bermuda to directly connect a well pump to any drinking water systems or potable water tanks.
   - Public relies upon Regulatory Authorities to provide limits of safe levels of glyphosate in foodstuffs and to require suitable monitoring to ensure the limits are enforced.

4.1 Glyphosate Ingestion from Water

The risks of ingestion of glyphosate from water and suitable mitigation measures have been provided in section 4 above.

There are a wide range of permissible drinking water limits that have been set for glyphosate from a range of jurisdictions. Table 1 shows the most stringent glyphosate limit exists in the UK and EU (*i.e*. 100 nano-grams per litre, ng/l, equivalent to 0.1 parts per billion (weight/volume)). In the UK and EU this limit is applied to any pesticide that may be present in drinking water. The Canadian Drinking Water Quality Guidelines states a maximum acceptable concentration for glyphosate at 280,000 ng/l and the

limits for the US and Australia are much higher at 700,000 and 1,000,000 ng/l. When comparing the glyphosate concentrations found in drinking water and groundwater in Bermuda this study will use the most stringent UK and EU standard for comparison.

Table 1. Comparison of glyphosate concentration standards for drinking water between other developed jurisdictions

Country	Organisation/Standard	Glyphosate Concentration Limit (ng/l)	Comment
UK	Drinking Water inspectorate (DWI) [10]	100	Measured at consumers tap. 2010
EU	Drinking Water Directive	100	Applies to any pesticide.
US	Environmental Protection Agency (EPA) [11]	700,000	Maximum contaminant Level Goal (MCLG) and Maximum Contaminant Level (MCL)
Canada	Guidelines for Canadian Drinking Water Quality 1987. [12]	280,000	Maximum Acceptable Concentration (MAC). 2008.
Australia	Australian Drinking Water Guidelines 6 (2011) [13]	1,000,000	February 2016

4.2 Glyphosate Ingestion from Foodstuffs

The considered risks associated with the local application of glyphosate and suitable mitigation measures have been provided in section 4. It is acknowledged, however, that there is also a risk of ingestion of glyphosate from within foodstuff products that are imported to Bermuda. It is understood that glyphosate serves primarily two purposes in agriculture[14]:

- To control weeds within crops that have been Genetically Modified (GM) to be resistant to glyphosate.
- To act as a desiccant at the point just before harvest to aid in the processing of non-GM crops.

[10] UK Drinking Water Inspectorate (DWI). Drinking Water Standards. Jan 2010.
[11] US Environmental Protection Agency (EPA) National Primary Drinking Water Regulations (NPDWR), EPA 816-F-09-004, May 2009.
[12] Canadian Water Quality Guidelines and associated Report Rationale – prepared by the Task Force on Water Quality Guidelines of the Canadian Council of Ministers of the Environment, Nov, 2008.
[13] Australian Drinking Water Guidelines 6 2011. National Water Quality Management Strategy. National Health and Medical Research Council. Ver. 3.2, Updated February 2016. ISBN: 1864965118.
[14] Myers J.P., *et al* 2016. Concerns over use of glyphosate-based herbicides and risks associated with exposures: a consensus statement. Environmental Health, 15:19, 13pp.

This suggests that there could be a risk of glyphosate being present in the resultant crops, especially if they are not effectively washed after harvest. Glyphosate is known to be applied in the US and other countries to corn/maize, soy beans, canola, wheat, barley and edible beans. To provide some context to the exposure data from roadside weed-control spraying of glyphosate this study focused on foodstuffs imported from the US that contained these types of crops.

To address this risk of glyphosate ingestion from foodstuffs causing harm to humans the regulatory authorities set maximum ingestion rates for various compounds that are determined, with appropriate safety factors, relative to the concentration where 'No Observed Adverse Effects Level' (NOAEL) was noticed in a range of controlled laboratory experiments on other mammalian test species.

In the US the Environmental Protection Agency (EPA) set a chronic Reference Dose (cRfD) of 1.75 milligrams per kilogram of body weight per day (*i.e.* 1.75 mg/kg bw /day). In the EU the European Food Safety Agency (EFSA) has set an 'Acceptable Daily Intake' (ADI) level for glyphosate at 0.5 mg/kg bw per day. The World Health Organization (WHO) has set an ADI of 0.3 mg/kg bw per day. The most stringent ADI that DENR could find in the literature has been set by the EFSA for 'Acceptable Operator Exposure Level' (AOEL) at 0.1 mg/kg bw per day. When comparing exposure risk from ingestion of glyphosate in foodstuffs DENR will use these maximum ingestion rates that have been stipulated by the most stringent standards as provided by the EU and WHO.

4.3 Glyphosate Inhalation

In Bermuda glyphosate is only applied as a weed control agent by either the Ministry of Public Works, (MPW) as part of the roadside weed control programme, and also by the public or other businesses that purchase pre-diluted products that are available from local retail stores. As discussed above the high solubility of glyphosate in water coupled with the very low vapour pressure suggest that inhalation of glyphosate will primarily occur through the inhalation of water mists that contain glyphosate as a result of spraying this weed control agent.

With respect to the roadside spraying of weeds by MPW the persons at risk include the glyphosate applicator employee in addition to the public who may be standing, walking or running along the roadside when the applicator vehicle approaches and passes. There are a range of mitigation measures that have been listed in section 4 that are focused on reducing the risk of glyphosate inhalation to the public and the applicator employee.

The purpose of this study was to determine the concentration of glyphosate that could be inhaled by the public, who passed near to the herbicide applicator truck while spraying, and also by the herbicide applicator employee. The aim was to compare the air sample concentrations to stated inhalation limits that are provided in the occupational health legislation or other legislative instruments from a range of other developed jurisdictions.

Currently in the US there is not an OSHA (US Occupational Safety & Health Administration) permissible exposure limit (PEL) nor ACGIH (American Conference of Governmental Industrial Hygienists) threshold limit value (TLV) for glyphosate. However, an arbitrary limit of 1 mg/m^3 (method PV2067) has been set by OSHA, which will be used as the threshold for this study. In Europe there are also not any defined occupational exposure limits for glyphosate. This study will therefore compare any airborne concentration data to the OSHA arbitrary limit and for further corroboration will also compare the air-borne concentration of glyphosate, together with an expected person's inhalation rate from breathing during the potential exposure, to the ingestion levels provided in section 4.2 above. One other assumption when comparing the expected inhalation rate to legislated ingestion limits will relate to all of the inhaled glyphosate being retained by the body (*i.e.* none exhaled).

5 Methodologies

5.1 Sampling

Water, soil and sediment samples were collected in 250ml HDPE bottles that had been certified clean of a range of analytes including pesticides and semivolatiles (Fischer Scientific Inc. #05-719-736). Air samples were collected using preloaded adsorbent filter cartridges (*i.e.* glass fibre, Type AE, 37mm, SKC Inc. #225-706) using the methodology defined by the US Occupational Safety & Health Administration (OSHA) analytical method PV2067. Air was drawn through the filter cartridge at a rate of 1 litre per minute for 90 minutes using an air pump according to OSHA method PV2067 (SKC Inc. Universal Sample Pump, #224-PCXR8). Figure 1 shows the configuration of the air pump and filter cartridge located within the vehicle cab of the glyphosate applicators truck and also at the rear of the truck. Samples of foodstuffs from supermarket shelves were placed in 250ml Nalgene PP bottles provided by Axys. Samples were collected and stored in the refrigerator until being sent by courier in a cool box to Axys with appropriate Chain of Custody forms. Samples of water were collected on 27-28th June, soil on 28th June, air on 24-29th June and foodstuffs on the 29th June 2016.

Figure 1. Photographs of the air sample collection pump, applicator truck with sign and air sampling filter cartridges set up in the vehicle cab and at the back of the truck.

5.2 Analytical

DENR consulted with a range of analytical laboratories in the US, UK and Canada for expertise in monitoring glyphosate and its degradation products at detection limits appropriate to this study in a range of matrices including; soil, sediment, water (groundwater, pond water and potable water), air filtration cartridges and a range of foodstuffs from supermarket shelves. It was not possible to find an analytical service company that could analyse for the two different surfactants used in the herbicide mixtures Roundup® and Rodeo®[15].

The company selected to meet the above requirements was Axys Analytical Services Ltd at 2045 Mills Road W, Sidney, BC, Canada V8L 5X2. Axys method MLA-054[16] was used for glyphosate and two degradation products; Glyphosinate and Aminomethyl Phosphoric Acid (AMPA) with detection limits of approximately 10 nano-grams per litre (ng/l) for aqueous samples and 25 ng/l for solid samples. A summary of the method included: addition of isotopically-labelled internal surrogate standards in addition to extraction recovery standards, derivatisation of the target analytes using 9-fluorenylmethylchloro-formate with sample clean-up using solid phase extraction. Solid samples were also extracted initially using potassium hydroxide. Analysis was performed on a high performance liquid chromatograph (HPLC) using a reverse phase C18 column to isolate the analytes with a triple quadrupole mass spectrometer (HPLC/MS/MS). Procedural blanks were included with every batch of samples analysed.

5.3 Roadside Spraying

Roadside spraying of glyphosate is performed by personnel from the Ministry of Public Works (MPW) using a truck carrying a 100 US Gallon container with a Diesel operated water pump. The product used by MPW is Rodeo® from Dow Chemicals Ltd containing glyphosate isopropylamine salt concentrate that is diluted in water to a final application concentration of between 0.53 and 0.56%. It is noted that the smaller pre-diluted products that are sold in retail stores typically contain between 0.75% and 2% glyphosate concentration. The herbicide applicator uses two spray settings depending on the width of the swath that is required (*i.e.* narrow or wide verges of weeds, average 4ft), which equate to flow rates of 7.1 and 5.8 litres per minute, respectively. As a rough approximation this spray area and volume at a vehicle speed of 5 mph equates to approximately 40 ml per square metre of coverage. The spray nozzle is adjusted by the operator to limit the amount of stray water mists that are generated in order to focus the effect of the herbicide onto the roadside weeds and to not create greater impact to other plants over a wider area through drift to non-target plants.

Each 100 USG container will therefore typically last for between 54 and 65 minutes. Roadside spraying is performed in two morning shifts that avoids the rush hour (*i.e.* 5.00am to 7.30am and 9.00am to 12.00pm). The applicator does not spray when it is raining or when the winds are over 10 mph or if the roadside conditions are considered to be gusty. The applicator PPE includes coveralls, nitrile gloves, goggles and a reusable half face mask that filters particles and organic vapours.

[15] Surfactants: Octylphenoxypolyethoxyethanol (in Rodeo® by Dow Chemicals) and Polyethoxylated tallow amine (in Roundup® by Monsanto).

[16] Summary of AXYS Method MLA-054 Rev.5, Ver. 04: Analytical procedure for the analysis of glyphosate and related compounds in aqueous and solid samples by LC-MS/MS. Axys Analytical Services Ltd, 23 Jan 2004.

6 RESULTS

6.1 RESULTS - Groundwater, Pond Water and Potable Water

In order to determine the full potential impact of glyphosate use, with consideration of its high solubility, it was necessary to measure glyphosate concentrations in groundwater, pond water and the Reverse-Osmosis treated groundwater to generate potable water for the public of Bermuda. Table 2 shows the results of the water samples that were analysed for glyphosate and two of its degradation products.

Table 2. Concentrations of Glyphosate and degradation products found in groundwater, pond-water and potable water.

Sample No.	Description	Glyphosate (ng/l)	Glufosinate (ng/l)	Aminomethyl-phosphonic Acid [AMPA] (ng/l)
1	GROUNDWATER Monitoring Well - Vesey St North (CVSN)	*<10.4*	*<10.3*	*<10.2*
2	GROUNDWATER Monitoring Well - Orange Valley (CORV)	**10.2**	*<9.84*	*<9.74*
3	Cloverdale POND WATER	**10.8**	*<10.2*	*<10.1*
4	GROUNDWATER FEED (*i.e.* INFLUENT) to Government Potable water RO Plant (Prospect location)	*<10.2*	*<10.1*	*<9.98*
5	POTABLE WATER * from Government (Prospect) RO Plant	*<10.2*	**NQ**	**NQ**

"NQ" - Not Quantifiable - Low sample recovery (i.e. 10%) based on internal standard.
"<" = Below stated detection limit
**** Potable water limits for EU: 100 ng/l; US: 700,000 ng/l; Canada: 280,000 ng/l; Australia: 1,000,000 ng/l***

From Table 2 it is apparent that the glyphosate was detected at very close to the very low detection limit of the analytical method in one groundwater and one pond water sample. Glyphosate was not detected in the groundwater sample used to feed the Reverse-Osmosis plant and was also not detectable in the potable water generated by the Ministry of Public Works.

Comparison of the sample glyphosate concentrations with the maximum permissible levels for drinking water from other developed jurisdictions can be made by referring to table 1.

It is apparent that the glyphosate detected in the ground water and pond water was typically an order of magnitude (10x) lower than the most stringent drinking water standard that is stipulated for both the UK and EU countries. It is important to note that the permissible drinking water limits vary considerably between the countries of the EU, Canada, US and Australia.

Other standards that were found in the literature to address maximum environmental concentrations to protect ecosystems and wildlife were also much higher than the UK/EU drinking water standard but were more stringent than drinking water standards of other jurisdictions. For example, the California

State Water Resources Control Board recommends an aquatic guideline of 130 µg/l (*i.e*. 130,000 ng/l in Table 2) of glyphosate for waterborne residues of Roundup® due to the increased toxic effect of the surfactant in the Roundup® formulation[17]. The Canadian Water Quality Guidelines for the Protection of Aquatic Life state a freshwater guideline of 65µg/l glyphosate (*i.e.* 65,000 ng/l in Table 2) [12].

The groundwater and pond water data suggests that the concentrations of glyphosate and its degradation products are well below the most stringent drinking water and environmental quality standards that apply in other jurisdictions. This information suggests that the current use of glyphosate in Roundup® and, Rodeo® and other glyphosate products with respect to weed control only in Bermuda is not considered to be creating any measurable environmental impact to the groundwater or pond water and is not detectable in the potable water for public use.

The Ministry of Public Works Water Section already analyses the potable water they generate using overseas accredited laboratories. The results of this study are consistent with the results previously collected by MPW in that the glyphosate was below the analytical detection limit, albeit at higher analytical detection limits (*i.e.* <10µg/l, <10,000 ng/l).

[17] Corcoran D.P, D.B. Cohen and G.W. Bowes (1984). Glyphosate use in forestry (Roundup®) and aquatic weed control (Rodeo®): A Water Quality Assessment. Special Project Report No. 84-11sp. California State Water Resources Control Board, Sacramento, California.

6.2 RESULTS – Soil and Sediment Samples

Although glyphosate has a high solubility in water it is understood to be readily adsorbed onto particles of soil and sediment. For completeness it was necessary to analyse pond sediments in addition to road-side soils that had been either recently or previously sprayed with glyphosate as part of the MPW weed control programme. Table 3 shows the results of glyphosate and degradation products detected in pond sediment and roadside soils.

Table 3. Concentrations of Glyphosate and degradation products found in road-side soils and sediments from Cloverdale Pond.

Sample No.	Description	Glyphosate (ng/g)	Glufosinate (ng/g)	Aminomethyl-phosphonic Acid [AMPA] (ng/g)
1	Cloverdale Pond – Sediment at water line.	<31.3	<31.0	<30.7
1b	Cloverdale Pond - Sediment at water line (#2) (DUPLICATE)	<30.4	<30.1	<29.8
2	McGall's Hill - Roadside (sprayed more than 4 months prior)	**886**	<27.1	**618**
3	Harrington Sound Road - Roadside (Near Quarry) (sprayed more than 4 months prior)	**949**	<29.3	**1310**
4	North Shore Road - Roadside (near Tynes Bay) (Sprayed within 1 week of sampling)	**6120**	<27	**1670**
5	Black Watch Pass - Roadside (Western side) (Sprayed within 1 week of sampling)	**51200**	<27.4	**7250**

"<" = Below stated detection limit

From Table 3 it is apparent that the glyphosate was not present in the sediments of Cloverdale pond, a result that was consistent with the pond water data. The soils from the roadside from areas that had either been sprayed recently (*i.e.* within 1 week, #4 and #5) or in the recent past (*i.e.* over 4 months ago, #2, #3) as part of the MPW weed control programme showed considerable variation in glyphosate concentration. The highest glyphosate concentration that was found in the Black Watch Pass road section (*i.e.* sample #5) that was observed to have negligible soil adjacent to the pavement and limestone cliff (*i.e.* 51,200 ng/g = 51.2 mg/kg) with weeds largely growing out of the rock. This may have resulted in a higher inundation of glyphosate per amount of soil present when compared to other roadside areas. It is also important to note that the breakdown product AMPA degrades in soil at a slower rate than glyphosate such that is exceeded the glyphosate concentration in one soil sample that was last sprayed over 4 month prior to sampling (*i.e.* sample #3).

DENR is not aware of any sediment or soil quality guidelines that provide environmental limits for glyphosate. It is noted that the Canadian Council of Ministers of the Environmental (CCME) provide limits for 'pesticides' in general in soils at 0.7 mg/kg (*i.e.* 700 ng/g) for agricultural and residential land and 12 mg/kg (*i.e.* 12,000 ng/g) for commercial and industrial land. It is therefore noted that the roadside soils typically fall within the commercial and industrial guideline for pesticides under CCME but,

within 4 months or more, do not consistently meet the CCME agricultural and residential guideline for pesticides in general.

It is also important to note that the soils that had been sprayed over 4 months before sampling (*i.e.* samples #2 and #3) demonstrated concentrations of less than 1,000 ng/g, which as can be seen from Section 6.4 later in this report, is less than the maximum glyphosate concentration found in certain foodstuffs.

In addition to considering the environmental risk to organisms that inhabit the ponds, soils and sediments another group of organisms that can be readily affected by various pesticides includes bees. Publications report various effects ranging from glyphosate having relatively low toxicity to honey bees[18] to causing harm to bees' spatial learning when foraging on glyphosate-treated GM crops[19]. It is noted that GM crops are not grown in Bermuda, which would be expected to reduce the potential impact to bees in the Bermuda environment compared to other areas considered in other studies.

[18] Cheng Zhu Y, et al., (2015) Spray toxicity and risk potential of 42 commonly used formulations of row crop pesticides to adult honey bees (Hymenoptera: Apidae). Journal of Economic Entomology, Sept. 2640-2647.

[19] Balbuena, M.S. et al., (2015) Effects of sub-lethal doses of glyphosate on honeybee navigation. The Journal of Experimental Biology, 218, 2799-2805.

6.3 RESULTS – Air Samples from inside herbicide applicator truck and at the rear of the vehicle

The data in table 4 shows that the freshly diluted glyphosate in the Rodeo® herbicide product does not contain any of the known degradation products of glyphosate. Glyphosate exposure for each of the 90 minute air sampling periods, at 1 litre per minute, equated to an exposure amount of 13.3 to 33.7 ng/l within the cab of the vehicle and 17.6 to 46.8 ng/l at the rear of the vehicle. It is noted that the units of nanograms per litre (ng/l) are equivalent to micrograms per cubic metre of air (*i.e.* µg/m^3).

Table 4. Concentrations of Glyphosate and degradation products detected in the air samples collected from within the occupied cab of the applicator vehicle and at the rear of the applicator vehicle..

Sample No.	Description	Vehicle Route	Glyphosate (ng/litre)	Glufosinate (ng/litre)	Aminomethyl-phosphonic Acid [AMPA] (ng/litre)
1C	Inside Cab	BlackWatch Pass, North Shore Road	**13.3**	<0.71	<0.70
1R	Behind Vehicle		**17.6**	<0.71	<0.70
2C	Inside Cab	North Shore Road Devonshire	**33.7**	<0.71	<0.70
2R	Behind Vehicle		**33.8**	<0.71	<0.70
3C	Inside Cab	North Shore Road, Devonshire.	**31.6**	<0.71	<0.70
3R	Behind Vehicle		**24.7**	<0.71	<0.70
4C	Inside Cab	Southside Road, St George's	**25.9**	<0.71	<0.70
4R	Behind Vehicle		**46.8**	<0.71	<0.70
5C	Inside Cab	Barkers Hill, North Shore Road.	**21.7**	<0.71	<0.70
5R	Behind Vehicle		**28.0**	<0.71	<0.70

"<" = Below stated detection limit

Comparison of the glyphosate concentration detected in the air within the vehicle cab to that behind the vehicle demonstrated that the two samples could not be differentiated at the 95% confidence level suggesting that the exposure to glyphosate within the cab for a given time was the same as the exposure from directly behind the cab for the same period of time. It is noted that the proportion of time that a person on the side of the road would be exposed to the water-glyphosate mist from the passing vehicle would be significantly less than the exposure to the applicator person from within the vehicle cab. The sampling point behind the vehicle was also at the edge of the rear of the vehicle on the same side that the spraying was occurring. It is noted that the glyphosate has a very low vapour pressure which suggests the airborne exposure route would be via water droplets that contain glyphosate in a water mist that remain in the air before they fall to the ground. It is also noted that the standard operating procedure for the applicator is to not apply herbicide when passing persons stood on the side of the road and to avoid application when wind speeds are over 10 mph or are considered to be gusty at the roadside. This information suggests that the herbicide applicator employee would be considered to be the 'Critical Group' with respect to being exposed to the highest concentrations of glyphosate over an 8-hour working day.

In order to determine whether this airborne exposure route for glyphosate is significant it was necessary to equate the exposure for the worst case scenario critical group (*i.e*. herbicide applicator) to the known maximum inhalation limits based on occupational or other standards.

Currently OSHA (US Occupational Safety & Health Administration) does not set a permissible exposure limit (PEL) for glyphosate and similarly the ACGIH (American Conference of Governmental Industrial Hygienists) does not set a threshold limit value (TLV) for glyphosate either. In Europe there are also not any defined occupational exposure limits for glyphosate exposure through inhalation. DENR is not aware of other occupational exposure limits that have been set in other developed jurisdictions. It will therefore not be possible to relate the inhalation exposure of glyphosate in Bermuda to any specific international occupational exposure limits. However, an arbitrary limit of 1 mg/m^3 (method PV2067, units of milligrams per cubic metre) has been set by OSHA, which was stated in the strategy document to be used as the threshold for this study (See Annex A).

From table 4 it is apparent that the concentrations of glyphosate detected in the air of the vehicle cab and from behind the vehicle are significantly lower than the OSHA arbitrary limit. The highest level detected in the air at the rear of the vehicle was 46.8 ng/l, which is the same as 0.0468 mg/m^3, a factor of 21 times lower than, or less than 5% of, the OSHA arbitrary limit of 1 mg/m^3.

Due to the set OSHA inhalation limit being an arbitrary limit it was also important to relate the air-borne glyphosate exposure data to other limits, such as that stated for ingestion. As a comparison the World Health Organisation (WHO) Acceptable Daily Intake (ADI) limits for ingestion of glyphosate is from 0 to 0.3 mg/kg body weight per day[20]. The most stringent ingestion limit that DENR is aware of is quoted by the European Food Safety Authority (EFSA) which provides an Acceptable Operator Exposure Level (AOEL) of 0.1 mg/kg bw per day (*i.e.* 0.1 milli-grams of glyphosate per kg of body weight of a person per day). The EFSA also quote an ADI for consumers of 0.5 mg/kg bw per day. If it is assumed that all of the glyphosate inhaled entered the body (*i.e*. none exhaled) then the limit for a typical 60 kg person would be 6 mg per day for a glyphosate spray operator (*i.e*. 60 kg x 0.1 mg/kg/day).

In order to relate the air-borne glyphosate exposure of the applicator (*i.e.* critical group) to the most stringent legislated ingestion limit (*i.e.* 0.1 mg/kg bw per day) it is necessary to estimate the amount of air that is breathed in by the person over a worst case 8-hour exposure day (although it is noted that the MPW operator normally spends a maximum of 5.5 hours on spray routes, with the remainder of the workday on other duties so as to avoid the rush hour).

The typical amount of air breathed by a person was determined from a California Environmental Protection Agency study[21] which states that it can vary depending on the type of activity for adult males:

- 9 litres of air per minute (Sitting)
- 11 litres of air per minute (Driving)
- 24 litres of air per minute (Walking at 2.5 mph)
- 58 litres of air per minute (Running at 5 mph).

Assuming that the MPW operator has a worst-case very high breathing rate within his vehicle of 22 litres of air per minute (*i.e.* twice the expected average for driving) then the total volume of air breathed in over a typical 8 hour working day would be 10,560 litres (*i.e.* 22 litres x 60 minutes per hour x 8 hours).

[20] Glyphosate and AMPA in Drinking Water – Background document for development of WHO Guidelines for Drinking-water Quality. World health Organization 2005.

[21] How much air do we breathe? California Environmental Protection Agency, Air Resources Board. Research Note 94-11: August 1994. https://www.arb.ca.gov/research/resnotes/notes/94-11.htm

This equates to a worst-case maximum of 10.6 cubic metres of inhaled air containing glyphosate per day.

Using this high estimate of the amount of air breathed in by the MPW operator over an 8-hour day (*i.e*. 10.6 m^3) coupled with the highest recorded air-borne concentration of glyphosate (*i.e.* 46.8 ng/l – Table 4) then this equates to a glyphosate exposure of 0.496 mg per 8-hour day.

Table 5 shows the amount of air-borne glyphosate converted into the amount of air, in cubic metres, that would need to be breathed in order to exceed the ESFA AOEL ADI limit of 0.1 mg/kg bw per day and also the WHO ADI of 0.3 mg/kg bw per day. For a typical 60kg person the amount of air that would need to be breathed in to exceed the more stringent EFSA AOEL ADI would be 128 cubic metres (average = 243m^3).

Table 5. Concentrations of Glyphosate in the air samples collected from within the occupied cab of the applicator vehicle and at the rear of the applicator vehicle with conversion to the amount of air required to exceed the EFSA AOEL ADI limit and WHO ADI limit for a typical 60kg person.

Sample No.	Description	Glyphosate (ng/litre)	Glyphosate Concentration in milligrams per cubic metre (mg/m^3) *	Calculated volume of air required to exceed EFSA AOEL ADI limit (*i.e.* 0.1 mg/kg bw/day). (m^3) †	Calculated volume of air required to exceed WHO ADI limit (*i.e.* 0.3 mg/kg bw/day) (m^3) †
1C	Inside Cab of herbicide applicator vehicle	**13.3**	**0.013**	**450**	**1350**
2C		**33.7**	**0.034**	**178**	**535**
3C		**31.6**	**0.032**	**190**	**570**
4C		**25.9**	**0.026**	**232**	**695**
5C		**21.7**	**0.022**	**277**	**831**
1R	At the rear of the herbicide applicator vehicle	**17.6**	**0.018**	**342**	**1025**
2R		**33.8**	**0.034**	**178**	**533**
3R		**24.7**	**0.025**	**243**	**730**
4R		**46.8**	**0.047**	**128**	**385**
5R		**28.0**	**0.028**	**214**	**643**

† ***Volume of air containing glyphosate that is required to be inhaled to exceed the EFSA AOEL and ADI for a person of 60 kg body weight.***
Note that the worst-case estimated volume of air to be inhaled by the herbicide applicator employee over an 8-hour shift is expected to be less than 10.6m^3.

Using the worst case exposure (i.e. Table 5, 46.8ng/litre) the glyphosate applicator employee (i.e. critical group) is expected to be exposed to less than 9% (i.e. 10.6m^3) of the EFSA AOEL Acceptable Daily Intake (ADI) amount (i.e. 128 m^3) assuming that all inhaled glyphosate would be retained by the body.

The above information suggests that relative to the respective OSHA inhalation and EU ingestion limits for glyphosate the exposure risk from road-side weed-control spraying for the applicator employee (*i.e.* highest risk critical group) is low. DENR will monitor the developments in legislation from other developed jurisdictions for potential future changes to these exposure limits and will use the data collected as part of this study to update the exposure risk accordingly.

6.4 RESULTS – Foodstuffs from Supermarket Shelves

Foodstuffs were collected from a range of supermarkets in Bermuda for the purpose of providing some scale of the exposure risk to the public and herbicide applicator employee relative to the potential exposure route from eating crop foodstuffs sprayed with glyphosate. The intention of this very small-scale analysis of the foodstuffs was therefore not to identify specific food products that may or may not contain glyphosate and degradation products but to focus on the generic levels present in foodstuffs for indicative purposes only.

It is acknowledged that Genetically Modified (GM) crops are not understood to be grown by farmers in Bermuda. All foodstuffs selected from the supermarket shelves were therefore from overseas sources and these were largely from the US. Foodstuffs from the US do not need to specify whether the crops are from GM sources or not so the generic products selected were randomly chosen based on corn, wheat and oat products. It is acknowledged that any glyphosate present in the products selected may result from either the crops being from a GM origin or from the use of glyphosate as a pre-harvest desiccant on non-GM crops. Contrary to the US it is noted that 64 countries around the world currently require labelling of GM foods[22].

Table 6 shows the results from 8 different samples of foodstuffs including a triplicate sample of 'All-Purpose Flour' in order to determine the analytical variation of the methodology (See footnote to Table 6).

It is apparent from table 6 that glyphosate and only one of the two potential degradation products (*i.e.* AMPA) was detected in the whole wheat flour, all-purpose flour, quick oats and cornmeal. The other degradation product, glyphosinate, was not detected in any of the samples analysed. Glyphosate and AMPA were not detected in either of the two types of popcorn selected (one Non-GM and other not stated) (*i.e*. <0.47 ng/g). It is not known whether the popcorn selected were naturally free of glyphosate or whether the heating process in the manufacture/preparation of the kernels caused thermal decomposition of any glyphosate present. Glyphosate degradation is understood to begin above 230°C[23]. A very small amount of glyphosate only was present in the non-branded cornflakes selected (*i.e.* 10.8 ng/g) and the 'organic' labelled cornmeal contained a very small amount of AMPA (*i.e.* 2.01 ng/g) but without glyphosate being present (*i.e.* <0.452 ng/g). Typically the degradation product AMPA was present at less than 10% of the concentration of glyphosate. The highest concentrations of glyphosate were found in Quick Oats (*i.e.* 1140 ng/g) and Whole Wheat Flour (*i.e.* 603 ng/g).

[22] http://www.justlabelit.org/right-to-know-center/labeling-around-the-world/

[23] Fei-Xiong Chen et al., 2012. Study on thermal decomposition and the non-isothermal decomposition kinetics of glyphosate. Journal of Thermal Analysis and Calorimetry, Vol. 109, pp 1457-1462. http://link.springer.com/article/10.1007/s10973-011-1834-9.

Table 6. Concentrations of Glyphosate and degradation products found in a range of foodstuffs available from the shelves of supermarkets in Bermuda.

Sample Description	Glyphosate (ng/g)	Glufosinate (ng/g)	Aminomethyl-phosphonic Acid [AMPA] (ng/g)
Whole Wheat Flour	**603**	<0.459	**40**
All Purpose Flour - Triplicate sample for determination of analytical precision (CV). †	**171**	<0.465	**11**
	190	<0.461	**9.48**
	241	<0.447	**16.4**
Quick Oats	**1140**	<0.439	**34.7**
Popcorn	<0.47	<0.466	<0.461
Popcorn - Non-GMO	<0.467	<0.463	<0.458
Cornflakes	**10.8**	<0.422	<0.418
Cornmeal (Organic)	<0.452	<0.447	**2.01**
Cornmeal	**26**	<0.452	**3.04**

"<" = Below stated detection limit

† GLYPHOSATE Average = 201ng/g, Standard Deviation = 36.2ng/g, Coefficient of Variation (CV) = 18.0%

† AMPA Average = 12.3ng/g, Standard Deviation = 3.6ng/g, Coefficient of Variation (CV) = 29.6%

Table 7 highlights how many kilograms (kg) of the various foodstuffs that would be required to exceed the Acceptable Daily Intake limits as defined by both the World Health Organization and the European Food Safety Agency.

From Table 7 it is apparent that the amounts of foodstuffs that would need to be consumed daily in order to exceed even the most stringent Acceptable Daily Intake limits (*i.e.* WHO) are prohibitively large. The food stuff containing even the highest levels of glyphosate (*i.e.* Quick Oats at 1140 ng/g = 0.00114 mg/g) equated to a very large amount of 16 kg of Quick Oats that would need to be consumed each day in order to exceed the WHO ADI. Also in order to exceed the most stringent Acceptable Operator Exposure Level (AOEL) of the EFSA over 5 kg of quick oats would need to be consumed each day.

This data suggests that based on the existing most stringent legislated Acceptable Daily Intake levels that the foodstuffs sampled do not pose a health risk with respect to glyphosate ingestion.

As stated above the purpose of measuring glyphosate within foodstuffs was to provide some scale of the exposure risk to the herbicide applicator employee (*i.e*. critical group) and to the public from roadside weed-control. Comparison of the exposure risk from inhalation by the herbicide applicator employee to the exposure risk through ingestion to certain foodstuffs was required to provide some further context. Using the worst-case exposure risk for the applicator employee from inhalation over an 8-hour day this equated to 0.496 mg glyphosate per day (*i.e.* See Section 6.3). In addition to the worst case airborne levels being used and the very high assumed breathing rate of the employee it is also acknowledged that the actual exposure risk will, in fact, be much lower as the employee also wears a particle mask which was not taken into account with this sampling methodology and the spraying period is less than 8 hrs/day.

Table 7. Conversion of glyphosate concentration detected in foodstuffs to weight of food stuff required to exceed the WHO ADI and EFSA ARfD daily intake limits for glyphosate, based on a typical person's body weight of 60kg.

Sample Description	Glyphosate (ng/g)	Kilograms of food stuff required to exceed WHO ADI daily limit of 0.3 mg/kg bw /day (kg) †	Kilograms of food stuff required to exceed EFSA ADI daily limit of 0.5 mg/kg bw /day (kg) ‡	Kilograms of food stuff required to exceed EFSA AEOL ADI daily limit of 0.1 mg/kg bw /day (kg) ‡
Whole Wheat Flour	**603**	**30**	**50**	**10**
All Purpose Flour - Triplicate sample for determination of analytical precision.	**171**	**105**	**175**	**35**
	190	**95**	**158**	**32**
	241	**75**	**124**	**25**
Quick Oats	**1140**	**16**	**26**	**5.3**
Popcorn	<0.47	N/A	N/A	N/A
Popcorn - Non-GMO	<0.467	N/A	N/A	N/A
Cornflakes	**10.8**	**1667**	**2778**	**556**
Cornmeal (Organic)	<0.452	N/A	N/A	N/A
Cornmeal	**26**	**692**	**1154**	**231**

† World Health Organization (WHO) Acceptable Daily Intake (ADI) limit of 0.3 mg/kg body weight per day for a 60kg person equates to 18 mg/day per person. For example, the amount of Quick Oats that would need to be consumed to exceed the WHO ADI equates to 18,000,000 ÷ 1140 = 15,789 grams = 15.8 kg (rounded to 16 kg in Table 7).

‡ European Food Safety Agency (EFSA) Acceptable Daily Intake (ADI) limit of 0.5 mg/kg body weight per day for a 60 kg person equates to 30 mg/day per person. Also the EFSA Acceptable Operator Exposure Level (AOEL) limit of 0.1 mg/kg body weight per day for a 60 kg person equates to 6 mg/day per person.

Table 8 shows how much food stuff would need to be consumed per day to equate to the same low exposure risk as the herbicide applicator employee over an 8-hour day.

From table 8 it is apparent that the exposure risk from consuming 0.44kg (*i.e.* 0.97 lb) of Quick Oats per day food stuff is equivalent to the worst case exposure risk through inhalation of the critical group herbicide applicator employee over an 8-hour day.

This information suggests that glyphosate exposure from consuming certain foodstuffs is low and can be comparable in scale to the low exposure risk experienced by the herbicide applicator employee.

Table 8. Comparison of glyphosate exposure risk from inhalation for the herbicide applicator employee to the exposure risk via ingestion from eating certain foodstuffs from supermarket shelves.

Sample Description	Glyphosate (ng/g)	Amount of foodstuff to be consumed per day to be equivalent to the exposure risk of the herbicide applicator employee at 0.496 mg per 8-hr day (See Section 7.3) (kg)
Whole Wheat Flour	**603**	**0.82**
All Purpose Flour - Triplicate sample for determination of analytical precision.	**171**	**2.90**
	190	**2.61**
	241	**2.06**
Quick Oats	**1140**	**0.44**
Popcorn	<0.47	NA
Popcorn - Non-GMO	<0.467	NA
Cornflakes	**10.8**	**45.93**
Cornmeal (Organic)	<0.452	NA
Cornmeal	**26**	**19.08**

7 CONCLUSIONS

This study determined glyphosate and its degradation products in a range of different matrices that could form potential vectors of exposure to the public, herbicide applicator employee, and organisms found in Bermuda's environment.

Groundwater used to supply the Ministry of Public Works reverse osmosis potable water treatment system and the resultant potable water generated for public use was shown to be free of glyphosate and degradation products at very low detection levels (*i.e.* <10 parts per trillion, nano-grams per litre, ng/l). One of the three groundwater samples and one pond water sample was shown to contain glyphosate-only at just above the analytical detection limit (i.e. 10.8 ng/l), which was one order of magnitude lower than the most stringent drinking water standard that has been set in the UK and EU. Groundwater and Government potable water do not therefore pose a risk of glyphosate exposure to the public of Bermuda. The Department of Environment & Natural Resources is not aware of any sediment or soil quality guidelines that provide environmental limits for glyphosate, though according to soil standards in Canada for generic pesticides the roadside verges after weed control would be considered as meeting the standards for Commercial/Industrial land.

Air samples collected from both inside the cab and at the rear of the herbicide applicator vehicle while spraying demonstrated similar concentrations of glyphosate that ranged from 13.3 to 46.8 ng/l. The herbicide applicator employee was considered to represent the 'Critical Group' with respect to being exposed, through inhalation of glyphosate for the longest period in the day, to the highest expected concentrations on a daily basis. Comparison of the worst-case inhalation exposure risk of the herbicide applicator employee, without taking into account the benefits of wearing a half face particle/organic vapour mask, suggested that he was exposed to less than 5% of the maximum permissible OSHA arbitrary limit of 1mg/m^3 glyphosate. In the absence of other occupational inhalation standards a comparison to the known ingestion exposure standards was made as a cross comparison. With the assumption that all inhaled glyphosate was retained by the body the worst-case inhalation rate equated to less than 9% of the most stringent daily ingestion rate of glyphosate that is stipulated by the European Food Safety Agency (EFSA).

Foodstuffs imported to supermarkets in Bermuda were sampled to provide some scale of the exposure risk to the public and herbicide applicator employee from road-side spraying relative to the potential exposure route from eating generic crop foodstuffs that may have been sprayed with glyphosate. It is acknowledged that any glyphosate present in the foodstuffs selected may result from either the crops being from a Genetically Modified (GM) origin or from the use of glyphosate as a pre-harvest desiccant on non-GM crops. Glyphosate was present in most of the foodstuffs sampled, however, the levels are considered to be safe according to the Acceptable Daily Intake (ADI) stipulated by the World Health Organization (WHO) at 0.3 milligrams per kilogram body weight per day (*i.e.* 0.3 mg/kg bw per day) and the EFSA AOEL limit of 0.1 mg/kg bw per day. Quick oats and whole wheat flour were found to have the highest glyphosate concentrations at 1140 and 603 ng/g (*i.e.* parts per billion), respectively, which for a typical 60kg person equated to having to eat more than 16 kg of quick oats and more than 30 kg of whole wheat flour per day to exceed the WHO ADI or more than 5kg quick oats and 10kg whole wheat flour to exceed the EFSA AOEL. Therefore based on the existing most stringent legislated ADI levels the foodstuffs sampled do not pose a health risk from glyphosate ingestion.

Comparison to the exposure risk through inhalation of the herbicide applicator employee (*i.e*. critical group) suggest that the worst-case inhalation dose of glyphosate, without considering the positive effects of wearing PPE (*i.e.* half-face particle and organic vapour mask), was equivalent to eating less than half a kilogram of quick oats per day. Based on the current most stringent exposure limits the results from this study highlight that the risk to human health posed by roadside spraying of glyphosate

in Rodeo® for weed control meets stringent international standards provided that the current standard operating procedures and safety precautions are maintained.

8 RECOMMENDATIONS

The following recommendations are made:

a. Based on the determined exposure risk to the public, herbicide applicator employee and the environment the Department of Environment & Natural Resources can find no reason from the existing legislation from other developed jurisdictions to continue the ban on the concentrated glyphosate formulation that was tested (*i.e*. Rodeo®).

b. The Minister responsible for Health and the Minister for the Environment have sufficient information in this report to suggest that the current ban on the concentrated glyphosate product Rodeo®, which is used by MPW roadside weed control programme, be lifted.

   It is acknowledged that only the Rodeo® product was tested as part of these trials but in terms of the stated known exposures that other concentrated glyphosate-based products would also be expected to show similar low exposure risk to humans.

c. The Department of Environment & Natural Resources and Department of Health shall monitor any future changes to the legislation from other developed jurisdictions (*i.e*. UK, EU, US, Canada) with respect to the human exposure limit standards from inhalation and ingestion for:
   - Glyphosate,
   - Glyphosate degradation products
   - Any of the active/non-active ingredients that may be highlighted from within certain glyphosate formulations (*i.e*. Roundup®, Rodeo®, etc.).

d. It is strongly recommended that the importation of concentrated pesticide formulations (*i.e*. not *Ready To Use* products) be controlled and limited to personnel who have demonstrated sufficient training and certification to ensure that all pesticide products are applied in a safe and sustainable manner. It is understood that the Department of Health is starting a training programme (*i.e.* course/exam/certification) in Quarter 1 of 2017 for pesticide applicators that will be based on the US National Core Pesticide Applicator Programme. It is understood that the Department of Health will assess pesticide applicators for competency once they have met the US certification process whether from Bermuda-organised courses or via other training and certification routes.

e. All certified pesticide applicators (*i.e.* commercial and private) that have been deemed competent by the Department of Health shall perform a risk assessment process for each type of pesticide application that takes into consideration potential avoidance of the use of harmful pesticides through Integrated Pest Management (IPM). IPM can mitigate the use of harmful pesticides via an ecosystem-based strategy that may use biological control, habitat manipulation, or alternative more natural chemical control.

f. As a precaution the herbicide applicator employee shall be provided with annual health assessments to the requirements of the Chief Medical Officer (CMO) for the Ministry of Health & Seniors.

g. The Department of Environment and Natural Resources shall continue to monitor the impact of various pesticides in the environment.

h. Any new valid information that is brought to the Department's attention will be used to update the exposure risk to the applicator or public by either using the existing data collected or, if a subsequent study is required, on any new data generated.

i. As a precautionary approach for roadsides that border or drain into adjacent agricultural land the Ministry of Public Works shall ensure that alternatives to glyphosate weed control processes are adopted that have been approved by DENR first.

j. Providing a method for the Ministry of Public Works to inform the public of the routes sprayed for weed control will also be considered.

k. Before any of the above recommendations are implemented it is recommended that a Communication Plan be prepared that in addition to health and environmental will also take into account the economic, social and political considerations. One of the outputs from the Communication Plan shall include a second presentation to stakeholders and an opportunity for feedback before implementing the recommendations from this report.

A.1. GLYPHOSATE MONITORING STRATEGY – MAY 2016

Ministry of the Environment
Department of Environment and Natural Resources

Glyphosate Monitoring Study

Objectives: To monitor the risks of exposure of glyphosate, its degradation products and associated surfactants used in the herbicides Rodeo® and Roundup® in Bermuda and to consider the ecotoxicity in the environment.

Background: Glyphosate currently has the highest global production volume of all herbicides. The largest use worldwide is in agriculture. The agricultural use of glyphosate has increased sharply since the development of crops that have been Genetically Modified (GM) to make them resistant to glyphosate. Glyphosate is applied directly on these crops. Glyphosate is also used in forestry, urban, and home applications. In March 2015 the World Health Organization (WHO) changed the associated risk category of glyphosate-based formulations from 'Possible Carcinogen' to 'Probable Carcinogen' to humans.

As a result of pressure from the public and following various stakeholder meetings the Minister of Health, Seniors & Environment suspended the importation of glyphosate to Bermuda in May 2015. During the suspension, officers of the Bermuda Government were to conduct a range of analyses to understand the level of risk to the public from a variety of potential exposure pathways. Furthermore, in November 2015 the European Food Safety Authority (EFSA), reported that glyphosate (only) is unlikely to pose a carcinogenic hazard to humans and has proposed a new safety measure that will tighten the control of glyphosate residues in food.

Approach: In order to define the sampling strategy it was first necessary to consider which groups of people were most likely to be exposed to the herbicide in Bermuda. Also, in addition to the primary active ingredient, glyphosate, it would also be appropriate to determine concentrations of its degradation products[1] and the surfactants[2] that are used in Rodeo® and Roundup®.

A total of 5 samples shall be analysed for glyphosate, degradation products and surfactants from the following matrices related to potential exposure pathways (see justification statements below for each type of sample):

- Groundwater and potable water prepared from groundwater.
- Air within the vehicle cab of the glyphosate applicator truck.
- Air from behind the glyphosate applicator vehicle.
- Roadside soils and pond sediments.
- Genetically Modified and other types of food stuffs from supermarket shelves.

Timescales: The Department has been working to source analytical laboratories overseas that can conduct the analyses to appropriate detection limits (*i.e.* 0.01 µg/l in water, 160µg/100 litres in air, 10 µg/kg in foods). It has taken the Department considerable effort to date to identify analytical laboratories that can determine all analytes (glyphosate, derivatives and surfactants) at the required detection limits in all the matrices listed above. It is estimated that the sampling will start in June 2016 and will be completed by end of July 2016.

Properties of Glyphosate and Derivatives: Bio-concentration of the herbicide glyphosate in aquatic organisms is low and glyphosate is not suspected of being an endocrine-disrupting chemical[3]. Although glyphosate is readily soluble in water it undergoes rapid ionization causing it to be strongly adsorbed to sediments and soils[3]. Glyphosate degrades to natural products such as carbon dioxide and phosphate ions predominantly via microbial processes. It is rapidly removed from water to sorption sites on sediments and suspended particulate matter[3].

Previous Glyphosate Data for Bermuda: The Department has contracted research through the Bermuda Zoological Society who in turn hired Fort Laboratories Inc. in Oklahoma to assess pollutant exposure and its effects on critical

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[1] Degradation products: Aminomethylphosphonic acid (AMPA) and glufosinate

[2] Surfactants: Octylphenoxypolyethoxyethanol (in Rodeo® by Dow Chemicals) and Polyethoxylated tallow amine (in Roundup® by Monsanto).

[3] Maycock, D., Crane M, Atkinson, C and Johnson, I (2012) Proposed EQS for Water Framework Directive Annex VIII substances: glyphosate (for consultation). Water Framework Directive, UK Technical Advisory Group (TAG).

groups in ponds in Bermuda (*i.e.* toads, killifish and terrapins). This work assessed a wide range of pollutants that included pesticides and herbicides. Over the 2001 to 2013 timeframe glyphosate was not detected in pond sediments (<0.5µg/kg), water column (<0.05 µg/l), SPMD's[4] in the road drainage pipes nor in tissues of the animals dissected. Glyphosate is also routinely monitored, with other chemicals in the Government drinking water sources and distribution mains and it has not been detected to date (*i.e.* <10 µg/l).

Justification for Glyphosate Analysis in Groundwater: Due to Bermuda's high permeability limestone and high rainfall, chemicals applied at the ground surface may rapidly make their way to the water table and affect groundwater. Treatment of groundwater by reverse osmosis (*i.e.* to produce potable grade water) will be expected to remove most of the glyphosate or residues that may be present in the feed water. Although it is illegal to fill potable water tanks from untreated groundwater sources in Bermuda (*i.e.* wells) there is a risk that this practice may occur. In addition groundwater from wells may be used for irrigation, laundering and swimming pool supply, providing other exposure pathways. For this reason, in addition to understanding the ecotoxicological impact to water borne species, it is necessary to analyse Bermuda groundwater for glyphosate and associated residues. However, understanding what concentration limit to apply for glyphosate in Bermuda will be a challenge. WHO has not set a guideline limit as glyphosate and degradation products occur in drinking water well below the levels where toxic effects may occur[5]. The EU limit for glyphosate (or any pesticide, herbicide, etc.) is 0.0001 mg/l (*i.e.* 0.1µg/l)[6] and the US drinking water limit for glyphosate is 0.7 mg/l, Canada 0.28 mg/l and Australia 0.01 mg/l. This wide range of legislated drinking water limits from various developed countries is not consistent and highlights that the understanding of glyphosate toxicity to humans is not agreed.

Justification for Glyphosate Analysis in Air Samples: Locally, glyphosate is typically applied as weed control to roadsides and other areas but not to any crops as farmers do not grow GM crops in Bermuda. Persons that are most likely to be exposed to glyphosate from roadside spraying include the operator of the herbicide spraying vehicle (Ministry of Public Works) and potentially persons waiting, walking or driving along the roadside behind the applicator truck. In one study it was reported that glyphosate exposure was not associated with cancer incidence overall for herbicide applicators[7]. Currently in the US there is no OSHA (US Occupational Safety & Health Administration) permissible exposure limit (PEL) or ACGIH (American Conference of Governmental Industrial Hygienists) threshold limit value (TLV) for glyphosate. However, an arbitrary limit of 1 mg/m^3 (method PV2067) has been set by OSHA which will be used as the threshold for this study. In Europe there are also not any defined occupational exposure limits for glyphosate. It will therefore not be possible to relate the inhalation exposure of glyphosate in Bermuda to any specific international occupational exposure limits. Also the occupational exposures are unlikely to be much lower than the WHO Acceptable Daily Intake (ADI) limit (see foodstuffs below).

Justification for Glyphosate Analysis in Foodstuffs: There appear to be a limited number of independent peer reviewed publications on glyphosate residues within GM crops that will have been sprayed with glyphosate up until harvest. One study has shown that the glyphosate intake from cereals in Denmark for an adult of 60kg equated to 7 µg/day, which is only 0.04% of the WHO Acceptable Daily Intake (ADI) for glyphosate at 0.3 mg/kg body weight[8]. However, it is not stated whether the glyphosate (761 tons used in 1999 in Denmark[8]) was applied as a general weed killer in Denmark or whether it was applied specifically to GM-type crops that were subsequently harvested. Although GM crops are not grown in Bermuda most of the Island's produce is sourced from the US where GM cereals are more common. Analysis of glyphosate residues in some food stuffs (*i.e.* corn maize) on shelves in Bermuda that are sourced from the US (mid states) will be conducted to assess whether any level of risk exists to Bermuda residents. However, sourcing suitable food stuffs for testing in Bermuda may present a challenge because labelling of GM food stuffs is not required in the US.

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[4] Semi-Permeable Membrane Devices (SPMD's) that mimic the concentration effect of organic pollutants from the environment to the cells of organisms.

[5] WHO Guidelines for drinking-water quality (3rd Edition), Volume 1 Recommendations. Geneva 2008. 668pp.

[6] EU Council Directive 98/83/EC EC of 3 November 1998 on the quality of water intended for human consumption.

[7] De Roos, A.J *et al* (2005). Cancer incidence among glyphosate-exposed pesticide applicators in the agricultural health study. Environmental Health Perspectives, Vol. 113, N. 1,

[8] Granby, K and Vahl, M (2001). Investigation of the herbicide glyphosate and the plant growth regulators chlormequat and mepiquat in cereals produced in Denmark. Food Additives and Contaminants, Vol. 18, N.10.

A.2. INTERNATIONAL AGENCY FOR RESEARCH ON CANCER (IARC). Definitions of Chemicals or Activities wIth Respect to Carcinogenicity to Humans.

Table A.2.1. Agents Classified by the IARC with respect to carcinogenicity

IARC Group #	Carcinogenic rating to humans	Number of agents/chemicals
Group 1	**Carcinogenic** to humans.	118 Agents
Group 2A	**Probably** carcinogenic to humans.	79 Agents
Group 2B	**Possibly** carcinogenic to humans.	291 Agents
Group 3	**Not classified** as to its carcinogenicity to humans.	507 Agents
Group 4	**Probably not** carcinogenic to carcinogenic to humans.	1 Agent

(http://monographs.iarc.fr/ENG/Classification/)

Table A.2.2. Examples of Group 2A "Probable Carcinogenic" chemicals and occupational hazards to humans

Example IARC Group 2A Compounds (79 total)	Products and Activities where the agent is either used or is present
Certain Poly Aromatic Hydrocarbons (PAH's)	Including *Dibenz[a,h]anthracene* and *Dibenzo[a,i]pyrene*. Found in motor oil, soot, smoke, open fires, road runoff, etc.
Dichorormethane.	Occurs naturals in the environment at low levels but is largely produced industrially as a solvent in paint strippers, degreasers, decaffeinated coffee/tea.
Acrylamide.	Used in binding chemicals, cement, pesticides and cosmetics. Found in cigarette smoke, certain starchy foods after heating (Frying, baking) though expected dose is 500 times lower than dietary intake limits.
Malathion	Used in Bermuda as a general use insecticide and for household use from retail stores (e.g. Ortho), used in treatment of head lice.

Creosotes (from coal and wood tars)	Used as a preservative for treating wood and has some medical uses.
Anabolic steroids	Found in certain sports/body building dietary products to enhance performance, prescribed medicines,
Glyphosate	Herbicides manufactured by Monsanto, Dow Chemicals and a range of companies in China.
Activities/Occupation:	Manufacture of glass, art glass, burning wood, Hairdresser/barber, high temperature frying, Petroleum refining, consumption of red meat.

Table A.2.2. Examples of Group 1 "Carcinogenic" chemicals and occupational hazards to humans

Example IARC Group 1 Compounds (118 total)	**Products and Activities where the agent is either used or is present**
Certain Poly Aromatic Hydrocarbons (PAH's) Benzo[a]pyrene	Found in motor oil, soot, smoke, open fires, road runoff, etc.
Acetaldehyde	Present in indoor air in especially new buildings and associated with other volatile organic compounds. Present in emulsion paint, particle board, chipboard and other woods and tobacco smoke.
Formaldehyde	Naturally forming and also present in particle board, various coatings and resins.
Ethanol	Alcoholic beverages
Benzene	Crude oil, gasoline (exposure via automobile service stations), coal, tobacco smoke.
PCB's	Used as a dielectric or coolant in early electrical transformers. Replaced with environmentally friendly alternatives in Bermuda.
Outdoor air pollution	Includes both gases/vapours/VOC's and particulates (i.e. PM-10) from combustion processes (See PAH's)
Mixtures	Processed meats, wood dust, paints, mineral oils, Oestrogen-based contraceptives, coal tars, exhaust from Diesel engines.
Activities/Occupation:	Painting, sand blasting, tanning devices, smoking, furniture/cabinet making.