THE USE OF SCIENCE IN ENVIRONMENTAL POLICY MAKING AND THE IMPLICATIONS FOR HEALTH: A CASE STUDY OF BISMUTH SHOTSHELLS

by

Nathan Satya Cragg Fahey

A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Master of Environmental Studies
in
Environment and Resource Studies

Waterloo, Ontario, Canada, 2005

Author’s declaration for electronic submission of a thesis

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

ABSTRACT

Scientific information is required to make environmental policy that will enhance and protect the health of ecosystems. The issues placed on the policy agenda come from the interactions amongst stakeholders, decision makers and other influential actors. These actors include government, civil society, private sector, and planning regimes. Ideally, scientific research then provides members of the policy community with assessed options upon which final decisions are eventually made.

This process is more complex than most in the realm of environmental policy because the goal of sustainability, commonly advocated by government, should serve to guide choices regarding policy alternatives. Sustainability, in practice, requires simultaneous attention to factors such as the needs of present and future generations; consideration for vastly differing social, environmental, and economic perspectives; and development of effective strategies to deal with the interconnectedness and complexity of the world. Management of these factors demands an ability to collect and process massive amounts of information at different temporal and spatial scales. The complexity of such situations means that there are instances when scientific information is not available and decisions need to be made quickly.

Using a case study approach, this thesis investigates the Canadian Wildlife Service's attempts to achieve its mandate of conserving migratory birds while approving bismuth as an alternative to lead that was shown to cause poisoning of birds. This case study serves as an example of the tension between limited or ambiguous scientific information and urgent decisions. The chosen policy alternative to the use of lead shot was the approval of bismuth shot as a non-toxic substitute in 1997 and banning the use of lead shot nationwide in 1999. This decision to approve bismuth shot was based upon a few studies that were interpreted in a way that made it appear benign when compared to lead. This thesis examines the implications of this decision by conducting a comprehensive literature review of bismuth's interactions with soil, vegetation, and animals, with some medical information on humans to put findings into an anthropocentric context. Also, analysis has been carried out on the results of a four-year study on bismuth in a wetland site near Kingston, Ontario, Canada. Finally, a 'post-normal perspective' exploration of the Canadian Wildlife Service revealed that decisions could be harmful to both human and environmental health if the values and knowledge of stakeholders are not taken into account and if uncertainties are overlooked.

Key findings generated by the literature review were potential chronic impacts to the neurological and reproductive health of animals exposed to bismuth shot. In turn, bismuth-contaminated meat may be a source of bismuth for humans and therefore guidelines for consumption should be investigated. Also, soil and vegetation has also been shown to accumulate bismuth, but it is unknown if it accumulates to toxic levels. The wetland study helped to address the literature gap of bismuth's fate in the environment. The mean concentration of bismuth in the soil after four years was 6.40 µg/g, which was significantly higher than the control soil mean of 0.42 µg/g. Ultimately, a 'post-normal perspective' offers three main tools for decision makers faced with urgent issues and uncertain facts. Namely, extended peer communities, acknowledgement and demonstration of uncertainty, and making values explicit.

ACKNOWLEDGMENTS

The process of writing a thesis is a long one. Along the way there are many obstacles that crop up, opportunities to change direction, and countless reminders of how important family and friends are to one's success.

I would first like to thank my supervisor, Len Tsuji, for his patient guidance and ability to give his students great latitude. Without that space I would have certainly finished earlier, but I would have missed out on many other projects that made my time at the University of Waterloo more fulfilling.

Thanks to Mary Louise McAllister for her unfailing enthusiasm. Her talent for cutting down to the essence of topics often kept me from going off on far greater tangents.

I am grateful to Jim Karagatzides for his nearly uncanny eye for detail in reviewing my thesis. The care that he put into helping with the statistical aspects as well as analysis was outstanding.

Thanks to Ruwan Jayasinghe for his work on the analysis of the soil and vegetation samples for bismuth and lead. Also thanks to Larry Lamb for letting me use his laboratory and to Ian McKenzie for his soil sieves.

I am astounded at all of the fantastic people that I have met during my two years in Waterloo. I am thankful to Jessica Kwik for persistently reminding me to keep things in perspective and for being there for me. Thanks to Bob Gibson for plenty of laughs while doing the Off the Beat column for Alternatives. I am also lucky to have awesome fellow grad students – thanks to Ellie, Tom, Meghan, Ben, Tara, Judy, Lisa, Hendrik, Carol, Christina, and Josh for potlucks, friendship, and support.

Finally, a big thanks to my family for their love and cheerleading that was integral to getting me here.

DEDICATION

To my dear family.

Daphne – Thanks for always making our education a priority. You have given me a lifelong gift. I credit my analytical and critical thinking abilities to you.

Poppa – I often think back to when I was a kid and we had those talks about the importance of staying in school. Perhaps you did not intend for me to be staying this long, but I took your message to heart.

Nanny – Thanks for the many care packages along the way. Your carefully crafted butter tarts have always been a symbol to me of your caring.

Michael – Your patience, tolerance, and perspective have been imparted to me. They were essential tools for making this thesis become a reality.

Jaya & Ananda – Both of you have shown an abundance of bravery in the face of crucial life changes during recent years. I am very proud to have both of you as sisters.

TABLE OF CONTENTS

LIST OF FIGURES

List of Tables

LIST OF ACRONYMS AND SYMBOLS

µ	micro 10^{-6}
AAS	Atomic absorption spectrophotometry
AMG	Autometallography
Bi	Bismuth
BSC	Bismuth subcitrate
CWS	Canadian Wildlife Service
DL	Detection limit
EAAS	Electrothermal atomic absorption spectrometry
GFAA	Graphite furnace atomic absorption spectrophotometry
IPCC	Intergovernmental Panel on Climate Change
MDL	Method Detection Limit
Pico	10^{-12}
RBC	Ranitidine Bismuth Citrate
TBT	Tungsten-Bismuth-Tin

1. INTRODUCTION

1.1. Health and environmental policy making

Policy decisions affect both human and, more broadly, environmental health. The term ‘environment’ has come to mean many things such as one’s physical surroundings or a particular business or political climate. However, in this case ‘environment’ is being used to mean an ecosystem. Thus, ecosystem health is the capacity of ecosystems to sustain themselves and fulfill their normal functions. Some of these functions include the conversion of energy into biomass, nutrient recycling, water cycling and transport, contaminant sequestration, climate regulation and habitat provision for a diverse array of organisms (Rapport et al. 2003:353). Damaged ecosystems impact the health of humans as we are completely dependent on the services provided by ecosystems such as protection from solar radiation, clean air, water, and food.

About a century ago, some of the invisible entities and substances that affected human health were bacteria, viruses, and various toxic chemicals such as lead, mercury, and arsenic. Today, we have equipment and techniques that would have been inconceivable in the past. We are still, however, struggling with many of the same health problems. Moreover, during this century various compounds, some completely novel to the planet, have become virtually ubiquitous (e.g., dioxins, pesticides, and genetically-modified organisms).

We find ourselves in a situation where we can detect and monitor many of these substances, largely because of improved instrumentation, but there is a large degree of uncertainty surrounding our ability to prevent further harm or remediate in cases where damage has already taken place. Although decision makers have access to large volumes of monitoring and outcome data, making the ‘right’ decisions is often difficult.

Over the last few years, Canadian governmental departments, such as Environment Canada have begun to incorporate the concept of sustainability into their mission statements (2002) to help guide them towards making the ‘right’ choices. Simply put, the notion of sustainability prompts us to focus on the needs of both present and future generations and to plan and manage with consideration given to social, environmental, and economic perspectives. This includes creating policies, laws, regulations, and institutions that will be able to address the interconnectedness and complexity of the world; blending scientific and traditional knowledge systems. Moreover, it is necessary to recognize and change the values, attitudes and beliefs that are no longer perceived to serve our needs in a complex environment (Mitchell 2002:88). Thus, the principle of sustainability has become the yardstick with which we measure our policy options and then make the 'right' decisions.

In response to an ever-increasing awareness of both perceived and actual uncertainty and complexity, decision makers ironically have chosen a guiding principal, namely, sustainability – making their job more arduous and multifaceted. However, it should come as no surprise that intricate problems require nuanced and sensitive solutions. While a business model may demand streamlined operations and compartmentalized viewpoints, working towards sustainability requires more flexible procedures and holistic perspectives.

Science-based research operates by compartmentalizing phenomena so that they can be broken down into their most basic of building blocks. The scientific method is a process where after the purpose and functioning of each building block is more or less understood, they are all put together again in order to create a general theory of the phenomenon. Sometimes certain parts are too complex to understand or are not detectable by our current methods of analysis.

There is no doubt that science is important and, in some ways, it has been very good to humanity. By dismantling systems and peering inside their inner workings, we have been able to understand an astonishing number of things about our world. However, science's fundamental mode of operation conflicts with the move towards sustainability because science is usually piecemeal rather than holistic. An important question therefore, and one that is particularly germane to this thesis is what will the role of science be in the creation of environmental policy that meets the demands of sustainability and environmental health.

1.2. The use of science in policy making

In policy making, science is depended upon to provide knowledge of the risks involved with taking certain policy routes, issues that should be flagged, and options for solving problems. For instance, science made us aware that the primary source of elevated lead exposure and poisoning in most bird species is from the ingestion of lead shotshell pellets and fishing sinkers (Scheuhammer and Norris 1995:3). Based on estimates of ingestion and mortality rates from 1986, Scheuhammer and Norris (1995:25) calculated that on an annual basis, of the average autumn flight of waterfowl of about 60 million birds, 240 000-360 000 were dying from lead poisoning due to lead shotshell pellet ingestion in Canada. It was decided that this was not acceptable from a wildlife management perspective. This decision led to regulations brought into force in 1999, which required the use of non-toxic alternatives throughout Canada for the hunting of most game birds (Canadian Wildlife Service Waterfowl Committee 2001:12). Prior to this date, non-toxic alternatives were being sought and scientists developed various criteria that were used to assess the acceptability of each shot option (Canadian Wildlife Service 1993). However, as always, full knowledge of the shot options was never achieved because the resources of equipment, personnel, funding and time were finite.

The limited information meant that certain facets of the shot options become ranked in importance. These rankings depend on available resources and the priorities of those who have a stake in the issue at the table and their relative degree of influence. This notion of multiple stakeholders working towards their own particular goals, with an eventual outcome usually codified as some form of policy (the form being regulation in the case of lead shotshells), has become known by some as ‘actor-system dynamics’. The diagram below (Figure 1.1) serves to highlight the uncertainty that surrounds policy making. It can be seen that the stakeholders sometimes have diametrically opposed objectives and when a decision is finally made, there are still uncertainties around implementation at the ground level. This synergy of stakeholder interests and availability of resources can result in the introduction of products that could negatively affect environmental health. This could happen for a variety of reasons such as: inadequate testing due to misallocation of resources and prioritization; scientific findings ignored or exaggerated due to contradictions with political or stakeholder objectives; or the involved policy makers were unable to incorporate the findings into their policies. Henceforth, the focus of this thesis will be upon this last scenario. Figure 1.2 illustrates several possible reasons for this inability to respond.

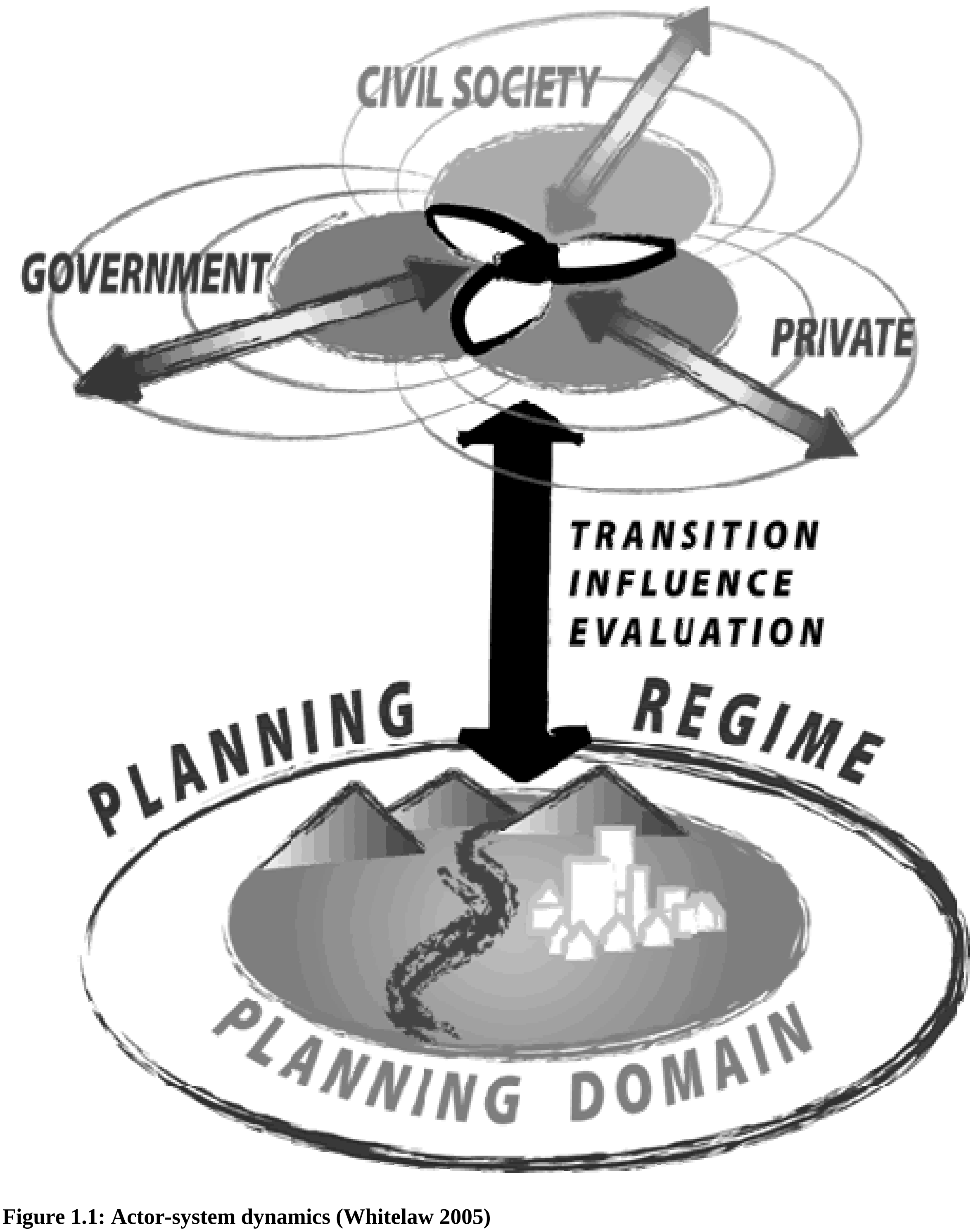

Figure 1.1: Actor-system dynamics (Whitelaw 2005)

Figure 1.2: A scientific study is received by policy makers, but the new information is not represented in old and new policies.

Three possible ‘lens filters’ can prevent up-to-date information from being represented in old and new policies when a scientific study is adopted by policy makers. For the first filter, abstracts and conclusions are written in plain language so that policy makers without scientific backgrounds can understand the findings. Unfortunately, findings can be complex and only relevant in extremely specific instances. Thus, by oversimplifying abstracts and conclusions, important pieces of contextual information can be lost.

The second filter essentially represents a condition of being unable to effectively respond because of a failure to view the situation from a larger perspective. This can manifest because “the forces against change are systemic, pervasive and multifaceted”, which can lead to “the lowest common denominator” prevailing in decision making (Dale 2001:97). Inability to respond can also occur because the ‘big picture’ is not taken into account due to the “dominance of prevailing paradigms, myths, and metaphors” (Dale 2001:96).

The third filter is relatively straight-forward in that certain types of research will not be carried out because funding or other resources is not available. A prime example is the shift from funding priorities in trace metal research to that of climate change (Senesi et al. 1999:348). Additionally, various findings will be ignored or exaggerated depending on the specific policy goals they may legitimize (Walker 2001:286). These three filters will be further clarified through the use of a case study, which now follows.

1.3. Case study: Approval of bismuth shotshells

Environment Canada’s approval of bismuth, in 1997, as a non-toxic lead substitute, for shotshells and sinkers for hunting waterfowl and fishing (Scheuhammer 2005) will be used as a case study to provide examples of the abovementioned filters in action. These concepts are important to understand to show the impact on health when current methods of science and policy making are considered. The rationale for studying this case and the importance of fitting it into the larger contextual consideration of policy making is outlined in the next section.

1.4. Research rationale

There are gaps in the literature with regard to how bismuth interacts with ecological and biological systems. This is shown by the existence of many scientific uncertainties about how bismuth behaves in the body. This behaviour has been and continues to be a mystery since a rash of encephalopathies occurred in France during the 1970s (Mueller 1989, Slikkerveer and de Wolff 1989:317, Ross et al. 1994:191, Heinemann et al. 1995:48). It is still unknown exactly how bismuth is absorbed within the body or how it causes neurological disorders (Slikkerveer and de Wolff 1989:307). Moreover, it is unknown as to how much bismuth the body can tolerate before negative impacts occur.

Although information specific to humans with respect to bismuth in a pharmaceutical preparation does exist; the fate of bismuth in the environment is scarce if non-existent (see chapter 2). Specifically, once the primary use of bismuth has been fulfilled (i.e., spent pharmaceutical products or shotshells or fishing sinkers), its fate, in terms of where it goes and what it does in the environment, is unknown. These are critical gaps in our knowledge that must be explored before emitting more of this substance. In most arenas of public policy, science is useful for learning about and overcoming various obstacles.

The implications of not having basic information about bismuth's behaviour in the natural environment should be explored, in the case of bismuth being approved and promoted as non-toxic by the Canadian Wildlife Service since 1997 (Scheuhammer 2005). Specific areas for study could include: its mobility in soil, which would affect its potential to diffuse into the environment; its degree of bioavailability, which would affect vegetative uptake; and its long term impacts on neurological and reproductive health of wildlife when ingested or embedded in muscle tissue. These types of exploration require fresh studies, one of which is provided in this thesis.

Finally, the policy move towards sustainability makes us re-evaluate the position of science in the overall process of environment policy creation. Canadian citizens depend upon the knowledge and expertise of the government to assess the safety of new, as well as foreign, compounds so that the natural environment and human health can be both preserved and enhanced. Due to increasing levels of uncertainty and complexity that are both real (i.e., introduction of new chemical and biological compounds) and perceived (i.e., shift towards sustainability) the fulfillment of government's obligations to its citizens has become more difficult than before. These new challenges have prompted government departments, such as Environment Canada's Canadian Wildlife Service (CWS) to adopt new principles to guide their decision-making processes, such as the utilization of the ecosystem approach (Canadian Wildlife Service 2000). An evaluation of these principles and strategies, as well as the use and utility of science, will be carried out by addressing three primary research questions, which are now explained.

1.5. Research questions

This thesis is transdisciplinary by blending the natural and social sciences. It is recognized by some that there are gaps in our knowledge with regard to the fate of bismuth in the environment. Thus, the bismuth literature, is critically reviewed, which, to my knowledge, has not been done elsewhere. This review examines bismuth's impact on the health of terrestrial ecosystems, animals, and to a limited extent, humans. Furthermore, the results of a four-year study are provided that monitored bismuth's mobility in soil and its capacity to be taken up by vegetation. In addition, policy making is explored within the context of Environment Canada's Canadian Wildlife Service. Discussion then focuses on this agency's goals, which are attempts to cope with high risk and high uncertainty scenarios while aiming for sustainability. Ultimately, the approach of the CWS is assessed to determine if it is adequate to reach their desired objectives.

In summation, this thesis addresses the following questions:

1) Are policy decisions made on the basis of science? This is important to ask because science is the primary system of knowledge that informs policy makers, which leads to the next question.

2) Is it problematic if environmental policy is not made on the basis of science? If it is a problem then we must ask the last question.

3) Is science adequate to deal with the uncertainty and complexity found in the domain of environmental policy making? If not, what else is required?

The process of addressing these questions will be organized in the following manner.

1.6. Organization of the thesis

This thesis is composed of five chapters. Subsequent to the introduction, the second chapter is divided into four parts. Part 1 is an analysis of the scientific studies on which the CWS based its decision to approve bismuth as non-toxic for shotshells and sinkers. Part 2 emphasizes the elements of the Service's toxicity test guidelines that required further attention. Parts 3 and 4 give a review of the literature as it pertains to the fate of bismuth in soil, natural and background levels, vegetation, animals, and humans, before and after 1997. The literature was divided into these two time periods because bismuth was approved as a non-toxic alternative to lead in 1997. In this way, one can see what was known before approval and what has since been discovered. In the third chapter a critical gap in the literature is addressed via a four-year wetland study. This study also serves to illustrate the complexities and uncertainties that still exist following the studies that took place after the approval of bismuth shot. The fourth chapter discusses the CWS' adoption of a 'post-normal perspective' to illustrate ways in which the policy making process can acknowledge and act upon high risk and high uncertainty scenarios. Briefly defined, the term 'post-normal perspective' has spawned from the term 'post-normal science'. Post-normal science is an extension of traditional problem-solving strategies that is necessary when the issues typically have uncertain facts; values, such as the merits and definition of sustainability, are in dispute; the stakes are high; and decisions need to be made urgently (Ravetz 1999:649). It can be said that those using the above mentioned extended strategies are taking a post-normal perspective. The co-originator of the term post-normal science began referring to it as a perspective to facilitate discussion on issues that are not normal, but require many of the solutions that post-normal science has to offer (Ravetz 2002). Chapter five revisits the research questions, highlights the contributions of this research, and suggests areas for further investigation.

2. FATE OF BISMUTH IN THE ENVIRONMENT

Bismuth is a rare metal, neighbouring lead on the periodic table. Natural sources of bismuth include rock, soil dust, sea salt, and volcanoes (Ferrari et al. 2000:945). It is not prevalent within the natural environment, but its presence in the environment has been increasing in recent years. For instance, a study in Greenland showed that between 1967 and 1989 that there was a five-fold concentration increase compared to 8 000 years ago; Ferrari et al. (2000:945) postulated that this was due to human activities. These activities would include waste incineration, lead and silver mining and smelting (which produces bismuth as a by-product), and the combustion of fossil fuels (Ferrari et al. 2000:945). In terms of other anthropogenic sources, it has been used for the treatment of gastrointestinal disorders for nearly two centuries and was once used to treat syphilis (Dresow et al. 1991).

Since bismuth has been used in our society for a long period of time, what is now the impetus behind studying its effects on the environment? Duration of past use is certainly not a helpful argument for continued use, lead being a case-in-point. The need to learn more about bismuth has become urgent in recent years because it has been approved as a non-toxic substitute for lead in shotshells for hunting game birds and in sinkers for fishing. This will translate into a significant amount of bismuth accumulating in our environment. While it may appear that its introduction through its use in hunting and fishing would be insignificant in amount, Environment Canada (2003a) provides information that demonstrates the contrary. Canadians lost 500 tonnes of lead in the form of sinkers every year and hunters, using shotshells, dispersed an estimated 1700 tonnes of lead per year. It could be assumed that similar amounts would enter the environment in the form of bismuth since its use does not require shotgun upgrades nor changes in technique because of similar ballistic properties (Michie 1992:31, Boddington 1994:86, Carmichel 1997:74). Moreover, Feldmann (1999) estimated that a further 5 000 tonnes of bismuth are emitted every year due to the use of bismuth-containing pharmaceutical products such as Pepto-Bismol.

In addition to the necessity of understanding how bismuth behaves in our environment, given that new sources are being introduced, there is the underlying issue of environmental public policy. Environment Canada (2003b) (in the form of the Canadian Wildlife Service) promotes bismuth as a non-toxic alternative to lead, despite the existence of a large body of medical literature that explicitly states that it is a toxic metal (Dresow et al. 1991, Bruinink et al. 1992, Bouchon and Cottin-Bouchon 2001, Stoltenberg et al. 2002b). Symptoms related to its neurological effects include confusion, drowsiness, hallucinations, severe headaches, along with damage to renal tubules, and nephrotoxicity (Fergusson 1990:559).

Soil and vegetation are the key elements of terrestrial ecosystems and they are essential for the production of food and life support functions, such as the degradation and recycling of dead biomass (Alloway 1990:7). Soil is a dynamic system that experiences short-term fluctuations in the form of variations in moisture status and pH conditions as well as an ability to adsorb ions, which can, in solo or in concert, affect the bioavailability or the ability of plants and other soil organisms to take in a certain substance (Alloway 1990:7). "It is more likely that direct toxic effects to plants and soil organisms will occur before observations of effects to higher trophic levels" (Fairbrother and Kapustka 2000:15).

In summation, soil and vegetation are the gateway for contaminants to move up the food chain; therefore, it would be wise to gain a greater understanding of how easily bismuth move into higher trophic levels. The beginning of such an understanding can be found by examining the available literature on bismuth. What follows from here is the methodology that was used to obtain the relevant literature.

2.1. Methodology

The literature on bismuth as it relates to soil, vegetation, animals, and humans was collected by conducting computerized searches of the relevant databases. These databases included TOXLINE [CSA], TOXLINE [Toxnet site], Medline [CSA], and Environmental Sciences and Pollution Management [CSA]. The TOXLINE database covers the biochemical, pharmacological, physiological, and toxicological effects of drugs and other chemicals. The MEDLINE database covers journal literature in the fields of medicine, nursing, dentistry, veterinary medicine, the health care system, and the preclinical sciences. Environmental Sciences and Pollution Management (ES&PM) is a multidisciplinary database that comprehensively covers the environmental sciences.

TOXLINE is available from the Toxnet site and Cambridge Scientific Abstracts (CSA). The latter was favoured as its intuitive interface permitted advanced searches, results could be easily managed, and TOXLINE, MEDLINE, and ES&PM could be searched simultaneously. The drawback of CSA was that it only provided results from 1999-present and 1993-present for TOXLINE and MEDLINE, respectively. This was not an issue for ES&PM because it supplied results for 1967-present. To account for this gap of time, the Toxnet site was also used for TOXLINE since results went back until 1965. This was not done for the MEDLINE database as it primarily covered human medicine, which is important for the big picture of bismuth, but outside the scope of this literature review. The search was limited to English-language materials and there was no date restriction. The search terms, date of search, number of results and ones relevant are noted in Table 2.1. Supplemental searches were carried out on the Toxnet Core and Special versions of TOXLINE on March 27, 2004. Search terms of bismuth, soil, water, plants, and animals were applied to all search fields. Results were typically high in number (e.g. 278 for bismuth + soil and 404 for bismuth + water). Approximately 15 of these studies were relevant and were conducted between 1979 and 1998. Details of search terms and results are shown in Table 2.1. It was found that the number of results was reduced when using 'bismuth' as a 'descriptor' instead of a 'keyword'. By making it a descriptor, results that did not examine bismuth were avoided. As a keyword, bismuth garnered a large number of results because of its prevalence in other studies.

The majority of the results were irrelevant because they did not examine the effect of bismuth use. Many focused on its use as treatment for a variety of gastrointestinal problems, radiotracers, and root canal sealers. There were also an abundance of biochemical studies that examined aspects of bismuth that were well beyond the scope of this thesis. Finally, for the articles that were relevant, their reference sections were examined for other papers of interest. Combined with the articles found with database searches and backtracking through their reference sections, a total of 72 journal articles were produced. This literature was then divided into the two categories of 1) up to and including 1997 and 2) 1998 to present. As mentioned in §1.6, this division was used to demonstrate what was known before and after the approval of bismuth as a non-toxic alternative to lead. What follows are observations of the differences between these two categories of literature.

Table 2.1: Summary of databases searched, keywords, results, and relevant findings

Date of Search	Database	Keyword(s)	Descriptor	Results (#)	Relevant (#)
01/28/04	TOXLINE	bismuth	--	237	N/A†
01/28/04	TOXLINE	bismuth soil	--	3	1‡
02/08/04	TOXLINE	--	bismuth: adverse effects	51	0
02/08/04	ES&PM	bismuth risk assessment	--	4	1
02/08/04	TOXLINE	animal	bismuth	43	4
02/08/04	ES&PM	animal	bismuth	12	2
02/08/04	MEDLINE	animal	bismuth	27	1
02/08/04	MEDLINE	water	bismuth	42	2
02/08/04	TOXLINE	water	bismuth	9	1‡
02/08/04	ES&PM	water	bismuth	76	0
02/08/04	MEDLINE	soil	bismuth	3	1‡
02/08/04	TOXLINE	soil	bismuth	2	1‡
02/08/04	ES&PM	soil	bismuth	19	3
02/08/04	MEDLINE	plant*	bismuth	5	1‡
02/08/04	TOXLINE	plant*	bismuth	2	1‡
02/08/04	ES&PM	plant*	bismuth	13	2‡
02/08/04	MEDLINE	vegetation	bismuth	0	--
02/08/04	TOXLINE	vegetation	bismuth	0	--
02/08/04	ES&PM	vegetation	bismuth	0	--

† Scanned all articles for useful search parameters
‡ Including repeat find of Jung et al. (2002)
* Wildcard searching

2.2. Differences between $\leq$ 1997 and $\geq$ 1998 bismuth literature

The volume of literature pertaining to bismuth in soil, vegetation, animals, and humans before and including 1997 began in 1972 and spanned twenty-five years. Notably, this period of literature amounts to less than written between 1998 to the present. This difference in size could be attributed to the advancement in the accuracy of analytical equipment for detecting trace elements such as bismuth. However, Senesi et al. (1999:348) found that research in the field of trace elements peaked in the 1980s and has been declining in recent years. The reduced level of interest is attributed to shifts in research priorities towards issues such as acid rain and climate change, making it more difficult to obtain funding for trace element research.

The thinking behind these shifting priorities is debatable since metals are not degradable and continuously accumulate in every sector of our environment, which concerns humans, wildlife and ecosystems (Nriagu 1988:140). This stress, due to the limited carrying capacity of the environment, caused by metal contamination, may eventually mitigate itself by manifesting scenarios that could be unfavourable. Some authors have postulated that chronic exposure to bismuth may cause neurodegenerative diseases because of its affinity for central nervous system tissues (Bruinink et al. 1992:290, Bouchon and Cottin-Bouchon 2001:246). Other authors found that there may be negative impacts for males in terms of reproduction as a consequence of bismuth exposure (Stoltenberg et al. 2000:70, Stoltenberg et al. 2002b:114, Pedersen et al. 2003:238).

Fortunately, while it seems that general trace element research is on the decline, interest in bismuth is increasing. However, since the decision by the Canadian Wildlife Service (CWS) to approve of bismuth as a non-toxic shot alternative occurred in 1997 (Scheuhammer 2005) all of the new research that has emerged after that time does not appear to have been considered by this regulatory agency. But uncertainties are just important as certainties because they highlight the gaps in knowledge that require further exploration. The work done before the 1997 approval demonstrated gaps in understanding that could have important impacts upon the health of ecosystems, wildlife, and humans. The studies on the acute and chronic toxicity tests, as well as, reproductive effects of bismuth on waterfowl were carried out by Sanderson et al. (1997a, 1997b) and these studies were central to informing the final approval decision of the Canadian Wildlife Service (Scheuhammer 2005). The following section will examine the studies that took place up to and including 1997.

2.3. Bismuth literature $\leq$1997

2.3.1. Sanderson studies

The studies on the effect of bismuth on mallards began with a publication in 1992. Sanderson et al. (1992) concluded that 100% bismuth shot (as opposed to the bismuth-tin alloy that is now used) was not acutely toxic to game-farm mallards. However, while most of the CWS toxicity test guidelines (Canadian Wildlife Service 1993) were followed, more emphasis should have been placed upon the neurotoxic effects of bismuth that are highlighted in the literature. This would have meant that studies would have been conducted on the brains of the mallards and special attention would have been given to being able to detect minute concentrations of bismuth. Jayasinghe et al. (2004:14) and Tsuji et al. (2004) have criticized Sanderson et al. (1997a, 1997b) for the detection of unreasonably high concentrations of bismuth in control mallards and the overlooked effects of lead in conjunction with bismuth.

To begin with, the detection limit of the Sanderson et al. (1992) study for bismuth was 3.00 µg/g, which was too high considering they cited exposure limits for possible encephalopathy in humans at 50 ppb or 0.05 µg/g. They also cited another study that stated that blood bismuth should not exceed 20 µg/L or 0.02 µg/g. While their reported bismuth blood levels were below the detection limit, Sanderson et al. (1992:537) concluded that the bismuth concentrations in various tissues, ranging between 3.00 µg/g and 42.3 µg/g, were low based on references to bismuth in mammals. However, these concentrations were in fact approximately 100 times greater than what has been found to cause neurotoxic symptoms. It is, therefore, unfortunate that they were unable to fashion their experimental plan in a way that would permit them to detect 0.05 µg/g bismuth.

In addition, to the relatively high detection limit for bismuth, the study only reported bismuth values for Day 3 out of the 30 day study because they were unable to obtain the other results before going to press (Sanderson et al. 1992:537). This was unfortunate because this did not allow them to demonstrate blood-bismuth concentration trends. It was also concluded that bismuth exits the bodies of the ducks via their feces, but the manner of collecting the feces was not systematic. The decision to collect feces samples was not part of the original method and was collected after the pens had been cleaned (Sanderson et al.

1992:537). These were not representative samples and while they made a disclaimer to the accuracy of these feces-related findings, their related conclusions were phrased in an authoritative manner.

Conversely, to put this study into its proper context, this was the first one done on acute toxicity of bismuth shot in waterfowl. Sanderson et al. (1992) were in some ways breaking new ground and had a limited literature base since bismuth had been largely ignored by the scientific community. Their next studies (Sanderson et al. 1997a, 1997b) were much more comprehensive than their first. Their detection limit of 0.05 µg/g for graphite furnace atomic absorption spectrophotometry (GFAA) was a more appropriate level to study potential neurotoxic effects. They also designed a feces collection and analysis experiment, which allowed them to determine that an average of 88% of the bismuth, dissolved from the shot in the gizzards, was excreted in the feces (Sanderson et al. 1997a:208). This high rate of bismuth excretion was also supported by other authors (Mueller 1989, Dresow et al. 1991:648, Islek et al. 2001:512).

On the other hand, while many of the previous study's oversights had been remedied, the new Sanderson et al. (1997a, 1997b) research contained ambiguities that created new uncertainties that they did not address. For instance, inductively coupled, argon-plasma emission spectroscopy (ICP) was used for the analysis of blood cells, blood plasma, livers, kidneys, gonads, and feces, in order to detect a series of metals (Sanderson et al. 1997a:189). Ironically, they then encountered the same problem that they did in 1992; their detection limit for bismuth was, again, too high. They reported their detection limit as the method detection limit (MDL), which they defined as the minimum concentration of a substance that can be identified with a certain level of statistical confidence. Their MDL for blood plasma and cells varied over the 30-day experiment, but averaged to be around 13 µg/g, which is far above the concern level of 0.05 µg/g in blood. They were unable to re-analyze their samples with GFAA, which had the 0.05 µg/g detection limit, because their first analysis used up too much of the sample leaving insufficient amounts for testing (Sanderson et al. 1997a:204); thus no information about blood-bismuth levels in mallards was provided.

Fortunately in their subsequent study (Sanderson et al. 1997b), they analyzed their samples with GFAA. All of their blood-bismuth concentrations were below their MDL of 0.081 µg/g for both the dosed and undosed mallards (Sanderson et al. 1997b:236). This suggests that little bismuth was absorbed into the blood. However, the presentation of the data is confusing because inexplicably the sample size declined from 10, on Day 0, to 2, on Day 150. Furthermore, it is interesting that mallards that had yet to receive a bismuth treatment had bismuth levels in their blood that were close to the level of toxicological concern noted in seven of their nineteen literature sources. More work is needed in this area of blood bismuth concentrations and neurotoxicity as well as differences in avian versus mammalian tolerances for bismuth.

Both studies (Sanderson et al. 1997a:231, 1997b:195) found that the kidneys contained more bismuth than the liver and all other organs and tissues (Table 2.2). This occurrence of bismuth storage in the kidney was also found by Stemmer (1976:154).

Table 2.2: Comparison of bismuth concentrations (µg/g) in mallard kidneys, liver, and gonads in Sanderson et al. (1997a, 1997b) studies.

		(Sanderson et al. 1997a)			(Sanderson et al. 1997b)		
Dosing		Kidneys	Liver	Gonads	Kidneys	Liver	Gonads
Control	Female	0.140	0.140	< 0.10*	< 0.054	< 0.054	< 0.073
	Male	0.528	0.246	< 0.10	< 0.054		< 0.073
Bismuth	Female	8.05	2.79	0.677	1.095	0.637	< 0.073
	Male	4.77	1.25	0.155	1.659		0.098

* Sanderson et al. (1997a, 1997b) noted their values that were below detection limits as half the detection limit. Here, the values have been denoted as less than the detection limit with a ‘<’ sign.

1997a kidneys
Difference between sexes in bismuth-dosed ducks
P = 0.1127
Difference among doses
P = 0.0001

1997a liver
Difference between doses
P = 0.0020

1997a gonads
Difference between 0-dosed males and bismuth-dosed females
P = 0.0406

1997b kidneys
Differences among doses with sexes combined
P = 0.0002

1997b liver
Differences among doses (differentiation between sexes not given)
P = 0.0024

1997b gonads
Differences among doses
P = 0.0039

In all cases, bismuth concentrations were significantly greater in the bismuth-dosed mallards versus the control mallards. This indicates that bismuth does get absorbed and enters the kidneys, liver, gonads, while its presence in blood is inconclusive (not detected in first study and samples sizes decreased to 2 in the second study).

Clearly, there are many uncertainties with regard to how bismuth behaves in the body. In 1997 and before, it was still unknown where exactly it is absorbed within the body or how it causes neurological disorders. After 1997, several studies used a new technique known as autometallography that allowed researchers to locate the organs for which bismuth has an affinity. Moreover, it is unknown as to how much bismuth the body can tolerate before negative impacts occur. Once the primary use of bismuth is fulfilled, i.e., via pharmaceutical products or shotshells or fishing sinkers, where does it go and what does it do in the environment? This type of fundamental information must be explored before emitting more of this substance. When bismuth is compared to lead, as was done in these studies, it appears to be an ideal substitute. However, that may only be the case because little is known about bismuth. A part of the Canadian Wildlife Service's mandate is to "preserve and enhance the quality of the natural environment, including water, air and soil quality; conserve Canada's renewable resources, including migratory birds and other non-domestic flora and fauna [and] conserve and protect Canada's water resources". So that this mandate can be fulfilled, they have developed toxicity test guidelines, which will now be examined.

2.3.2. Canadian Wildlife Service toxicity test guidelines

The Canadian Wildlife Service (CWS) (1993) requires information about the acute and chronic toxicity of bismuth to wildlife before approving a particular substance as non-toxic and the Sanderson et al. (1992, 1997a, 1997b) studies were designed to deal with those. At this point, this critical review will examine some of the other guidelines that could have been more fully addressed during the process of approving the use of bismuth over lead in shot pellets.

Upon review of the guidelines, it becomes apparent that the studies used in the approval of bismuth as an alternative non-toxic shot (Sanderson et al. 1997a, 1997b) only addressed a portion of what CWS required. The following items were apparently disregarded or inadequately assessed in the toxicity test guidelines:

- Based upon a review of the scientific literature, what is the potential toxicity of the candidate shot to migratory birds, other wildlife species, and humans which may be exposed to the shot directly or indirectly?

- Based upon a review of the scientific literature, what is the environmental fate and toxicology of the spent material and its most likely decomposition products?
- “Environment Canada shall determine that a specific shot material is acceptable as non-toxic for the purpose of hunting migratory game birds if, after a review of an application and supporting data submitted, together with other relevant evidence, including public comment, it is concluded that the spent shot material does not post a significant toxic threat to migratory birds, or to their ecosystems.”
- “In addition, Environment Canada may require the applicant to submit plans for conducting other tests as prescribed by Environment Canada in order to fill essential data gaps required to complete the assessment of the risks to the health of the environments receiving the spent shot.”
- “If the applicant is able to show:
    - By way of the required comprehensive written assessment and literature review that the spent shot product is stable and will not decompose and give rise to degradation products that are harmful to the long-term health of the receiving environment;
    - That no significant negative effect has been detected in the acute test or its equivalent, and;
    - That the accumulation of the major constituents of the shot in blood and internal organs in ducks undergoing the acute test is negligible. Then the product may be given a conditional approval.”

With these gaps in understanding, this section of the thesis aims to first explore the fate of bismuth in the environment by reviewing the literature that was available up until the approval decision was made. This will be done to give a snapshot of the information available up until approval in order to demonstrate the knowledge available to policy makers at the time of their decision. This will then be followed by a review of the literature that became available afterwards, i.e., 1997, so that the reader can have an understanding of the current state of bismuth knowledge. This will, therefore, be a review of the literature that pertains to bismuth in soil, vegetation, animals and, to a limited extent, humans. Data have been summarized into tables when appropriate. However, before examining these different media, some attention, in the following section, will be given to the sources of bismuth and its background levels.

2.3.3. *Sources of bismuth and background levels*

The environmental science community and, as a result, the policy community, does not fully realize how inconsistent natural or background levels of trace elements, such as bismuth, can be. Obtaining accurate baseline values are confounded by variables such as fluctuations in concentration, bioavailability, and synergistic/antagonistic effects of contaminants (Reimann et al. 1997b:53). Such data are important to researchers for comparison purposes and are summarized in Table 2.3.

There are many different chemical forms of bismuth, which makes it difficult to conclusively state that it will always act in a certain way since its form and the mode of delivery to the environment will partially dictate its behaviour (Serfontein and Mekel 1979:393). In addition, the quality of literature on bismuth is limited by the fact that older studies used analytical techniques that do not measure up to the accuracy of today’s methods, hence making it difficult to compare results from older studies (Slikkerveer and de Wolff 1989:305). This review drew the limited literature on this together with the intention of providing researchers with data on background levels.

The primary production of bismuth has been rapidly increasing over the years as is illustrated in Figure 2.1. An updated estimation will be provided in the ≥1998 section of this review.

Table 2.3: Summary of background bismuth concentrations in ≤1997 bismuth literature

Source	Bismuth Concentration	Reference
Volcanoes	1200-1700 tonnes/year	(Candelone et al. 1995:1847)
Intermediate volcanic rocks	<1-4 μg/g	(Janatka and Moravek 1990:379)
Rock and soil dust	40 tonnes/year	(Candelone et al. 1995:1847)
Albite granite	1-2 μg/g	(Janatka and Moravek 1990:379)
Oil and coal combustion	15 tonnes/year	(Candelone et al. 1995:1847)
Snow in Scotland Highlands	0.00021 μg/g	(Jickells et al. 1992:399)
Snowmelt water (Russia, Finland, Norway)	0.0002 μg/g	(Reimann et al. 1996:148)
Terrestrial moss (Russia, Finland, Norway)	Range: <0.004-0.544 μg/g Mean: 0.027 μg/g	(Reimann et al. 1997a:3890)
Terrestrial moss (Norway)	0.04 μg/g	(Berg et al. 1995:356)

Candelone et al. (1995:1847) reviewed the literature on emissions of bismuth into the atmosphere and reported that volcanoes are the greatest natural contributors at 1200-1700 tonnes/year; rock and soil dust at 40 tonnes/year; and oil and coal combustion at 15 tonnes/year (1975 value). In another study, the bismuth concentration was 0.00021 µg/g within a suite of trace elements analyzed in snow samples in the Scotland highlands (Jickells et al. 1992:399). The same authors found that for trace elements in general, solubility is likely a function of its source and elements in an aerosol form are more soluble at a low pH.

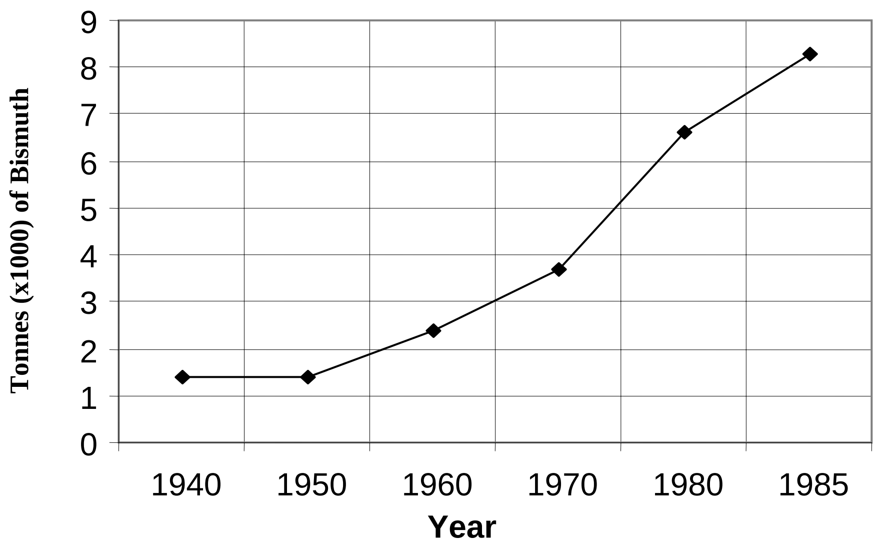

Figure 2.1: Primary production of bismuth (Nriagu 1988:141).

In a geochemical study in the Celina deposit within the former Czechoslovakia, it was determined that intermediate volcanic rocks and albite granite contain <1-4 µg/g and 1-2 µg/g bismuth, respectively (Janatka and Moravek 1990:379). In a relatively recent snowpack survey in Russia, Finland, and Norway, Reimann et al. (1996) also found bismuth concentrations of around 0.0002 µg/g in snowmelt water. They postulated that a rapid melting of snow in the spring results in a rapid release of the elements that accumulated during the winter, which bypasses the normal binding and buffering effects of soil, enabling them to move directly into surface water supplies (Reimann et al. 1996:148). This bypass occurs because the soil is still partially or completely frozen at that time. Furthermore, snowmelt water tends to be very acidic (pH 4.5-5) which can cause trace elements or heavy metals to leach from the soil that accumulated during summer months (Reimann et al.

1996:148).

In the subsequent year, Reimann et al. (1997a:3889) studied the atmospheric deposition of various trace elements, including bismuth, by examining their presence in over 600 samples of terrestrial moss (*Hylocomium splendens* and *Pleurozium schreberi*) in three different countries (Finland, Norway, and Russia). For bismuth, they found a range of <0.004 – 0.544 µg/g with a mean of 0.027 µg/g (Reimann et al. 1997a:3890). Berg et al. (1995:356), who also did a study on moss (*Hylocomium splendens*), found a mean concentration of 0.04 µg/g bismuth in Norway. They also found that concentrations rapidly declined as the distance from the coast increased (Berg et al. 1995:355). Reimann et al. (1997a:3899) supported this finding by theorizing that ocean currents may be, in addition to the atmospheric route, a vehicle for long-range transport of bismuth and can be deposited onto land via sea spray.

This method of transportation is important to keep in mind since many cities expel their untreated sewage directly into the ocean and 50% of the world's production of bismuth was used in pharmaceutical products in 1990 (Feldmann et al. 1999:740). It would be prudent to assume that the vast majority of this bismuth goes into the waste stream since, under the right conditions, only a small percentage is absorbed in the intestinal tract (Stemmer 1976:153, Mueller 1989, Kraabel et al. 1996:6). Other sources of bismuth include nickel smelters and roads (Note: In this cited study, the alkaline rocks used in road construction were noted as being rich in bismuth) (Reimann et al. 1997a:3893). One repository of these sources of bismuth is soil and discussion of its behaviour in this medium follows.

2.3.4. Soil

Polemio et al. (1982:76) reported the world mean of bismuth to be 0.20 µg/g, but was unable to supply a mean for Canada and the US. In Italy, the mean bismuth concentration in rural areas was 2.10 µg/, while industrial areas had a mean concentration of 0.67 µg/g (Polemio et al. 1982:76). The differences in concentrations may not be noteworthy because bismuth was only found in 50-60% of the rural soil samples. The soil-related bismuth concentrations are summarized in Table 2.4.

Table 2.4: Summary of soil-bismuth concentrations in ≤1997 bismuth literature

Source	Bismuth (μg/g)	Reference
World soil-bismuth mean (1982)	0.20	(Polemio et al. 1982:76)
Rural Italian soils	2.10	(Polemio et al. 1982:76)
Industrial Italian soils	0.67	(Polemio et al. 1982:76)
Topsoil (Russia, Finland, Norway)	0.04-0.34	(Reimann et al. 1997b:51)
Sewage sludge	Mean: 34; Range: 12-100	(Berrow and Webber 1972:96)

Frozen topsoil (0-5 cm) in Russia, Finland and Norway were found to have a mean range of 0.04 – 0.34 μg/g bismuth (Reimann et al. 1997b:51). Within two of these sites a slightly positive correlation between bismuth concentration and organic matter was found (Reimann et al. 1997b:54).

One of the ways that bismuth can enter the environment is through soil via sewage sludge that is applied in order to increase soil fertility (Gerritse et al. 1982:359). Berrow and Webber (1972:96) used a spectrochemical method of analysis to estimate that the amount of bismuth in sewage sludges in England and Wales ranged from <12 to 100 μg/g with a mean of 34 μg/g. It was noted that the normal concentration in soil is less than 1 μg/g. It has been shown that bismuth can leach into soil, but estimating its movement depends on a number of factors. These were found to include the following: erosion, tillage, uptake and removal by crops, biomethylation, pH, element speciation, ionic strength, composition of soil solution, and clay and organic matter content of the soil (Gerritse et al. 1982:359). In sandy top soil, bismuth has a similar rate of mobility to the majority of other trace elements, but greater than lead and mercury. In a sandy loam top soil, bismuth has a similar rate of mobility to lead and mercury, but it is slower than copper, nickel, and iron (Gerritse et al. 1982:362).

All of the authors who wrote about bismuth in soils expressed concern that it could accumulate over time and subsequently create toxic effects for plants and animals (Berrow and Webber 1972:93, Senesi et al. 1979:1112, Gerritse et al. 1982:359, Polemio et al. 1982:71). Berrow and Webber (1972:97) clarified their position by noting that the degree of plant uptake is more dependent upon the soluble or available form of bismuth rather than its total content in the soil. Li and Thornton (1993:142-3) reported that the availability for vegetative uptake is affected by soil conditions. Berg et al. (1995:358) reported that one type of moss, *Hylocomium splendens* had a 31% uptake efficiency for bismuth when assuming lead to have a 100% uptake efficiency. However, it is important to be aware that Holdner et al. (2004:572) hypothesized that neutral to alkaline soils reduce the mobility of lead when its source is lead shot pellets. Therefore, if both the mobility of lead and bismuth are very low then the difference in percentage of uptake efficiencies becomes less of an issue. The bismuth-vegetation literature will now be addressed.

2.3.5. Vegetation

To my knowledge, there are no studies that exclusively focused upon bismuth's interactions with vegetation, but there were studies that included it within a suite of other trace elements. In 1984, Kovacs et al. (1984:173) sampled several types of submerged and floating aquatic plants for bismuth. They discovered that these plants were able to accumulate large concentrations of elements that are present in low amounts in the environment. The bismuth concentrations are summarized in Table 2.5.

Table 2.5: Summary of vegetation-bismuth concentrations in $\leq$1997 bismuth literature

Source	Bismuth (µg/g)	Reference
Ceratophyllum submersum	0.41	(Kovacs et al. 1984:177)
Myriophyllum spicatum	0.27	(Kovacs et al. 1984:180)
Potamogeton perfoliatus	0.34	(Kovacs et al. 1984:182)

* 1-100 µg/g bismuth in nutrient solution - moderately toxic to plants and bacteria (Senesi et al. 1979)

On occasion, some elements could be detected within the plants, but not in the water in which they grew (Kovacs et al. 1984:185). Of the different types of plants sampled, *Ceratophyllum submersum*, a submerged, rooting plant that grows in the littoral zone; *Myriophyllum spicatum*, a submerged plant in reed stands and open water; and *Potamogeton perfoliatus*, a rooted pondweed species that grows in the littoral zone and open water, had bismuth concentrations of 0.41, 0.27, and 0.34 µg/g, respectively (Kovacs et al. 1984:177,180,182). In terms of comparing these concentrations to what is believed to be toxic, Senesi et al. (1979) grouped concentrations of 1-100 µg/g bismuth as being moderately toxic to plants and bacteria while in a nutrient solution.

Nine years after the aquatic vegetation study, Li and Thornton (1993) published research on arsenic, antimony, and bismuth distribution in soil and vegetation. They also explored the possibility of livestock ingesting these chemicals in old metalliferous mining areas in England. Li and Thornton (1993:141) found that bismuth concentrations decreased considerably at sites 300 m downwind of smelter chimneys, while Reimann et al. (1997a:3897) found the return to background levels to be about 100-150 km from industrial facilities.

Li and Thornton (1993:143) found a significant correlation for concentrations of arsenic and antimony between soil and vegetation, but could not find such a relationship for bismuth. However, they did find a significant positive correlation ($p < 0.01$ $r = 0.65$) for bismuth between vegetation and soil pH (Li and Thornton 1993:143). Their report was concluded by stating that contaminated vegetation could be an important exposure pathway to grazing livestock and "the chemical forms of these elements and other related metals in soil and herbage, and possible sub-clinical effects of long term, low-level exposure to livestock require further study." (Li and Thornton 1993:143). Presently, their work has been cited on twenty-six occasions and only one of these papers was on bismuth, which garnered only minor attention. These other studies examined the mobility, availability, and movement from soil to crop plants of arsenic and antimony and this kind of information for bismuth is still unknown and information that is required by the Canadian Wildlife Service's toxicity guidelines (1993:1). The Canadian Wildlife Service's toxicity test guidelines (1993:1) also demands to know the "potential toxicity of the candidate shot to migratory birds, other wildlife species, and humans which may be exposed to the shot directly or indirectly." This review will now focus on the bismuth literature on animals, followed by humans before and including the approval year of 1997.

2.3.6. Animals

A common thread throughout many of the papers that dealt with bismuth and its toxicity to animals and humans was bismuth's degree of absorption or water solubility in the gastrointestinal tract (Heinemann et al. 1995:48). In many of these studies, solubility is thought to be positively related to toxicity, but uncertainty still exists as to where and how bismuth is absorbed in the gastrointestinal tract (Slikkerveer and de Wolff 1989:307).

In bismuth literature, up to and including 1997, only two other studies, besides those carried out by Sanderson et al. (1992, 1997a, 1997b) explored the toxicity of bismuth in animals when used in shot. For the 1993 interim-approval of bismuth shot, the Canadian Wildlife Service website (2004) only cites Sanderson (1992) and Ringelman et al. (1993) for animal studies.

Ringelman et al. (1993) orally dosed mallards with tungsten-bismuth-tin (TBT) shot and observed the birds for signs of intoxication, such as behavioural changes and difficulties with coordination, locomotion, and posture. After 32 days of observation, "coordination, locomotor abilities, and posture were consistently normal in all birds" (Ringelman et al. 1993:731). They also determined the bismuth concentrations in the kidneys and liver (see Table 2.8 for comparison with other game bird-bismuth studies). The levels were statistically the same in dosed and undosed groups for liver ($p = 0.22$) and kidney ($p = 0.34$) samples. In the kidney and liver samples, the undosed ducks had bismuth concentrations of 4.72 µg/g ($n = 20$) and 13.67 µg/g ($n = 20$), respectively. For the dosed ducks, bismuth concentrations for kidney and liver samples were 5.96 µg/g ($n = 20$) and 15.84 µg/g ($n = 20$), respectively (Ringelman et al. 1993:730). These bismuth concentrations in the kidneys and liver do not seem reasonable since the undosed birds were somehow obtaining just as much bismuth as the dosed birds, despite the shot undergoing extensive erosion in the gizzard (Ringelman et al. 1993:728) . Furthermore, high bismuth levels in undosed birds were not reported by others in the literature up to and including 1997 (Sanderson et al. 1997a, Sanderson et al. 1997b). The study concluded that "…TBT shot presents virtually no potential for acute toxicity in mallards" (Ringelman et al. 1993:731).

Kraabel et al. (1996) studied the effects of embedded TBT shot on mallards. Instead of measuring bismuth concentrations they examined the reaction of tissues to the embedded shot. It was found that the tissue response to TBT shot resembled the response to lead shot. Furthermore, the size of tissue encapsulation for both steel and TBT shot were unacceptable with regard to thickness guidelines for human implantation. Kraabel et al. (1996:7) hypothesized that the disagreement in tissue capsule thickness with human implantation guidelines could have been due to differences in avian and mammalian immune responses and thereby be an unfair comparison. Unfortunately, the authors neglected to surgically implant the shot (i.e., failed to observe the use of surgically sterile methods) which they believe could have caused the observed inflammation despite the fact that their controls yielded no signs of inflammation. It is possible that this method more closely mimicked the 'true' effects of bismuth being embedded when launched by a shotgun. However, clean laboratory methods exist so that the presence of confounding variables can be constricted.

The postulation about the inaccuracy associated with the comparison of avian and mammalian immune systems is not mentioned throughout the Sanderson et al. (1992, 1997a, 1997b) studies. This is unfortunate because although Sanderson et al. (1992, 1997a, 1997b) borrow heavily from mammalian medical information, which they then overlook when comparing the concentrations that they found with those in the literature. Another omission is the fact that the method of administration affects the toxicity of bismuth (Stemmer 1976:154). This was ignored in the Sanderson et al. (1992, 1997a, 1997b) studies because they referred to the toxicity of bismuth in research that used oral administration, which is a very different route of administration in comparison to surgical implantation. As a final point, this study also concluded that TBT shot is not acutely toxic when implanted in mallard tissue, but recommended further investigation for its use as a non-toxic shot alternative (Kraabel et al. 1996:7). No studies have been conducted on the interactions between bismuth shot and humans; however the related literature on this subject will now be discussed.

2.3.7. Humans

It is beyond the scope of this review to give a comprehensive analysis of the toxic effects of bismuth on humans. It will, however, cover some of the more pertinent points because the CWS requires information on the "potential toxicity of the candidate shot to… humans which may be exposed to the shot directly or indirectly" (Canadian Wildlife Service 1993:1). The human-bismuth literature was noted in Sanderson et al. (1997a, 1997b), but there was little discussion on the uncertainties posed by the studies that they cited. Furthermore, Sanderson et al. (1997a:186) reported that Serfontien and Mekel (1979:392) favoured a 0.05 µg/g bismuth blood concentration as being potentially neurotoxic when the cited authors actually rejected this number on the grounds that it was "highly unlikely to be associated with meaningful toxicity in man." Slikkerveer and de Wolff (1989:314) did not believe bismuth blood concentration to be a reliable indicator for neurotoxicity due to findings of large variations in the susceptibility amongst individuals.

To begin with, much of the data on bismuth toxicity to humans is based upon the pharmaceutical intake of bismuth, which will be in a different chemical form than the bismuth found in shot. It is important to be cognizant of this as there is a large variation in the pharmacological actions of different organic and inorganic forms of bismuth (Serfontein and Mekel 1979:393). There is no $\leq$1997 literature that explored the effects of ingested bismuth shot fragments in humans. This could be a probable pathway of exposure for subsistence hunters (Tsuji and Nieboer 1997).

During the late 1950s, it was popular to orally administer insoluble bismuth salts (subnitrate, subcarbonate, subgallate, subsalicylate and subcitrate) for the treatment of indigestion, cramps, nausea and common diarrhoea, as well as haemorrhoids and skin irritations (Bruinink et al. 1992:285). In the 1970s, it became evident, due to a large incidence of encephalopathies in France and Australia, that bismuth was being absorbed in the gastrointestinal tract and thus causing toxic effects (Mueller 1989, Slikkerveer and de Wolff 1989:317, Ross et al. 1994:191, Heinemann et al. 1995:48). However, clear cause-and-effect relationships could not be formulated because there were no apparent links between the type of bismuth salt administered, quantity ingested, duration of exposure, and to further confound, only approximately 0.1% of French patients taking high doses of bismuth showed signs of encephalopathy. The one clear relationship was that when bismuth therapy stopped, so did the symptoms of intoxication (Bruinink et al. 1992:285).

Symptoms of bismuth-induced encephalopathy include weakness, fatigue, headache, mild mental confusion, loss of attention and memory, muscle twitching, loss of fine muscle control and difficulties in walking and standing. It usually takes months or years after regular oral administration until the manifestation of these symptoms occurs (Serfontein and Mekel 1979:405). If bismuth treatment is halted, the effects are reversible, but if left unchecked, the disease can lead to a disability of several months or sometimes death (Bruinink et al. 1992:285-6).

It is still unknown as to why encephalopathies occurred primarily in France (Ross et al. 1994:191, Krari et al. 1995:357), a country that consumed approximately 700 tonnes/year bismuth in the form of pharmaceuticals in 1973, while at the same time, the United States consumed roughly 500 tonnes/year and reported no cases of bismuth intoxication (Mueller

1989). Difference in diet is one possible explanation because Heinemann et al. (1995:50) found that under certain conditions of pH and the presence of hydroxycarboxylic acids, available in fruits, vegetables and beverages, bismuth could be dissolved completely. In addition, Krari et al. (1995:357) found that when bismuth and L-cysteine (an amino acid involved in the synthesis of protein) were combined, they were toxic and 50 times more so then when on their own. Slikkerveer et al. (1992) also found citrate to be another factor that increases bismuth absorption. These are alarming discoveries since bismuth's low toxicity is credited to its low absorption by the body (Stemmer 1976:153, Dresow et al. 1991:648). As well as the presence of absorption enhancers, Slikkerveer and de Wolff (1989:318) theorized that a longer intestinal tract, and microorganisms capable of metabolizing the bismuth compounds into more toxic forms, could be factors that increase the susceptibility of certain individuals.

The chemical form of bismuth in the blood is unknown, which is essential to understand since the chemical form of bismuth has a role in determining the rate of absorption (Slikkerveer and de Wolff 1989:307-8). Even though there is a relationship between elevated bismuth concentrations in blood and the presence of bismuth-induced encephalopathy, no relationship was found between the concentration of bismuth in the blood and severity of symptoms. In 618 encephalopathy patients, bismuth concentrations in blood ranged between 10 and 4600 µg/L (or 0.010-4.6 µg/g) (Slikkerveer and de Wolff 1989:314). Concurrently, a correlation between declining bismuth-blood concentrations and patient recovery was found. However, Dresow et al. (1991:650) found bismuth mainly in the red cell fraction as opposed to the plasma fraction, which typically is monitored when assessing the safety of bismuth therapies.

There is no consensus in the literature as to what constitutes a safe quantity of bismuth in the body. The general population ingests 5-20 µg bismuth via the food and water that they consume (Fowler and Vouk 1986:117) and more if they are using bismuth-containing pharmaceutical products. Additionally, as previously mentioned, subsistence hunters could consume even more if they use bismuth shot. This is of concern because there is the potential for bits of the bismuth shot pellets to get lodged in the appendix and thereby be a chronic source. Such accumulation in the appendix was shown in a study on lead shot pellets (Tsuji and Nieboer 1997).

Examining bismuth concentrations in the brain may be the most revealing since the occurrence of encephalopathy is of concern, but the pivotal studies by Sanderson et al. (1992, 1997a, 1997b) never analyzed for neurotoxic changes (anatomical, physiological, behavioural) in the mallards. Such an analysis was possible at the time because Ross et al. (1994:196) had developed the autometallographic (AMG) technique that allowed researchers to pinpoint where bismuth was sequestered in the brain or any other organ. In their study, Ross et al. (1994:197) found bismuth accumulations in the olfactory bulb of mice that were intraperitoneally dosed (administered by entering the peritoneum, which is a smooth transparent serous membrane that lines the cavity of the abdomen of a mammal) with bismuth subnitrate. This finding could be significant due to the relationship between olfaction deficits and chronic neurodegenerative disease. In addition, Bruinink et al. (1992:290) reported that bismuth has a strong affinity for central nervous system tissues and noted that to a limited extent, concentrations of bismuth in the rat brain were related to those in the blood. The duration of bismuth exposure was also found to be important with regard to the development of neuronal damage (Bruinink et al. 1992:290).

In summary, the reason that bismuth is viewed as being primarily non-toxic is because the body only absorbs a small amount of it, usually about 1% and the excretion is rapid (Stemmer 1976:154). This assumption of safety, conferred by this frequently reported statistic, detracts from the need to comprehend the behaviour of bismuth within the body, especially taking into account that diet affects bismuth absorption. In Slikkerveer and de Wolff's (1989:304) study, they mused that since this heavy metal had been used for medicinal purposes for a long period of time, it would be natural to assume that a wealth of information on its potential side effects would be in existence. To the contrary, they found the literature to be "lacking and scattered". This sentiment was echoed by others (Dresow et al. 1991:646, Ross et al. 1994:197). However, despite the patchy literature for $\leq$1997, many important questions about the safety of bismuth, in relation to the health of environments, wildlife, and humans, were raised and these should have been flagged by CWS as issues that did not meet the terms of their toxicity test guidelines. This critical review now moves to the literature that emerged after bismuth was approved as being non-toxic shot – post-1997.

2.4. Bismuth literature ≥1998

In the ≤1997 literature section there were many questions left unanswered and many of the ≥1998 studies attempt to answer these questions by probing the finer aspects of bismuth behaviour within animals and humans. As before, for the other aspects of the environment, namely soil and vegetation, there has been no attention given to the behaviour of bismuth when its source is shot pellets. Instead, the studies examine bismuth generally by monitoring locations that either have been contaminated by a host of unknown sources or received mine tailings.

The important aspect is that bismuth from shot pellets will be different in terms of the pharmaceutical sources just mentioned. Bismuth from shot pellets will be condensed, a different chemical species, and large enough to be mistaken for food and thus possibly ingested by wildlife as was the case for lead shot (Scheuhammer and Norris 1995:3). It has been elucidated in the previous section that different chemical species of bismuth behave in diverse and divergent ways and therefore, in the form of shot pellets, we plainly have a new substance. The scientific community has not explored its behaviour once it is exposed to soil, water, air, or vegetation. Therefore, this review must draw from other studies that have examined bismuth in these environments. But it cannot be stressed enough that this bismuth studied is different from the bismuth in the shot pellets. This means that the information provided henceforth may be entirely inadequate to describe its true behaviour when in pellet form. Bismuth concentrations and movement in soils will now be examined.

2.4.1. Soil

In order to understand the difference between a natural and contaminated level of bismuth, baseline data needs to be acquired. However, this is a challenging task because levels vary around the globe and the factors that increase the quantity and mobility of bismuth are poorly understood. Some literature from different parts of the world was gathered in an attempt to obtain a better picture of current bismuth concentrations in soil, which are summarized in Table 2.6.

Table 2.6: Summary of soil-bismuth concentrations in ≥1998 bismuth literature

Location	Bismuth (μg/g)	Source
PCB, lead, copper, and chromium contaminated soils in Atlantic Canada	0.10-0.59	(Carter et al. 1998:302)
Uncontaminated Japanese soils	0.03-3.86	(Harada and Hatanaka 1998:450)
Top 30 cm of cultivated soils near smelters in northern France	0.24-0.48	(Sterckeman et al. 2002:179)
Night soil in Japan	41.6	(Kawasaki et al. 1998:436)
Regular soil in Japan	0.37	(Kawasaki et al. 1998:436)
Soils samples (0-15 cm depth) from copper and tungsten mine in Korea		
Mine dump soils	42-1510	(Jung et al. 2002:85)
Household garden soils-more than 600 m downstream from mine	4-186	(Jung et al. 2002:85)
Control site soils	0.9-1.8	(Jung et al. 2002:85)

Several sites in Atlantic Canada, contaminated with substances such as polychlorinated biphenyls (PCBs), lead, copper, and chromium, had ranges of 0.10-0.59 μg/g bismuth (Carter et al. 1998:302). Some of these levels are higher than in typical soils, but comparing them to another meaningful value is not possible since there are no governmental criteria for acceptable bismuth concentrations in Canada (Carter et al. 1998:302). Typical Japanese soils, sampled across the country, had a range of 0.03-3.86 μg/g bismuth (Harada and Hatanaka 1998:450). The sampling of the top 30 cm of cultivated soils near smelters in northern France revealed bismuth means of 0.24 μg/g and 0.48 μg/g (Sterckeman et al. 2002:179). The interesting part of this study was that bismuth was confined to the first 30 cm of soil and did not penetrate down past that level. Perhaps this indicates the depth to which bismuth can percolate in soil.

In the ≤1997 literature section, production of bismuth, in 1985, was reported as being about 8000 tonnes per year. Today, world production is over 10,000 tonnes per year and about 50% of that is used for pharmaceutical products, which quickly moves into sewage systems (Feldmann et al. 1999:740). As was mentioned in the ≤1997 literature on soils, sewage sludge is sometimes spread on agricultural lands in order to increase the levels of nutrients in the soil. The costs and benefits of such a practice should be carefully measured since the application of sewage sludge may lead to bismuth accumulation (Kawasaki et al. 1998:440), which could be taken up by crops and then later consumed (this point will be elaborated upon in section 2.4.2). A sampling of night soil, in Japan, revealed a mean concentration of 41.6 µg/g bismuth, whereas levels in Japanese soils only amounted to 0.37 µg/g (Kawasaki et al. 1998:436). Obviously, the level of bismuth in night soil sludges is extremely high, but not surprisingly since the use of bismuth-containing pharmaceuticals is widespread.

In addition to literature on sewage, information about bismuth in soil can also be extracted from other sources such as mining studies. In and around a copper and tungsten mine in Korea, bismuth concentrations in the first 0-15 cm of mine dump soils, household garden soils, and control site soils, had ranges of 42-1510 µg/g, 4-186 µg/g, and 0.9-1.8 µg/g, respectively (Jung et al. 2002:85). The bismuth concentrations in home garden soils were in residential areas that were more than 600 m downstream from the mine. Another study on tailings from a gold mine in Spain found a significant increase of bismuth in downstream sediment that ranged from 1.4 to 41.2 µg/g (Wray 1998:33). From here it is important to determine the extent to which bismuth moves from soil to vegetation.

2.4.2. Vegetation

Most trace elements have strong bio-activities in vegetation because they play a twin role of being essential nutrients and toxic chemicals (Harada and Hatanaka 1998:443). Therefore it is important to understand how vegetation interacts with bismuth so that an understanding, of what constitutes a healthy concentration, can be developed.

Table 2.7: Summary of vegetation-bismuth concentrations in $\geq$1998 bismuth literature

Location	Bismuth (µg/g)	Source
Crops plants in and around Korean copper and tungsten mine*	0.01-0.42	(Jung et al. 2002:83)
Normal concentration in plants	0.06	(Jung et al. 2002:83)
Wild plants in uncontaminated sites across Japan	0.02-0.038	(Harada and Hatanaka 1998:449)

* Jung et al. (2002:83) found that plant leaves (soybean leaves, spring onions and perilla leaves) had significantly higher concentrations of bismuth than in grain or fruit (corn grain, red pepper and jujube grain)

The best study on the relationship of bismuth with vegetation was conducted by Jung et al. (2002:83). They sampled several types of crop plants in and around a Korean copper and tungsten mine that included corn grain (*Zeamays*), jujube grain (*Zizyphus jujuba*), perilla leaves (*P. frutescens var. japonica*), red peppers (*Capsicum annuum*), soybean leaves (*Glycine max*) and spring (Welsh) onions (*Allium cepa*). The bismuth concentrations in the plants ranged from 0.01 to 0.42 µg/g, whereas normal levels are 0.06 µg/g (dw). Wild plants in sixteen uncontaminated sampling sites across Japan had bismuth concentrations ranging from 0.02-0.038 µg/g (Harada and Hatanaka 1998:449). Jung et al. (2002:83) also found that plant leaves (soybean leaves, spring onions and perilla leaves) had significantly higher concentrations of bismuth than in grain or fruit (corn grain, red pepper and jujube grain). They could not find one factor that was individually responsible for bismuth uptake and therefore postulated that a suite of variables such as pH, organic matter, cation exchange capacity, and soil texture were responsible for this uptake. On the other hand, while there is an abundance of influencing variables, it is accepted that as concentrations of bismuth increase in soils, they also increase in vegetation. Soils in this study area were found to have a low pH (3.0-5.7), a low organic matter content (<1-7%), a typical cation exchange capacity (3–18 meq/100 g) and a high fraction of sand (70-97%).

Moreover, researchers who conduct studies on vegetation should be cognizant that different species of plants have different responses to metals (Fairbrother and Kapustka 2000:16). Brake et al. (2004) carried out a study on plant uptake of trace elements in soils amended with coal fly ash. Bismuth concentrations in the potted plants were all reported as being equal to or close to analytical limits (samples were analyzed by inductively coupled plasma–mass spectrometry [ICP-MS]). They concluded that the absence of bismuth may have been because it was in a form that was not conducive to uptake. Brake et al. (2004) hypothesized that bismuth may have been sequestered and stored in belowground biomass, which acts as a protective mechanism by restricting the movement of toxic elements to aboveground parts of the plant, as was suggested by MacNicol and Beckett (1985). From here the focus of the discussion shifts to the literature on bismuth and its interactions with animals.

2.4.3. Animals

Since 1997, some studies have been conducted on the toxicity of bismuth shot pellets. However, these studies have shown where bismuth is accumulating within the animals and still little is known about the consequences of this build-up over the long term (Pamphlett et al. 2000a:262). Recent animal studies, with regard to bismuth have used a technique known as autometallography (AMG), which is a method that enhances bismuth with silver. This enhancement permits the taking of an electron micrograph of the desired specimen and the locations of the bismuth can be visually seen at the subcellular level. In the past, amounts of bismuth in a general area could be measured, but the AMG technique allows researchers to see exactly where the bismuth is within cells, which in turn will permit the study of how bismuth operates (Locht et al. 2002:77). Due to the fact that an electron microscope can give a magnifying level of up to 500,000 times, extremely minuscule amounts of bismuth can be detected within a specimen.

Researchers using this technique report interesting results about the behaviour of bismuth. Locht et al. (2002:82) undertook an *in vitro* study of rat hippocampuses and the effect of bismuth citrate upon them. They found that even at picomolar concentrations, bismuth was still absorbed and stored intracellularly in lysosome-like organelles. Pamphlett et al. (2000b:561) discovered large numbers of Bi^{AMG} grains in the brain stems and motor neurons of mice that were fed ranitidine bismuth citrate, at levels that humans would normally receive therapeutically, in conjunction with selenium. Other AMG experiments with rats exposed intraperitoneally to bismuth subnitrate have found bismuth embedded in the heads of nearly mature spermatids (Stoltenberg et al. 2000:70). In a follow-up study, Stoltenberg et al. (2002b:112) found that the rats intraperitoneally exposed to bismuth subnitrate had significantly less serum testosterone than the control group.

Pamphlett et al. (2000a:262) implanted sterilized bismuth shot pellets into mice and discovered, via the autometallographic technique, that the bismuth was later found in the nervous system and other organs of these animals. Stoltenberg et al. (2003b) found that when bismuth shot pellets were implanted into rats, no bismuth could be found in the first 2-4 months. However, after 12 months, bismuth could be found in large amounts in the kidney, Leydig cells, responsible for the production of testosterone, and the central nervous system. As an aside, it was later found that bismuth was not accumulating in the Leydig cells, but in the adjacent macrophages (Stoltenberg and Hutson 2004). A subsequent study found that bismuth lowers testosterone levels by killing testicular macrophages, but the mechanisms of these deaths are unknown (Hutson 2005:237). The aforesaid 12 month waiting time is of interest because chronic toxicity testing procedures such as those provided by CWS (1993) require less than 3 months. The chronic toxicity study by Sanderson et al. (1997b) was completed in 5 months. From this it appears that more testing time is required for an accurate estimation of chronic toxicity.

Finally, it is difficult to start with a “clean slate” for these types of studies because little data exists on background concentrations. Jayasinghe et al. (2004:14) obtained livers and striated muscle (gizzard tissue) from game birds that were harvested with lead shot between 1993 and 1996 by First Nation Cree. Bismuth concentrations for these birds were much lower than in the 0-dosed birds reported by Ringelman et al. (1993) and Sanderson (1997a, 1997b) (see Table 2.8). Jayasinghe et al. (2004:19) concluded that lead shot is a source of bismuth since they are naturally associated with each other. In another study, Tsuji et al. (2004) arranged for First Nation Cree of the western James Bay region to use bismuth shot for their normal harvest of upland game birds. They were then permitted to salvage parts of the birds for their study. The results of that study are provided in Table 2.8 along with other game bird research for comparison purposes. Tsuji et al (2004:131) reported that 85% (*n* = 20) of the birds had at least one tissue sample contaminated with bismuth at levels greater than 1.00 µg/g ww. They were unable to put this concentration into context because no consumption guidelines for bismuth-contaminated meats exist. From here follows a short description of post-1997 literature on bismuth in humans.

Table 2.8: Summary of Bi concentrations in game birds found in six animal studies

Tissue	$\bar{x}$ **±SD (µg/g)**	**Range (µg/g)**	***n***	**Source and Notes**
Sharp-tailed grouse				(Tsuji et al. 2004:132) Harvested with approved bismuth shot by First Nation Cree as part of normal hunt.
Heart	1.24±0.98	0.03-2.86	18	
Leg	0.72±0.84	0.03-2.27	18	
Breast	1.45±0.81	0.12-2.61	19	
Gizzard	1.02±1.00	0.1-2.27	10	
Liver	0.40±0.49	0.02-1.64	18	
Duck- Mallard				(Jayasinghe et al. 2004:17) Harvested with lead shot between 1993 and 1996. Livers and striated muscle from gizzard tissue were provided by First Nation Cree.
Liver	0.09±0.06	0.03-0.21	23	
Muscle	0.16±0.08	0.04-0.26	12	
Duck- Pintail				
Liver	0.10±0.12	0.02-0.39	19	
Muscle	0.29±0.33	0.06-1.92	34	
Duck- Teal				
Liver	0.05±0.02	0.02-0.08	11	
Muscle	0.06±0.02	0.05-0.08	5	
Goose- Canada				
Liver	0.15±0.11	0.02-0.77	80	
Muscle	0.22±0.44	0.02-4.59	109	
Goose- Snow				
Liver	0.06±0.06	0.02-0.23	13	
Muscle	0.24±0.22	0.03-0.90	39	
Duck- Mallard				(Ringelman et al. 1993:730) Mallards orally dosed with tungsten-bismuth-tin shot.
Liver- 0-dosed	4.72±2.15	---	20	
Liver- TBT dosed	5.96±3.89	---	20	
Kidney- 0-dosed	13.67±6.12	---	20	
Kidney- TBT dosed	15.84±8.06	---	20	
Duck- Mallard	Not reported here because only Day 3 out of 30-day study were reported and DL was 3.00-5.00 µg/g			(Sanderson et al. 1992:537) Mallards dosed with 100% Bi shot into the proventriculus (the glandular or true stomach of a bird that is situated between the crop and gizzard).
Duck- Mallard				(Sanderson et al. 1997a:195, Sanderson et al. 1997b:232-3) Mallards dosed with approved bismuth shot into the proventriculus. Both studies are recorded here and separated by a '/' with 97a first and 97b second.
Liver- 0-dosed	0.193/0.053	---/---	10/10	
Liver- Bi-dosed	2.23/0.637	0.63-5.63/---	11/11	
Kidney- 0-dosed	0.334/0.032	---/---	20/10	
Kidney- Bi-dosed	6.86/1.54	---/---	22/11	

2.4.4. Humans

The primary route of bismuth into humans will be through bismuth-containing pharmaceutical products, followed by water (see Table 2.6 for night soil bismuth concentrations) and food that is contaminated by bismuth. In terms of food, there are no consumption guidelines for bismuth-contaminated meats, which is unfortunate since game birds harvested with bismuth shotshells are a potential source of bismuth when ingested (Tsuji et al. 2004). This is postulated because the weight of bismuth and lead shot pellets are similar and Tsuji and Nieboer (1997) found that lead shot pellet fragments accumulate in the appendix and may remain there for years and thus represent a chronic source. Long term toxic effects are a very real prospect since it has been reported that the half-life of bismuth in blood can range from several minutes to approximately twenty years (Islek et al. 2001:513).

When the encephalopathies occurred in France and Australia in the 1970s, health officials reacted by reducing the dose and exposure of bismuth. In addition, other chemical species are now used because they have a reduced possibility of being absorbed in the gastrointestinal tract (Islek et al. 2001:510). These measures were taken because they control some of the factors that dictate which organs will have an affinity for bismuth. Furthermore, it is now known that certain compounds of bismuth have a greater ability than others to cause encephalopathy (Leussink et al. 2002:100). With these measures in place, it is now unlikely that bismuth intoxication, like in France, will develop, but the possibility of toxic effects due to chronic exposure cannot be excluded (Locht et al. 2002:77, Stoltenberg et al. 2002a:400). However, the aetiology of the encephalopathies in the 1970s is still unknown (Canena et al. 1998:282, Stoltenberg et al. 2003a:355).

The variability of the bismuth compounds that are absorptive in the gastrointestinal tract is highlighted by several animal studies. Pamphlett et al. (2000b:559) found that bismuth absorption increased when concurrently administered with selenium. Canena et al. (1998) undertook a study where they compared the distribution of bismuth in rats that were administered ranitidine bismuth citrate (RBC) and bismuth subcitrate. They found that the overall absorption and concentrations of bismuth were significantly less in the kidney and absent in the brain when RBC was used (Canena et al. 1998:279). Larsen et al. (2003) completed a study on orally administered RBC and bismuth citrate to mice and found that the former was more easily absorbed. In the following weeks after exposure, bismuth was found in lymph nodes, liver, spleen, and kidneys. Subcellular analysis revealed bismuth to be exclusively in lysosomes (accumulation was dose and time dependent) and largely within macrophages and dendritic cells. Some authors have noted that mercury and bismuth share certain mechanisms for entry and storage in the nervous system (Pamphlett et al. 2000a:261, Pamphlett et al. 2000b:559, Stoltenberg et al. 2001:709, Locht et al. 2002:82, Stoltenberg et al. 2002a:339). Thus, it seems that much is uncertain as to what variables, many of which are typically unseen, cause absorption of bismuth.

In the first use of the AMG technique for human brain autopsies of patients who had bismuth-intoxication, it was revealed that all of the patients had large amounts of Bi^{AMG} grains in the neurons of the cerebellum, thalamus, and neocortex (Stoltenberg et al. 2001:706). At the subcellular level, the pattern that many other studies have demonstrated also existed; within neurons, the Bi^{AMG} grains were located exclusively in lysosomes. They hypothesized that bismuth accumulates primarily in neurons involved in motor activities that would create myoclonic encephalopathy (Stoltenberg et al. 2001:707). This chapter will now be concluded with a brief summary.

2.5. Summary

Studies that were completed before and after the approval of bismuth as a non-toxic shot have demonstrated that bismuth is capable of entering various organs and the central nervous system of both animals and humans. The pivotal studies of Sanderson et al. (1997a, 1997b), behind the Canadian Wildlife Service’s decision to approve bismuth, claimed that it was non-toxic. Due to the occurrence of over 500 cases of bismuth-induced encephalopathy in France and Australia during the 1970s, the aforementioned studies should have examined the behaviour of their test mallards for signs of bismuth-intoxication.

The dangers associated with bismuth use have been illustrated in this critical review of the available literature and much is still unknown as to how it behaves within the environment. The following chapter begins to explore bismuth’s behaviour in a southern Ontario wetland in which the soil and vegetation were monitored over a period of four years.

3. EFFECTS AND FATE OF BISMUTH SHOT PELLETS IN A SOUTHERN ONTARIO WETLAND

3.1. Introduction

Bismuth shot has been approved as a non-toxic alternative to lead shot in Canada since 1997 (Scheuhammer 2005) . Despite approval being contingent upon satisfying various criteria of the Canadian Wildlife Service's (1993) toxicity test guidelines, little is known about it. After their 1989 review of the toxicity of bismuth compounds, Slikkerveer and de Wolff (1989:304) concluded that the literature was "lacking and scattered". More recently, this has also been noted by others conducting bismuth research (Dresow et al. 1991:646, Ross et al. 1994:197, Jayasinghe et al. 2004:14, Tsuji et al. 2004:129). From the literature that is available, it appears that bismuth is a toxic metal and has been responsible, in a pharmaceutical form, for close to a thousand cases of encephalopathy in France and Australia in the 1970s (Slikkerveer and de Wolff 1989:317). With this knowledge, it is unwise to substitute the known toxic metal of lead for bismuth, which can be characterized as toxic.

The role of the CWS toxicity test guidelines (1993) is to elucidate the circumstances in which bismuth is and is not toxic. These guidelines ask questions about scenarios such as the acute and chronic toxicity of bismuth in game birds and its effects on environments that receive the spent shot. Some research has been done on the former question (Sanderson et al. 1997a, 1997b), but little is known about the latter. Recent studies have been completed on levels of bismuth in game birds harvested with bismuth shot (Tsuji et al. 2004) and lead shot (Jayasinghe et al. 2004). To my knowledge, only one study has begun to address the effects of bismuth on trees (Karagatzides et al. unpublished data). Research must be done to fill the knowledge gap on the effects of spent bismuth shot pellets on the environments that receive them, namely soil and vegetation. There is some literature on bismuth behaviour in soil and vegetation (Li and Thornton 1993, Jung et al. 2002), but the source of bismuth has been from mining sites. Applying the results from these studies to the case of bismuth shot would be taking them out of context, since its origin has a bearing on its bioavailability (Kabata-Pendias 2004:144). Therefore, research must be carried out that specifically examines bismuth shot pellets in the kind of environment that would receive them, namely a wetland.

Studying a wetland environment is important because this is the primary type of habitat for game birds.

This study aims to begin investigating this data gap by addressing two objectives. The first objective is to assess whether or not bismuth is mobile or inert in a wetland soil. The second is to assess the uptake of bismuth by vegetation. These objectives will be accomplished by seeding several randomized plots that were in a fully factorial design in a wetland close to Kingston, Ontario, Canada, with bismuth shot pellets. In addition, some of these plots will be acidified in order to understand the relationship between pH and bismuth mobility. Jayasinghe et al (2004:19) reported that lead shot can be a source of bismuth and so the collected samples will also be analyzed for lead as to avoid potentially erroneous results.

3.2. Materials and methods

3.2.1. Site description and treatments

The soil and vegetative samples used in this study were taken from Osprey Marsh, a sedge marsh at the Queen's University Biological Station (QUBS) at Chaffey's Locks, which is 50 km north of Kingston, Ontario, Canada. Osprey Marsh borders the forested Hughson Track and the open grasslands of Stokes Field. The marsh begins about 25 m from forest edge and a lakebank sedge (*Carex lacustris*) stand stretches for approximately 50 m before cattails (*Typha sp.*) become prevalent.

Treatment plots were established at the site in 1999 in a 6x4 matrix of 24 plots where the centre of each plot was marked by a 2 m piece of PCV pipe. The plots were circular with a 1 m radius and were approximately 10 m apart. The two types of vegetation sampled in these areas were lakebank sedge (*Carex lacustris*) and rough hair grass (*Agrostis scabra*). The soil could be described as loam, clay loam, or silty clay loam using a soils field guide (Kalra and Maynard 1991). Also standing water was rare in the autumn when samples were collected. The four treatments were randomly assigned and consisted of applications as noted in Table 3.1.

Table 3.1: Treatment descriptions for four-year wetland study

Treatment	Description
Bismuth shotshell pellets ('Bi')	Applied only once to soil in November 1999 at a rate of 100 g or 628 #4 pellets per plot, which is equivalent to 200 pellets/m^2.
Soil acidifying agent ('Acid')	Granular ammonium sulphate fertilizer applied to soil annually at a rate of 0.6 kg/plot, which is equivalent to 2,000 kg/ha.
Bismuth + Soil acidifying agent ('Bi+Acid')	Rates of application as noted above for both 'Bi' and 'Acid' treatments.
Control	No application of bismuth or soil acidifying agent.

3.2.2. Sample collection

Soil samples were collected with a stainless steel corer (5.5 cm diameter) to a depth of 5 cm, prior to the application of the first treatment in 1999 and thereafter between October and November from 2000-2003. Three cores were taken in each plot and placed into one composite sample for each collection. This procedure was varied in the final year, 2003, when one soil sample was collected from the same location as where the vegetation was sampled. The samples were stored and transported to the lab in plastic bags and air dried immediately.

In August 2003, vegetation samples were collected from each plot (clipped with stainless steel scissors at ground level). These samples were collected by placing a 10 cm diameter ring at about 0.5 m from the plot centre so as to avoid possible interactions with the other plots. The stem density was then calculated by dividing the number of live stems by the area of the 10 cm diameter ring. These values were reported in number of stems per m^2. The samples were stored and transported to the laboratory in paper bags, number of live stems counted, and then oven dried at 70°C for 72 h.

3.2.3. Sample preparation

The air-dried-soil samples were sieved through a 100-mesh (150 µm) stainless steel screen and the oven-dried vegetation samples were ground in a spice mill with stainless steel blades. All soil and vegetative tissue samples were weighed to 0.20 g and placed into 15 mL test tubes (Sarstedt). The test tubes received 2 mL of HNO_3 (Ultrax, JT Baker) and 2 mL of distilled double-deionized water (DDW). They were then sealed with lid-locks (DiaMed) and stored overnight in a fumehood to allow for an initial acid digestion of the samples. The samples were moved into 12-hole test tube heating blocks (Multi-Blok, Lab-Line) and digested initially at a temperature of 60°C for 1 h and then at 80°C for an additional 5-7 hours. This was followed by a 10 min cooling period at room temperature. The contents of the test tubes were filtered through a Whatman 540 Harden Ashless Filter, transferred into 15 mL test tubes (Pyrex) with DDW and vortexed. Samples were then placed in a test tube rack until the determination of bismuth and lead by electrothermal atomic absorption spectrometry (EAAS). There are no certified reference standards for bismuth. Certified reference standards for lead (National Research Council of Canada, Mess-3 soil; National Bureau of Standards 1572, citrus leaves) were run with every 10 samples.

3.2.4. EAAS analysis of bismuth and lead

A bismuth intermediate standard (2000 mg/L) was made by diluting 1 mL of Bismuth Reference Standard (1000 mg/L; Ricca Chemical Company) after adding 0.72 mL of concentrated HNO_3 (Ultrex, JT Baker) and diluted to 500 mL with DDW. Working standards of 0, 2.5, 5, 10, 20, and 30 mg/L bismuth were made by adding 0-750 µL of the intermediate bismuth standard plus 25 µL Triton solution and diluted to 50 mL with 0.1% HNO_3.

A lead intermediate standard (2000 µg/L) was made by diluting 1 mL of the Lead Reference Standard (1000 mg/L; Ricca Chemical Company) after adding 0.72 mL of concentrated HNO_3 (Ultrex, JT Baker) and diluted to 500 mL with DDW. Working standards of 0, 2.5, 5, 10, 15, 25, 50 and 100 µg/L lead were made by diluting 1 mL of the Lead Reference Standard (1000 mg/L; Ricca Chemical Company) after adding 0.72 mL of concentrated HNO_3 (Ultrex, JT Baker) and diluted to 500 mL with DDW. Working standards were made by adding 0-1250 µL of intermediate lead standard plus 25 µL Triton solution and diluted to 50 mL with 0.1% HNO_3.

Sample digests of bismuth and lead were analyzed using a Varian Electrothermal Atomic Absorption Spectrometer (model Spectra AA 220) with graphite furnace. No modifier was used. Before the sample digests were analyzed and during each sample run, the calibration curves were recorded every 10^{th} sample to ensure that the spectrometer was fully optimized (±10%). The spectrometer was set to a wavelength of 223.1 nm for bismuth and 283.3 nm for lead, the lamp current was 10.0 mA, background correction was activated, the sampling mode was set to premix, the slit width was set to 0.2 nm for bismuth and 0.5 nm for lead and the measurement mode was set to record absorbance peak height. The temperature program was configured as was done by Jayasinghe et al. (2004). The detection limit for bismuth was 0.057 µg/g and for lead, 0.003 µg/g.

3.2.5. Soil pH analysis

The procedure used to measure soil pH was a modified version of that found in Forestry Canada's methods manual (Kalra and Maynard 1991:31). A 15 mL scoop of 1 mm sieved soil was placed into a small plastic cup. Deionized water was then added to create a liquid:soil ratio of 1:4. This was stirred every 5 min for 30 min to keep the soil particles in suspension and then allowed to sit for an additional 30 min in order to allow the particles to settle. After this time had elapsed, a Beckman Electromate pH meter probe (Beckman Coulter, Inc., Fullerton, CA) was inserted into the solution and the pH recorded.

3.2.6. Statistical analysis

Differences between treatment responses for soil in 1999 were determined using a multivariate analysis of variance (MANOVA) and Tukey's HSD test for comparisons between treatments. This same type of statistical analysis was used for the 2003 soil data. A combined analysis was initially done for both years via a MANOVA of 2003 data with the 1999 data used as covariates. However, the effect of the 1999 bismuth and lead concentrations were not significant (Pillai's Trace: $F = 0.094$, $p = 0.911$ and $F = 0.976$, $p = 0.397$, respectively).

Variances among treatments in soil bismuth-1999, lead-1999, and lead-2003 concentrations were homogeneous while they were not for bismuth-2003 concentrations. Log transformation on the bismuth and lead-2003 data homogenized the variance. The transformed data was also normally distributed (Shapiro-Wilk's test). The data for the Bi+Acid treatment for lead concentrations in 1999 was not normally distributed because lead concentrations were below the detection limit in five out of the six replicates and could not be normalized using log transformation. All other values for both lead and bismuth were normally distributed. Thus, a MANOVA was preformed on the untransformed bismuth and lead data.

Stem density and vegetation mass both satisfied homogeneity of variance. Data for the Bi+Acid treatment for stem density and biomass were normal after log transformation. The bismuth and lead concentrations in the vegetation samples were multiplied by the mass (grams of dry weight material) of the vegetation to derive a ‘stock’ amount of bismuth and lead. This was done to account for the differences in metal concentrations between smaller and greater vegetative masses. The variances among treatments for bismuth levels were homogeneous while they were not for lead. A log transformation on the lead vegetative stock data homogenized the variance. The transformed data were normally distributed.

The pH values were converted into [H+] values. Variances were not homogeneous for 1999 and 2002 [H+] (Levene’s test: $p = 0.018$ and 0.022, respectively) and therefore they were converted back into pH values since this is essentially the equivalent of a log transformation. This homogenized the variance for 1999 ($p = 0.095$), but failed to do so for 2002 ($p = 0.018$). As well, after transformation the test of normality was violated in at least one of the treatments each year. The 2002 pH data were not considered when running the general linear model (GLM) repeated measures test.

Correlation analysis was used to explore the relationships between bismuth and lead in the soil and vegetation samples. For the vegetation samples, some were omitted in treatments that had large number of readings below the detection limit. For vegetation samples, these included the bismuth (50% above the DL), acidifying (50%), and Bi+Acid (33%) treatments. Lead was detected in all of the vegetation samples. Bismuth was detected in all soil samples and so was lead with the exception of the lead-1999 samples in the Bi+Acid treatment (20% above the DL). In order to meet the assumptions for parametric tests, all data used had to be log transformed, with the exception of the 1999 soil data. Once these assumptions were satisfied, a two-tailed Pearson’s correlation test was used.

3.3. Results

3.3.1. Soil pH

A repeated measures test revealed that there were no significant differences (F = 2.317, p= 0.117, Figure 3.1) in pH during the five years between 1999 and 2003. Irrespective of treatment, all of the plots had increasing soil pH levels. The mean pH increase for the control, Bi, Bi+Acid, and Acid treatments were 0.7, 0.4, 0.5, and 0.8, respectively. The GLM repeated measures test showed that the rate of increase was statistically the same.

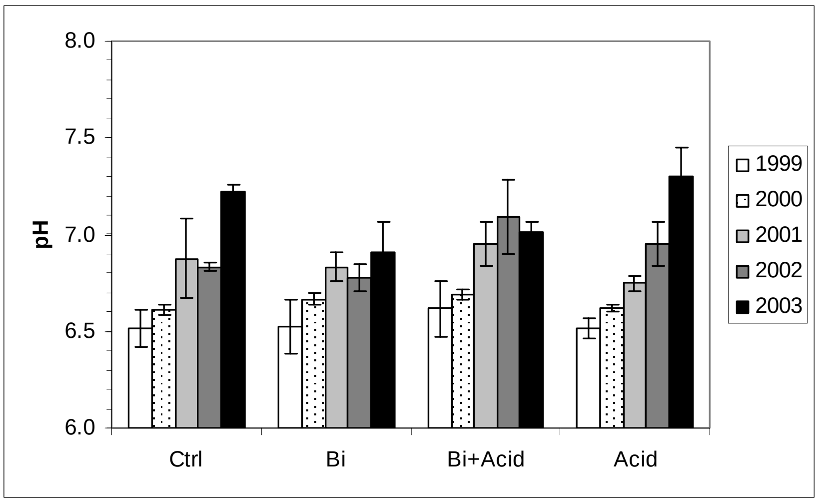

Figure 3.1: Mean soil pH and standard error bars (n = 24) over five years between 1999 and 2003 within 4 treatments (control, bismuth shotshell pellets, bismuth shotshell pellets and NH_4SO_4, NH_4SO_4) in southern Ontario, Canada

3.3.2. Soil mobility of bismuth and lead

MANOVA showed no significant differences among treatments for soil bismuth concentrations in 1999 (F = 2.336, p = 0.104, Figure 3.2). There was a significant difference for soil bismuth concentration in 2003 (F = 7.153, p = 0.002, Figure 3.2). The Bi and Bi+Acid treatments had the highest levels of bismuth. Tukey's HSD test revealed that for 2003 bismuth concentrations there were significant differences between the Bi treatment and the acidifying treatment (p = 0.003) and the control treatment (p = 0.004). The control treatment was not different from the acidifying treatment (p = 1.000) or the Bi+Acid treatment (p = 0.305).

No significant differences were found for soil lead concentrations in 2003 or 1999 (F = 0.722, p = 0.551 and F = 2.794, p = 0.067, respectively, Figure 3.3)

A significant positive correlation (r = 0.506, p = 0.027, Figure 3.4) was found between bismuth and lead concentration in 1999 soil samples. A positive correlation approached significance (r = 0.402, p = 0.051, Figure 3.5) for bismuth and lead in 2003 soil samples. The highest levels of bismuth and lead were found in the Bi treatment in 1999 (Figure 3.4) and in the Bi and Bi+Acid in 2003 (Figure 3.5).

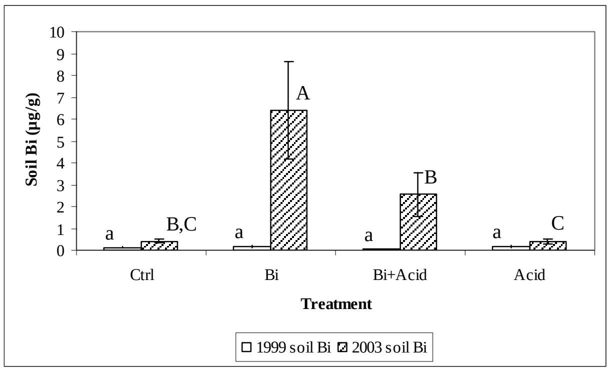

Figure 3.2: Soil bismuth concentration means and standard error bars (n = 24) in 1999 (pre-treatment) and 2003 within 4 treatments (control, bismuth shotshell pellets, bismuth shotshell pellets and NH_4SO_4, NH_4SO_4) in southern Ontario, Canada

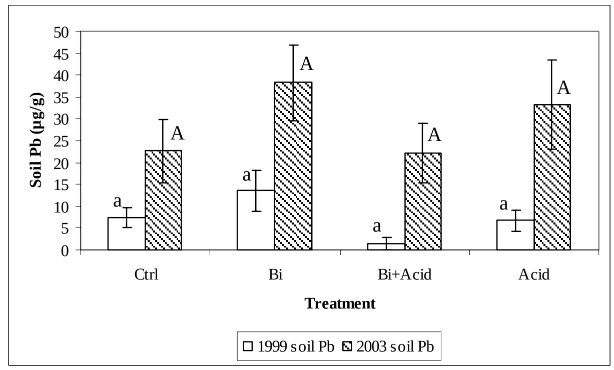

Figure 3.3: Soil lead concentration means and standard error bars (n = 24) for 1999 (pre-treatment) and 2003 within 4 treatments (control, bismuth shotshell pellets, bismuth shotshell pellets and NH_4SO_4, NH_4SO_4) in southern Ontario, Canada

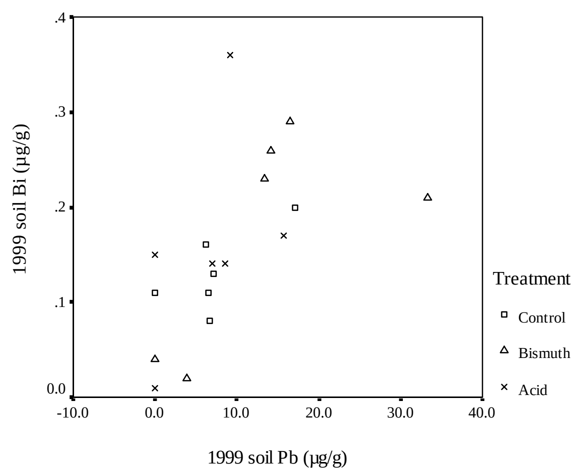

Figure 3.4: Relationship (*n* = 18, *r* = 0.506, *p* = 0.027) between lead (µg/g) and bismuth (µg/g) for 1999 soil samples within 3 treatments (control, bismuth shotshell pellets, and NH_4SO_4) in southern Ontario, Canada (Bi+Acid treatment removed because over 80% of the lead concentrations were below the detection limit)

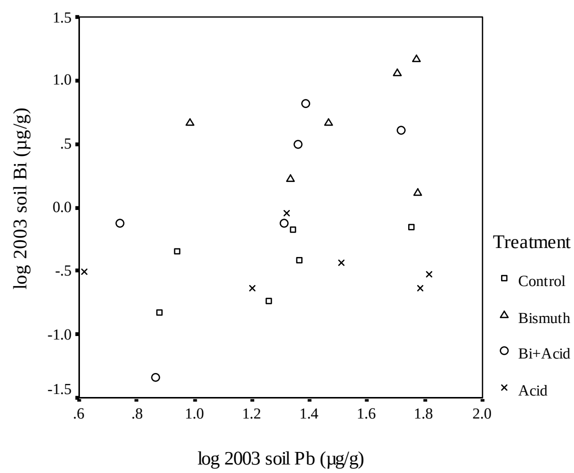

Figure 3.5: Relationship (*n* = 24, r = 0.402, *p* = 0.051) between log lead (µg/g) and log bismuth (µg/g) for 2003 soil samples within 4 treatments (control, bismuth shotshell pellets, bismuth shotshell pellets and NH_4SO_4, NH_4SO_4) in southern Ontario, Canada
* Note that this relationship *approached* significance.

3.3.3. Vegetative uptake of bismuth and lead

MANOVA revealed no significant differences among treatments for stem density ($F = 0.770$, $p = 0.524$, Figure 3.6), but the Bi treatment had approximately 1000 stems/m^2 more than the other treatments. The vegetative biomass was the largest in the control treatment, but the differences among treatments was not significant ($F = 2.22$, $p = 0.117$, Figure 3.7). The bismuth-vegetation ($F = 0.329$, $p = 0.805$, Figure 3.8) and bismuth-vegetation-stock ($F = 2.05$, $p = 0.139$, Figure 3.9) concentrations were the highest in the control treatment although the differences among treatments were not significant. The same trend of greater concentrations in the control treatment was also found in the lead-vegetation ($F = 1.331$, $p = 0.292$, Figure 3.10) and lead-vegetation-stock ($F = 3.68$, $p = 0.029$, Figure 3.11) concentrations while the differences among treatments were only significant for lead-vegetation-stock.

Tukey's HSD revealed significant differences between control and Acid ($p = 0.046$), and control and Bi ($p = 0.041$). A significant negative correlation ($r = -0.492$, $p = 0.015$, Figure 3.12) was found between lead concentrations in soil and vegetation. A positive relationship ($r = 0.580$, $p = 0.030$, Figure 3.13) existed between the stock amounts of bismuth and lead in vegetation. No other significant correlations ($p < 0.05$) were evident.

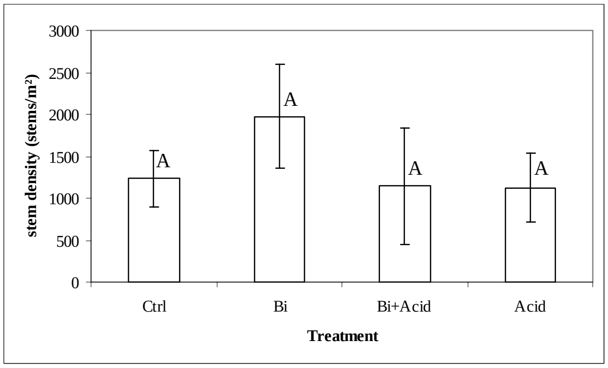

Figure 3.6: Live stem density means and standard error bars (n = 24) of *Carex lacustris* and *Agrostis scabra* within 4 treatments (control, bismuth shotshell pellets, bismuth shotshell pellets and NH_4SO_4, NH_4SO_4) in southern Ontario, Canada

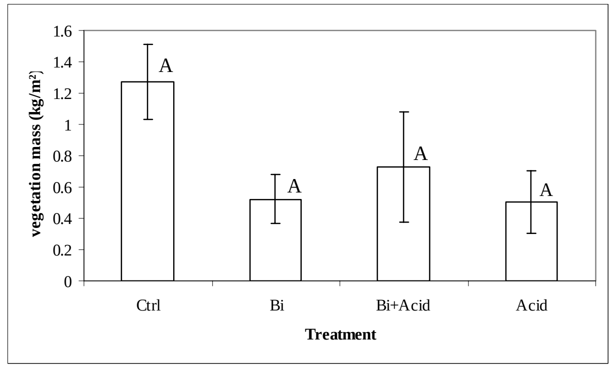

Figure 3.7: Vegetative biomass means and standard error bars (n = 24) of *Carex lacustris* and *Agrostis scabra* within 4 treatments (control, bismuth shotshell pellets, bismuth shotshell pellets and NH_4SO_4, NH_4SO_4) in southern Ontario, Canada

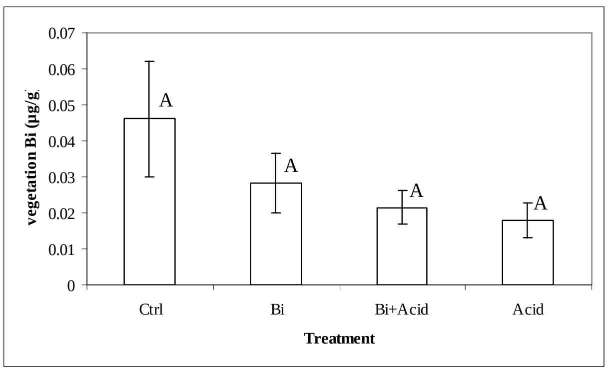

Figure 3.8: Bismuth concentration means and standard error bars (n = 24) in *Carex lacustris* and *Agrostis scabra* within 4 treatments (control, bismuth shotshell pellets, bismuth shotshell pellets and NH_4SO_4, NH_4SO_4) in southern Ontario, Canada

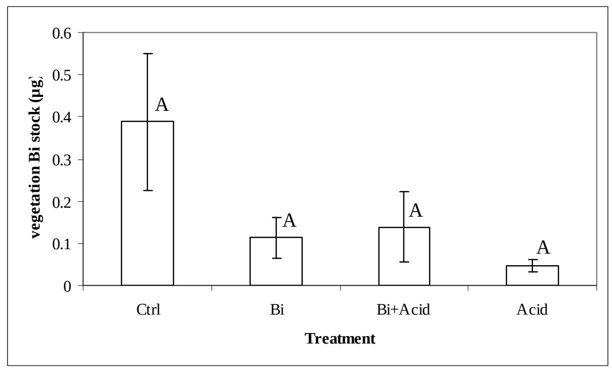

Figure 3.9: Bismuth 'stock' concentration means and standard error bars (n = 24) in *Carex lacustris* and *Agrostis scabra* within 4 treatments (control, bismuth shotshell pellets, bismuth shotshell pellets and NH_4SO_4, NH_4SO_4) in southern Ontario, Canada

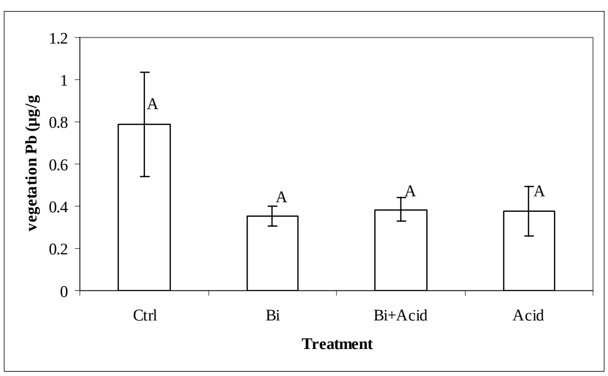

Figure 3.10: Lead concentration means and standard error bars (n = 24) in *Carex lacustris* and *Agrostis scabra* within 4 treatments (control, bismuth shotshell pellets, bismuth shotshell pellets and NH_4SO_4, NH_4SO_4) in southern Ontario, Canada

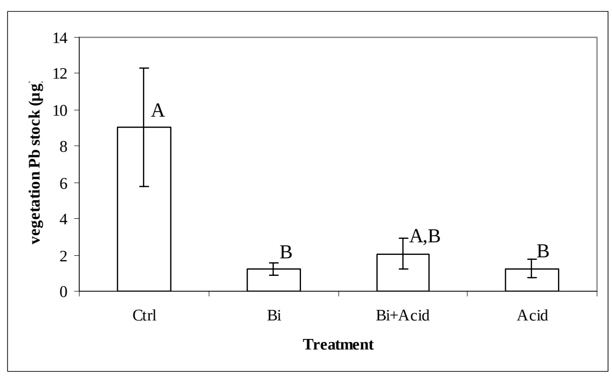

Figure 3.11: Lead 'stock' concentration means and standard error bars (n = 24) in *Carex lacustris* and *Agrostis scabra* within 4 treatments (control, bismuth shotshell pellets, bismuth shotshell pellets and NH_4SO_4, NH_4SO_4) in southern Ontario, Canada

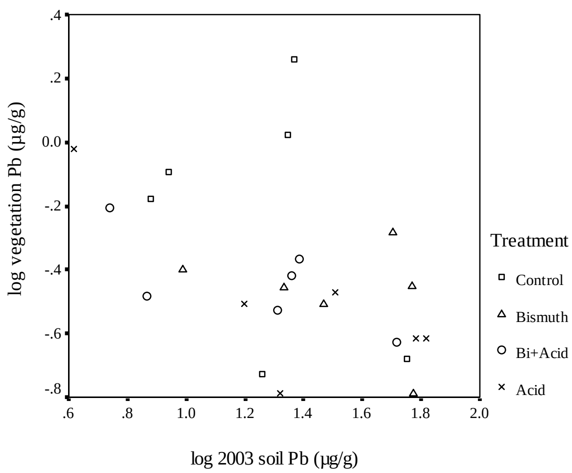

Figure 3.12:Relationship (*n* = 24, *r* = -0.492, *p* = 0.015) between log lead (µg/g) in vegetation (*Carex lacustris* and *Agrostis scabra*) and log lead (µg/g) for 2003 soil samples within 4 treatments (control, bismuth shotshell pellets, bismuth shotshell pellets and NH_4SO_4, NH_4SO_4) in southern Ontario, Canada

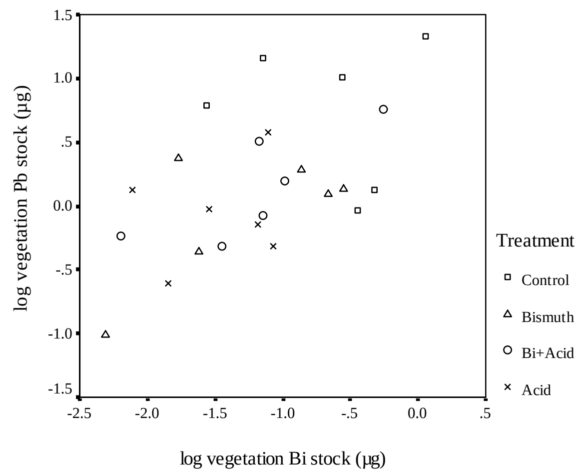

Figure 3.13: Relationship (*n* = 24, *r* = 0.580, *p* = 0.030) between log lead stock (µg) and log bismuth stock (µg) in vegetation (*Carex lacustris* and *Agrostis scabra*) within 4 treatments (control, bismuth shotshell pellets, bismuth shotshell pellets and NH_4SO_4, NH_4SO_4) in southern Ontario, Canada

3.4. Discussion

3.4.1. Soil pH

The first objective of this study was to determine the mobility of bismuth in soil. This was addressed by acidifying some of the soil plots so that the affect of pH on bismuth mobility could be observed. Between 1999 and 2003, the pH of the soil increased for all treatments. From these findings it is likely that the buffering capacity of the soil was strong enough to resist a lowering of the pH. A similar study conducted in a neighbouring forested test site, during the same period of time, also found the pH to be increasing by about 0.5 units per year in the control plots, but managed to decrease the pH in the acidified plots (Karagatzides et al. unpublished data). In the current study, it is possible that the applied NH_4SO_4 did not have a chance to acidify the soil because of a precipitation event that removed it from the soil. Perhaps it would have been appropriate to apply NH_4SO_4 more frequently (e.g., monthly) so as to ensure proper contact with the soil.

3.4.2. Soil mobility of bismuth and lead

The mean bismuth concentration of the pre-treatment 1999 measurements was 0.13 µg/g, which is comparable to the world soil mean of 0.20 µg/g (Polemio et al. 1982:76) and within the range found for frozen topsoil of 0.04 – 0.34 µg/g bismuth (Reimann et al. 1997b:51). In contrast, the mean bismuth concentration for the Bi treatment was 6.40 µg/g, 2.55 µg/g for the Bi+Acid treatment, 0.39 µg/g for the Acid treatment, and 0.42 µg/g for the control treatment.

The Bi treatment had significantly greater concentrations of bismuth in soil than both the control and acid treatments. Bismuth mobility from pellets was also evident in the Bi+Acid treatment, but to a lesser extent since there was a significantly greater increase than the Acid treatment, but not for the control treatment. Difference in mobility between the Bi and Bi+Acid treatment could be attributed to the lower pH in the former treatment for the majority of the years. These findings suggest that bismuth moves from the pellets and into the soil and is therefore not inert.

The soil samples were also analyzed for lead since Jayasinghe et al. (2004:19) found that lead, already in the environment and from lead pellets, can be a source of bismuth since the two metals coexist in ore deposits and are difficult to separate. Ignoring this relationship could be a cause for erroneous results. This relationship was again confirmed in the 1999 pre-treatment soils as there was a significant positive correlation ($r = 0.506$, $p = 0.027$) between the concentrations of bismuth and lead.

3.4.3. Vegetative interactions with bismuth and lead

The second objective was to assess the uptake of bismuth in vegetation. Although there were significant differences in bismuth-soil concentrations among treatments, bismuth uptake appears to be limited in the present study; there were no significant differences between stem densities, biomass, vegetation bismuth concentrations and ‘stock’ amounts (bismuth concentration multiplied by the biomass) between treatment sites. However, it is possible that the bismuth accumulated in the belowground biomass of the vegetation, which was not measured in this study. Such belowground accumulation is thought to be a protective mechanism of the plant to prevent potentially harmful metals from entering the other parts of their system (MacNicol and Beckett 1985). Brake et al. (2004) also did a study on the uptake of trace elements in plants, but were also unable to measure metal concentrations in the belowground biomass because the amended soils could not be completely separated from the root mass. In the current study, harvesting the belowground biomass would have been even more difficult because the roots were not confined in pots as they were in a natural setting.

In terms of comparison with other studies, the vegetation bismuth concentrations ranged from 0.018 – 0.046 µg/g. These are similar to background levels of bismuth in vegetation found in other studies. Jung et al. (2002:83) sampled several types of crop plants in and around a Korean copper and tungsten mine that included corn grain (*Zeamays*), jujube grain (*Zizyphus jujuba*), perilla leaves (*P. frutescens var. japonica*), red peppers (*Capsicum annuum*), soybean leaves (*Glycine max*) and spring Welsh onions (*Allium cepa*). The bismuth concentrations in the plants ranged from 0.01 to 0.42 µg/g, whereas they reported a normal level to be 0.06 µg/g (dw). Harada and Hatanaka (1998:449) sampled wild plants in sixteen uncontaminated sampling sites across Japan and found bismuth concentrations ranging from 0.02-0.038 µg/g. Therefore, there was no uptake in this current study if one assumes that the vegetation in above noted literature values were from pristine areas.

It was thought that there would have been a increase in vegetation bismuth concentrations in the Bi+Acid treatment because acidic conditions usually facilitates the mobility of trace elements (Reimann et al. 1996:148); however, in a study by Li and Thornton (1993:143) no significant correlation between bismuth concentration in vegetation and soil pH was reported. Jung et al. (2002:83) have found that it is a suite of variables that affect the uptake of bismuth, such as pH, organic matter, cation exchange capacity, and soil texture. Moreover, different species of plants have different responses to metals (Fairbrother and Kapustka 2000:16) and plant uptake is more dependent upon the soluble or available form rather than its total content in the soil (Berrow and Webber 1972:97).

There was also evidence of an interaction between vegetation lead and bismuth stock. As the amount of lead in the vegetation increased so did the bismuth. This finding further emphasizes the close relationship between lead and bismuth. Conversely, while there are similarities between the two metals, Berg et al. (1995:358) reported that the moss, *Hylocomium splendens*, has a bismuth uptake efficiency of only 31% whereas lead is the benchmark at 100%. This, however, may not be applicable to uptake efficiencies when bismuth is in the form of shot pellets because the origin of trace elements has a bearing on its bioavailability (Kabata-Pendias 2004:144).

3.5. Summary

This research contributed some important scientific knowledge about bismuth that was not previously known. Some research had been conducted on the acute and chronic toxicity of bismuth shot to game birds. However, there is no literature, to my knowledge, that addresses the CWS toxicity test guideline of determining the fate of bismuth after being introduced into the environment as shot. Thus, this study had two objectives. The first was to determine the mobility of bismuth when in bismuth shot pellet form and the second was to explore its interactions with vegetation.

Soil samples were obtained before the application of any treatments in 1999. At that time, the mean bismuth concentration was 0.13 µg/g, which is comparable to the world soil mean of 0.20 µg/g (Polemio et al. 1982:76). The treatments (n = 24) were then applied and soil and vegetation samples were analyzed for bismuth and lead in 2003. The mean bismuth concentration was 6.40 µg/g in the bismuth shot treatments, 2.55 µg/g for the bismuth shot and NH_4SO_4 treatment, 0.39 µg/g for the NH_4SO_4 treatment, and 0.42 µg/g for the control treatment. The mean bismuth concentration in the bismuth shot treatment was significantly greater than the NH_4SO_4 and control treatments. This meant that bismuth was moving from bismuth shot pellets into soil. These were in neutral pH soil conditions in all plots because the annual NH_4SO_4 amendments failed to acidify the soil plots to which it was applied.

The significant positive correlation in the 1999 soil samples between bismuth and lead concentrations (r = 0.506, p = 0.027) and an approaching significant positive correlation for these concentrations in the 2003 soil samples (r = 0.402, p = 0.051) highlighted the relationship between bismuth and lead. Jayasinghe et al. (2004:19) reported that lead pellets can be a source of bismuth since the two metals coexist in ore deposits and are difficult to separate. Erroneous results could occur if this relationship is ignored.

In addressing the second objective of vegetation and bismuth interactions, some literature is available, but focuses on bismuth from mining sites. In this study, bismuth was not detected in the aboveground biomass of the two types of vegetation sampled, specifically, lakebank sedge (*Carex lacustris*) and rough hair grass (*Agrostis scabra*). It was observed that the vegetation in the bismuth treatments had approximately twice the number of stems counts at around 2000 stems/m^2 than all other treatments. This was, however, not statistically significant. It was also observed that the highest concentrations of bismuth and lead in vegetation were found in the control plots. This finding was also not statistically significant, but unusual since the highest bismuth and lead concentrations were found in the bismuth, and bismuth and NH_4SO_4 treatments. Making conclusive statements about these findings is not possible as more information is needed about the bismuth concentrations in the belowground biomass. It is in the rooting structures were more bismuth may have accumulated since some plants sequester it at that point to prevent movement to its aboveground tissues. This is thought to be a protective mechanism (MacNicol and Beckett 1985).

Future research on belowground bismuth accumulation as well as bismuth interactions with soil microorganisms is warranted. Finally, regular amounts of soil acidifying agent should be applied in order to ensure that precipitation events do not cause the amendments to run-off. Acidifying the soil is of interest so that the relationship between low soil pH and bismuth can be observed for mobility in soil and vegetative uptake.

There has been evidence given in this chapter as well as the preceding one that may prompt policy makers to re-evaluate bismuth shot as a non-toxic alternative to lead shot. There are still many questions about bismuth's behaviour in the environment and waiting until all of the facts are available may result in large scale dispersion of bismuth, which may have undesirable side-effects. Furthermore, it is probable that all of the facts will never be known and a decision will be made instead upon reasonable assumptions based on generally accepted literature, public values relating to environment and human health, and recognition that the complex interactions of various elements in the environment require a precautionary approach. Such a mode of decision making is one of the key concepts at the heart of taking a post-normal perspective. The utility of this perspective will be discussed in the following chapter.

4. ADOPTING A POST-NORMAL PERSPECTIVE IN THE CANADIAN WILDLIFE SERVICE

4.1. Complexity and uncertainty

As shown in the previous chapter, bismuth can move from pellet form into soil. Therefore, bismuth concentrations in soils will increase as spent bismuth shotshells become more ubiquitous over time. These increases will occur because bismuth is favoured by hunters over other non-toxic shot alternatives because of its lead-like ballistic properties (Michie 1992:31, Boddington 1994:86, Carmichel 1997:74). This being the case, it is reasonable to assume that the amounts of bismuth dispersed will be similar to the 1700 tonnes of lead shot pellets (Environment Canada 2003a) that used to be emitted into the environment each year. Moreover, Feldmann (1999) estimated that a further 5000 tonnes of bismuth are introduced every year due to the use of pharmaceutical products.

As such, it becomes more urgent to understand its interactions with vegetation as well as the soil processes that make plant growth possible. Although this type of literature is scant, some maintain that contaminated vegetation could be an important exposure pathway to grazing livestock because they could be exposed to low-level amounts over the long term. This could result in symptoms that are difficult to trace to bismuth accumulation and therefore requires further study (Li and Thornton 1993:143).

This brings this thesis to an interesting point because the case study of bismuth is merely one out of many where scientific findings that warrant precaution are in conflict with the objectives of others. To go back to the idea of actor-systems dynamics in chapter one (Figure 1.1), it can be observed that the issue of bismuth can be buffeted between government, private sector, civil society, and actions on the ground level. It is now time to shift from bismuth and focus on how government can better manage issues like it within the context of other influential actors.

Thus far, this thesis has addressed two of the three questions that were set out in chapter one. It has been shown, in the case of bismuth shotshells that the use of science was limited when the Canadian Wildlife Service (CWS) approved it as a non-toxic alternative to lead. As for the second question, it has also been demonstrated that when science is not effectively utilized in the creation of environmental policy there are potentially preventable problems that can arise. The third and final question has been addressed in a preliminary manner in the previous two chapters by illustrating that even if the toxicity test guidelines were entirely followed, uncertainties would have remained. Therefore, science on its own is not adequate to deal with the uncertainty and complexity found in the domain of environmental policy making. The second part of this final question asks "what else is required". To answer this question the reader will be guided through:

a) Defining 'post-normal perspective';

b) Demonstrating why it is necessary to adopt a post-normal perspective in order to be able to cope with high risk and high uncertainty scenarios found in the realm of environmental policy;

c) How the Canadian Wildlife Service has acknowledged the need to change its approach; and lastly,

d) How their strategies to make this transition correspond with the literature on a post-normal perspective.

4.2. Necessity of a post-normal perspective

4.2.1. Normal science

Before defining 'post-normal perspective', a seemingly unrelated and multi-section detour is required by first defining 'normal science'. The term 'normal science' comes from Thomas Kuhn's famous book, the *Structure of Scientific Revolutions*. He defines it as cumulative research based upon theories and assumptions stemming from foundational paradigms (Kuhn 1970:10). Examples of well-known paradigms that serve as the bedrock for further studies would include the laws of gravity and thermodynamics. These laws were not always known, but when they were discovered, they changed the fundamental ways in which natural phenomena were explored in this thesisst. Kuhn (1970:96) characterizes normal science as puzzle-solving and credits its success to the selection of technical problems that can be solved with existing conceptual frameworks (e.g., analytical and reductionist modes of thinking as basis for knowledge generation) and instrumentation (e.g., technical problem-solving devices such as an atomic absorption spectrophotometer).

Through the use of existing conceptual frameworks and instrumental techniques, some of the effects and fate of bismuth shotshell pellets in a wetland were explored. It was a technical exercise as some parameters of concern were defined, such as mobility in soil and bioavailability for vegetation, and then bismuth was observed in relation to those criteria. Chapter 2 illustrated how new instrumental techniques, like the autometallographic technique, made it possible to find bismuth accumulations in certain parts of the human brain (Stoltenberg et al. 2001:706) and mature spermatids in rat testes (Stoltenberg et al. 2000:70). The researchers of the latter finding also found that the rats exposed to bismuth had significantly less serum testosterone than the control group (Stoltenberg et al. 2002b:112). Such a discovery opens up the possibility that bismuth may affect the reproductive health of certain animals. This is pertinent because both of these studies on rats (Stoltenberg et al. 2000:69, 2002b:112) supported the findings of the Sanderson et al. (1992, 1997a, 1997b) studies that the test animals gained weight, moved, ate, and drank normally. Locating the exact tissues for which bismuth has an affinity was a technique that was not utilized in the studies (Sanderson et al. 1992, 1997a, 1997b) that informed Canadian Wildlife Service policy makers. Even relatively analytical basics, used by those researchers, such as atomic absorption spectrophotometer techniques and assumptions about background levels of bismuth were strongly challenged in both chapters 2 and 3. This omission or misrepresentation of technical uncertainties is noted by Healy (1999:658) as being a failing of normal science. In the scientific report, this is reflected in the discussion and conclusion sections where ambiguous results are downplayed and certainties highlighted (Wynne 2001:7).

In this way, these studies are often debunking the ‘facts’ from other studies and *asking* more questions than providing answers. The case study of bismuth shotshells, used in this thesis, is just one incidence of normal science attempting to find ‘facts’ and instead increasing uncertainty. There is a growing realization that normal science is no longer a reliable base for the creation of environmental policy and its subsequent implementation (Ravetz 2002:255). If our main method of knowledge generation is not enabling us to make informed policy then perhaps we are facing a crisis.

On the other hand, some would counter that this spirit of inquiry has always been the lifeblood of science and that if there is any crisis occurring, it is the ongoing one of inadequate funding and inappropriate methodologies. Science purports to be an inherently logical and rational exercise and was famously put to print as such when Rene Descartes (1952) published his *Discourse on the Method of Rightly Conducting the Reason and Seeking Truth in the Field of Science*[1] in 1637 . While it may be true that science and its inhibitors have not changed, its surroundings or to what its findings are applied, have undergone extensive transformations. If its utility as a knowledge system for informing environmental policy making is to be safeguarded, it must evolve. Now that normal science has been defined, 'normal policy' will be defined in the next section.

4.2.2. 'Normal' policy

Policy making is shaped by the diverse values and assumption brought to the decision-making table and political reasoning is an exercise in metaphor-making where stories are told in a strategic way as to be able to persuade for the benefit of certain policies (Stone 2002:9). Science is often used to help legitimize and thus tell these stories (Walker 2001:286). Therefore, whether or not it is 'junk science' or 'sound science', once it enters the policy arena it can be manipulated to serve the social construction of the day (Walker 2001:280-1).

Stone (2002:8) contends that much of the literature on public policy comes from a belief that it goes wrong when it becomes mixed with politics and thus moves away from the hypothetical model of what is deemed to be good public policy making. She maintains that politics is in fact socially vital and our current model of public policy does not include how political reasoning operates. Such a model ought to account for the simultaneous pursuit of multiple, changing, and sometimes contradictory objectives that can, at times, be won by appearing to lose and attained by seeming to have already acquired them.

---

[1] "The first rule was never to accept anything as true unless I recognized it to be certainly and evidently as such: that is, carefully avoid all precipitation and prejudgment, and to include nothing in my conclusions unless it presented itself so clearly and distinctly to my mind that there was no reason or occasion to doubt it.

The second was to divide each of the difficulties which I encountered into as many parts as possible, and as might be required for an easier solution.

The third was to think in an orderly fashion when concerned with the search for truth, beginning with the things which were simplest and easiest to understand, and gradually and by degrees reaching toward more complex knowledge, even treating, as though ordered, materials which were not necessarily so.

The last was, both in the process of searching and in reviewing when in difficulty, always to make enumerations so complete, and reviews so general, that I would be certain that nothing was omitted.

Those long chains of reasoning, so simple and easy, which enabled the geometricians to each the most difficult demonstrations, had made me wonder whether all things knowable to men might not fall into a similar logical sequence" (Descartes 1952:15)

According to Stone (2002:9), the current concept of rational public policy can be conceptualized in at least three different ways, 1) Reasoning, 2) Society, and 3) Policy making. The model of reasoning is equivalent to rational decision making that is a series of sequential steps with which we are all familiar[2], but it does not explain the reality of political situations. The second model of society is based on the market concept where people are thought to be individuals who engage with each other, in a rational way, solely for the purpose of maximizing their own levels of satisfaction often referred to as the public choice model. The third model of policy making is a series of steps that include the following:

1) Defining an issue and putting it on the agenda;

2) Introducing it to the legislative and executive branches of government;

3) Proposing solutions to the defined problem and then having them analyzed, legitimized, selected, and refined;

4) Implementing the chosen solution by the executive agencies and this is constantly challenged and thereby potentially revised by stakeholders;

5) Finally, evaluation and revision of the chosen solution can occur if the policy making process is managerially sophisticated.

These three models fail to show policy making for what it really is; that is, a struggle for introducing, defining, and framing ideals that will guide people in their behaviours (Stone 2002:11). Today, a prime example of such an ideal would be sustainability. Many have been convinced that working towards this ideal is what ought to be done, but defining it and knowing how far to go with it is an ongoing ideological battle. From defining ‘normal policy’, the discussion moves to explaining what is meant by ‘post-normal policy’.

4.2.3. ‘Post-normal policy’

Environmental policy is not readily compared to other types of public policy and as such is not considered typical or ‘normal’. This breed of policy differs from others in that when dealing with the concept of sustainability, much greater amounts of information must be synthesized and analyzed. Working towards sustainability requires *simultaneous* attention to more facets of society *and* more details within each of those facets (Giampietro

[2] “1) Identify objectives; 2) Identify alternative courses of action for achieving objectives; 3) Predict the possible consequences of each alternative; 4) Evaluate the possible consequences of each alternative; 5) Select the alternative that maximizes the attainment of objectives” (Stone 2002:8).

1999:219). Moreover, indicators must then be assigned and models developed to understand the relations between all of these facets that are detailed in Table 4.1.

In addition to the expanded scope of the issues within environmental policy, there is also the need to:

i) Choose which issues to observe;

ii) Choose the salient features of the chosen issues;

iii) Determine the degree of human control over the chosen issues;

iv) Determine the level of uncertainty that the policy domain can cope with; and

v) Determine how to represent and define relevant contingencies

From his list above, Wynne (2001:12) contends that these types of decisions must be made explicit and deliberated upon democratically.

Environmental policy is further muddled by the uncertainties that reside in all of the observed issues. The term ‘uncertainty’ has been broken down into seven, but not mutually exclusive, components in Table 4.2. From here follows a definition of post-normal science.

Table 4.1: Information to be considered when engaging in the creation of environmental policy. Modified from Giampietro (1999:219).

Facet	Description
Expanded view of the welfare of the present generation	Perspectives of men, women, majorities and minorities within distinct social and ethnic groups plus the influence of geographic location on all of these perspectives
Welfare of future generations	Probably more variety and richer diversity of the types of perspectives mentioned above plus not knowing their desires and available resources and technologies
Environmental security	Sustenance of ecosystems so that they can function, provide humans and wildlife with resources, and also serve spiritual needs
Role of technology	Technology that is appropriate for the problem, and culture of the users as well as an awareness of positive and negative impacts linked with its use
Role of social institutions, cultural identities, and the diversity of systems of knowledge	Centralized versus decentralized government; Identity with nation, heritage, geographic region; Local and traditional knowledge systems

Table 4.2: Seven components of 'uncertainty' (Wynne 2001:5-6)

Component	Description
Risk	Known damage and probabilities
Uncertainty	Known damage possibilities but no knowledge of probabilities
Ignorance	Unknown unknowns
Indeterminacy	Issue and conditions, hence knowledge-framing open; maybe salient behavioural processes also non-determinate
Complexity	Open behavioural systems, and multiple, often non-linear processes so that extrapolation from robust data-points always problematic
Disagreement	Divergence over framing, observation methods or interpretation and competence of parties questioned
Ambiguity	Precise meanings (hence salient elements) not agreed, or unclear

4.2.4. Post-normal science

There have been attempts to address the abovementioned components of uncertainty (Table 4.2) by normal or reductionist science. This has been done by using several varieties of mathematical methodologies such as game theory, non-linear thermodynamics, catastrophe theory, and systems analysis. This appreciation for complex systems has been seen as a move towards uniting the fragmented disciplines of scientific knowledge (Funtowicz and Ravetz 1994:577). This new practice of science in emergent complex systems is also known as post-normal science.

By definition, post-normal science is an extension of traditional problem-solving strategies that is necessary when the issues being dealt with typically have uncertain facts; values, such as the merits and definition of sustainability, are in dispute; the stakes are high; and decisions need to be made urgently (Ravetz 1999:649). Employing post-normal science begins with the understanding that when it comes to environmental policy making, there are few ‘hard’ scientific facts. Instead, high-stake decisions must be made with ‘soft’ value-judgements and ‘soft’ scientific evidence and with this comes a new role for science (Ravetz 1999:649). Post-normal science begins with the idea of making the process of decision making more explicit and acknowledging, instead of ignoring, the existence of uncertainty and complexity (Funtowicz and Ravetz 1993:740). This new approach would increase the effectiveness of science and give itself an opportunity to recreate its ability to inform and influence decision makers and the public.

For instance, since normal science studies can be accused of failing to rigorously take into account broader contextual considerations (Healy 1999:658). This could be addressed by scientists who could instead create narratives, which would be descriptions of how the future may unfold when various policies are followed (Kay et al. 1999:728). These would be more useful to policy makers because they would then be able to understand the conditions under which certain scientific findings are applicable. It would not be expected that scientists could envision all possible scenarios. However, such a technique would help to make the exact context of their study clear and illuminate various situations in which their findings would hold little value in terms of predictability. Nevertheless, the use of scientific findings to legitimize policy cannot be controlled by scientists (Luks 1999:717, Walker 2001:285). Therefore, both scientists and policy makers must recognize the validity of a post-normal perspective. By taking such a perspective, neither of these areas of expertise becomes less rational, but decisions are no longer legitimate simply because they are rational from one organization's perspective. A post-normal stance on rationality may look something more like the following:

> A rational judgement is one which reflects the following: it is open to criticism; the person holding the view is prepared to listen to criticism, and revise their opinions in the light of better or more powerful explanations and understandings of the matters at hand, and that a person bases their beliefs wherever possible on the available information and forms of knowledge. Being rational in our judgements means no more and no less than recognizing our fallibility and the need to find grounds for the beliefs that we hold (Wilkin 2001:60)

It can be said that those using the abovementioned extended strategies are taking a post-normal perspective. The co-originator of the term post-normal science began referring to it as a perspective to facilitate discussion on issues that are not normal, but require many of the solutions that post-normal science has to offer (Ravetz 2002). However, both originators of the term post-normal science made an important disclaimer about it.

> It is important to appreciate that post-normal science is complementary to applied science and professional consultancy. It is not a replacement for traditional forms of science, nor does it contest the claims to reliable knowledge or certified expertise that are made on behalf of science in its legitimate contexts. The technical expertise of qualified scientists and professionals in accepted spheres of work is not being contested; what can be questioned is the quality of that work in these new contexts, especially in respect of its environmental,

societal and ethical aspects. (Funtowicz and Ravetz 1993:753)

With the terms of ‘normal’ and ‘post-normal’ defined, the following section examines how a post-normal perspective can be utilized.

4.3. Employing a post-normal perspective

4.3.1. Means versus ends

Up until now, this chapter has made a case for a post-normal perspective to be employed as a means for achieving sustainability-informed environmental policy. This can be initiated by adapting some sort of framework that will encompass what we wish to achieve. For this, clarity about the ‘end goal’ is vital.

Adopting a post-normal perspective is a means to an end and that end is typically identified as sustainability, but this is also not an end goal. There will never be one day when it can be declared that sustainability has been achieved because it continually evolves to be become more and more sustainable. Therefore the ‘end’ for the CWS could be defined as its mission statement, which is to “Conserve wildlife and the ecosystems of which they are a part, with a particular focus on migratory birds and species at risk” (Canadian Wildlife Service 2000:12). The value of the sustainability concept is that it can be used as a guide on the path to attaining an organization’s mission statement.

It now remains to be seen how situations can be viewed from a post-normal perspective. The following four subsections will be devoted to first starting broadly by outlining a general framework for sustainability since before starting the journey a reliable guide must be chosen. Second, the discussion becomes slightly more restricted by briefly exploring the melding of a post-normal perspective with governance (e.g., post-normal governance). Third, the focus becomes narrower still by examining actual post-normal practices in theory, and fifth, examples of them in practice. Finally, in the subsequent section (§4.4) the discussion will become as concrete as possible by moving onto the published CWS Strategic Plan.

4.3.2. Reconciliation framework

Dale (2001:121) has compiled what she terms as a 'reconciliation framework' that is a guide towards sustainability, which is inherently a post-normal perspective. This framework has been modified for this thesis and is composed of six characteristics and nine decision making principles (Table 4.3). These are then later compared to the CWS Strategic Plan.

4.3.3. Post-normal governance

Pellizzoni's (2004:543) review of governance literature reported that it is an alternative to traditional governing as it is an attempt to ensure scientific accuracy, policy effectiveness and political legitimacy. Governance is seen to be a new form of governing society by having interaction, partnership and co-operation with public and private actors and encouraging self-regulation. Market forces then assume the responsibility for various goods and services that were previously state-run endeavours. There is also a sharing in the commitment of resource allocation and conflict resolution.

Table 4.3: Reconciliation framework for sustainability. Adopted from Dale (2001:123-129).

Characteristics
Be easily understood
Be applicable in diverse contexts
Be transferable across space and time scales
Deal with individual concepts and ideas in concrete terms
Identify possibilities for both radical and transformative change and positive incremental change
Be regularly revisited, critically evaluated, and updated whenever appropriate

Decision-making principles	**Description**
Diversity	Important for maintenance and regeneration of the system (be it socio-economic, political, or ecological)
Enlarged decision-making contexts	Consultation of stakeholders and inclusion of their perspectives
Multiple perspectives and paradigms	Embrace different methods for obtaining information (i.e., not being completely reliant upon traditional science) and make paradigms more explicit so as to be able to discern whether or not old habits or beliefs are no longer useful and thus are obstacles to recognizing new ways of doing things
Information	The weighting of ecological information should be similar to that of social and economic information
Feedback loops	Necessary to be able to respond to negative or positive feedback that results from the implementation of a given policy
Precautionary principle	Being humble that we do not understand everything and accepting uncertainty. Therefore when a given activity is suspect there should be action to prevent damage
Resilience	The ability of the system to respond to change and how it may be altered by it
Scale	There should be a relative match between the scale of the natural phenomenon and the corresponding human intervention
Values	Traditional science is often portrayed as not being driven by values, but given that sustainability is being adopted, which is a normative concept, all other values should also be made explicit so that they can be examined. Some of the unearthed values may prove to no longer be suitable for dealing with today's challenges, however if they were not made explicit then they could continue, unnoticed, to influence decision making. Such transparency would ease communications between the stakeholders and decision makers since they would all have a better understanding of where each group is coming from

In this attempt to address the problems of legitimacy, effectiveness, and efficiency of traditional policy making, a paradox is struck upon. While Dale's (2001) type of reconciliation framework (see Table 4.3) is becoming more popular, which is evidenced, in part, by being adopted by governmental agencies such as the CWS (see §4.4), it is counter pointed by this trend of government becoming more streamlined and efficient. This is resulting in public participation becoming less of a priority (McCarthy 2003:79). This trend is quite powerful because the External Advisory Committee on Smart Regulation (2004:9) recently submitted a report to the Government of Canada entitled Smart Regulation: A regulatory strategy for Canada. This strategy has identified the need for the regulatory system to become more effective, responsible, cost-efficient, transparent, and accountable to Canadians. Moreover, upon receiving the report, the Prime Minister endorsed the work. He stated that, "Our objective is to modernize regulation to enhance conditions for an innovative economy while finding improved ways to meet high standards of social and environmental protection." He continued by stating that the work of the Committee will inform that effort (Office of the Prime Minister 2004).

Thus it can be seen that there is a tension between Dale's reconciliation framework, of which much has been adopted by the CWS, at least in language, and the push to become more efficient and streamlined. In fact, the External Advisory Committee on Smart Regulation (2003) has stated that "Environment Canada (which is responsible for the Canadian Wildlife Service program) is already on the path to Smart Regulation and with continued vigilance, will stay the course."

McCarthy (2003:79) has identified this push towards greater governmental efficiency as a form of market-based governance moulded from the managerial or corporate model. If this style of top-down management is embraced then we will be moving away from many of concepts that Dale (2001) has put forth and in so doing, shift away from working towards sustainability. McCarthy sees post-normal governance as a counter-proposal to the latterly described mode of management. Such a form of governance could be envisioned as "an interactive and adaptive process of education and decision making emphasizing the rights and responsibilities associated with citizenship" (McCarthy 2003: 84).

McCarthy (2003:85) admits that this is an abstract description, but this does not mean it is an unrealistic goal. On the contrary, the concept of becoming more sustainable has become engrained in many Canadian governmental departments and so is becoming less and less of a fringe concept. This means that the vision of sustainability is here and now there is a search for ways to make it more tangible. Adopting a post-normal perspective is one of the ways to achieve this goal and its *modus operandi* in theory and practice follows.

4.3.4. Post-normal perspective in theory and practice

As mentioned before, sustainability is merely a guide and so only the traveller taking the journey knows the destination. The guide is there to help the traveller avoid common pitfalls and the like. What has yet been elucidated in this chapter is the equipment for the journey and examples of it in use. The main pieces of equipment in the post-normal perspective toolbox are:

1) Extended peer communities
2) Acknowledgement and demonstration of uncertainty
3) Explicitness of values

An extended peer community is made up not only of governmental and private sector stakeholders, but also of those who wish to help resolve the issue through their own participation (Ravetz 1999:651). This improves the quality of the science being carried out because “what happens ‘out there,’ where manufacturers’ instructions are misunderstood or disobeyed, and where government regulations are evaded or flouted, is essential for understanding what the policy problem is really about and what sort of science will contribute to its resolution.” (Ravetz 2002:260)

A fine example of extended peer communities in action is that of community-based monitoring programs in the form of Environment Canada’s Ecological Monitoring and Assessment Network. “Community-based monitoring is defined as a process where concerned citizens, government agencies, industry, academia, community groups and local institutions collaborate to monitor, track and respond to issues of common community concern. Emphasis is placed on monitoring designed to promote sustainability, leadership of monitoring by the community rather than individual organizations and use of monitoring data to inform decision-making” (Whitelaw et al. 2003:410).

It is important to be as clear as possible about the uncertainties for any given issue. Wynne (2001:5-6) broke uncertainty down into seven components that was shown in Table

4.2. Being mindful of the different types of uncertainty when writing or evaluating a report that is being used to inform a policy would be useful. The acknowledgement and demonstration of uncertainty was further formalized by the NUSAP notation, which augments the quality of information. This in turn reduces the possibility of misunderstanding when formulating environmental policy. Going into the details of the NUSAP scheme in this thesis will only go so far as to note what each letter represents: N-Number, U-Unit, S-Spread, A-Assessment, and P-Pedigree (Funtowicz and Ravetz 1990). As an example of this kind of scheme in action, the Intergovernmental Panel on Climate Change (IPCC) has been acknowledging and demonstrating uncertainty in the form of its Working Group I, which assesses the science behind climate change. In their Second Assessment Report, along with the data, they also compactly provided technical, methodological, epistemological and ethical uncertainties. The rationale behind this is that as misunderstanding of climate science are reduced, so will the likelihood of serious errors in policy making (Saloranta 2001: 402).

One of the criteria for using a post-normal perspective is when values are in dispute. An example of this could be controversy over land that is important as a habitat and for groundwater recharge. Farmers on part of the land may want to sell to developers as part of their retirement plans. Community members may want to conserve it for ethical, functional, and spiritual reasons. Developers may place great value on it so that they can tap into lucrative housing markets. Obviously, these are conflicting values and uncertainty for policy makers would be reduced if all of the values are made explicit.

Another example would be to question the fundamental motivations behind why certain things are done as they are. For instance, from a medical view, the purpose of medicine is to save every life for as long as possible (Waltner-Toews 2000:658). From this stance, medicine focuses its energy and resources on making healthy individuals, which may be at the cost of the health of the community. Such a scenario can be seen in the case of malaria in so-called developing nations. Effective resolution of this problem does not come by the targeting of high risk individuals with medical intervention. Instead, a post-normal perspective of the different factors at play, such as the need to transform current labour and land use practices in the overall community, will lead to a sustainable reduction in cases of malaria (Waltner-Toews 2000:656). With the basics of a post-normal approach sketched out, this discussion will now move onto the CWS' progress with it.

4.4. Canadian Wildlife Service's Strategic Plan 2000

4.4.1. Desire to adopt a post-normal perspective

The CWS has identified a number of challenges to conservation in the foreseeable future. Some of which include climate change, "cumulative impact" (referring to the combined effects of exotic species, genetically modified organisms, and disease) and "habitat quantity and ecosystem quality" (referring to urbanization, agricultural intensification, forest harvesting, and other types of resource extraction plus the long term effects of acid precipitation, pesticides, and toxic chemicals) (Canadian Wildlife Service 2000:4-5). So that they may meet these challenges the CWS has outlined its four "guiding principles" in its Strategic Plan 2000. These 'principles' are "building on sound science", "collaborative conservation of biological diversity", the "utilization of the ecosystem approach" and "communication for wildlife" (Canadian Wildlife Service 2000:10-11).

This thesis asserts that all four of these 'principles' are part of a post-normal perspective and the CWS is positioning itself for experiencing difficulties because it is viewing this paradigm shift as something that can be *added* to their organization. This approach can be seen in the introduction to their 'principles' when they state that "[t]he activities of the Canadian Wildlife Service will be *influenced by* four overarching principles that *build on the culture of the organization* and epitomize its effectiveness. By *reflecting these principles* in all our programs, we will maintain and even strengthen our broad influence and leadership" (emphasises added) (Canadian Wildlife Service 2000:10). It is the contention of this thesis that transitioning to a post-normal perspective is change on the most fundamental of levels and so it cannot be treated as an extension to a house (e.g., the CWS organization) rather than the foundation on which the house is built.

Whether or not a post-normal perspective is viewed as an 'add-on' or as a culture in itself, the difficulties experienced by the CWS will not be limited to the clash of incompatible cultures that will inevitably occur. Conversely, they have saved themselves some trouble by defining the ecosystem approach as "a strategy for the *integrated* management of land, water, air, and living resources that promotes conservation and sustainable use in an equitable way, considers birds and all wildlife as components of ecosystems rather than as single species" (emphasis added) (Canadian Wildlife Service 2000:11). By using the word 'integrated' instead of 'comprehensive' they have shifted their work load from the initial stages of trying to understand all of the components and linkages of a system to an ongoing process where they concentrate on the components and linkages that are deemed to be the most important (Mitchell 2002:103).

This latterly described integrated method is a process because it must be constantly re-evaluated in order to determine if the right components and linkages have been chosen. This is where Dale's (2001:129) notion of being cognizant of feedback loops is important. It is quite possible that a lot of work could have been dedicated to underscoring certain parts of a system as being more important than others; then an analysis, after the policy was implemented, reveals that previously unseen parts are in fact more significant.

Beyond the challenges posed by the integrated method there are also many other factors that should be given consideration. Mitchell (2002:105-107) has devised a list of fourteen, which will not be elaborated upon in this thesis and are included merely to give the reader an appreciation for the expansiveness of a post-normal perspective. Some of these factors have already been touched upon in this chapter, but the full list includes the following:

1) Significance of context;
2) Long-term perspective;
3) Vision;
4) Legitimacy;
5) Leader or champion;
6) Redistribution of power;
7) Collaborative approach;
8) Consensus;
9) Sensitivity to burnout;
10) Turbulence and surprise;
11) Communication;
12) Demonstration projects;
13) Information and education;
14) Implementation and monitoring.

Mitchell's (2002:107) message is that seeing the world with a post-normal perspective is not a technical exercise and success depends on how well the 'human dimension' is acknowledged. The implementation phase will now be explored.

4.4.2. Implementing a post-normal perspective

The 'human dimension' is an important factor in all organizations and they all follow certain patterns of high and waning intensity for particular issues. Downs' issue-attention cycle categorizes this pattern as follows (Downs in Connelly and Smith 2003:131):

1) The pre-problem stage;

2) Alarmed discovery and euphoric enthusiasm;

3) Realizing the cost of significant progress;

4) Gradual decline of intense public interest;

5) The post-problem stage.

There is at least one advantage and one disadvantage to the occurrence of this cycle. The positive impact is that when the cycle revolves again there exists some sort of institutional base that grew out of the previous round and so more effective policy can be developed. The negative impact is that fluctuations in public opinion that change policy directions can make policy makers less committed to solving a particular problem and so they can devise solely symbolic responses that may serve to mollify the public (Connelly and Smith 2003:132).

It is beyond the scope of this thesis to analyze exactly where, on the issue-attention cycle, the CWS is currently located. It is difficult to know if the subsequent strategies were conceived from a state of "euphoric enthusiasm" or "realizing the cost of significant progress" because they are quite vague. They have outlined five strategies in their Strategic Plan 2000 (2000:18-22) and they are as follows:

Strategy 1 – Renew commitment to wildlife conservation priorities

Together with our partners, evaluate national and regional conservation needs for migratory birds, species at risk, habitat conservation, and supporting programs and determine the roles of CWS in meeting these priorities.

Strategy 2 – Enable an adaptive Canadian Wildlife Service institutional capacity

This strategy will lead to: support for CWS involvement in other federal wildlife concerns, including wildlife health and toxicology, transboundary wildlife issues, and international wildlife agreements, a renewed ability to communicate our scientific findings, management and enforcement activities, and conservation messages effectively within the department, among our partnerships, and to Canadians.

Strategy 3 – Strengthen Canadian Wildlife Service science capacity

Rejuvenate our scientific expertise and capacity to focus renewed resources on essential wildlife research and monitoring needed to address conservation priorities. This strategy will lead to a consensus among staff on how to strengthen, broaden, and apply our scientific expertise, with the increased capacity to do so, enunciated through the departmental science agenda.

Strategy 4 – Apply diversified policy and regulatory approaches

Diversify the mix of legislative, regulatory, and policy tools and use and enforce them to direct and influence activities of those whose activities affect Canada's wildlife.

Strategy 5 – Use partnerships

Strengthen existing partnerships and invest in new ones with non-traditional partners and land managers, using the joint-venture approach to implement common priorities.

Since sustainability is a broad guide for working from a post-normal perspective, the next section will be the point where Dale's (2001) reconciliation framework is compared with the CWS strategies to make the discussion more concrete.

4.4.3. Analyzing the CWS strategies

In post-normal language, strategy 1 can be reduced to what Mitchell (2002:104) would identify as an integrated approach where the most important components and linkages in the ecosystem are being determined. However, there is no elaboration as to how this importance will be evaluated. It is conceivable that the need for extended peer communities, (Ravetz 1999:651) where scientific findings receive a weighting[3] that is similar to information provided by non-scientist sources, will conflict with strategy 3 of strengthening the science capacity of the CWS. This will likely be a point of conflict if this 'strengthening' is simply an increase in the prevalence of traditional normal science attitudes.

Strategy 2 is to become an adaptive institution, which means that it will be responsive to feedback loops and changing values[4]. Additionally, there must be a willingness to engage in trial-and-error methods and in order to implement these three minimum conditions must be met:

1) The experiment cannot destroy the experimenter so that someone can learn from

[3] See Dale's (2001:124-7) principles for decision making of 'enlarged decision-making contexts', 'information', and 'multiple perspectives'.
[4] See Dale's (2001:123-9) principles for decision making of 'cyclical processes', 'dynamic, self-organizing, open, holartic systems (SOHOs)', 'equity', 'feedback loops', and 'values'.

> the experience; 2) The experiment should not create irreversible changes to the natural environment; and 3) The experimenter must be willing to start over after having learned from failures (Holling 1978:7).

In essence, the CWS must become comfortable with failure, but demonstrate that it is capable of carrying out its mandated tasks.

Strategy 3 of strengthening the CWS' science capacity can be assumed to have the aim of continuing down the traditional path of science where 'hard' facts are used to legitimize policy objectives. The unfolding of this strategy is obscure since it depends on their so-called "departmental science agenda", which in itself is not clear. Adopting a post-normal perspective would mean that this strategy would be reconfigured to be "A transformation of CWS science capacity". This would entail a transition from the traditional scientific paradigm where normal science makes good policy (since it has been demonstrated in the bismuth shotshell case study that this is a false notion) to a post-normal science where uncertainty is accounted and managed. Examples of these new ways, in theory and practice, have been discussed in section 4.3.4.

In strategy 4 it is unclear if the CWS is referring to working towards 'Smart Regulation' or favouring certain policy instruments over others. Generally, there are three such instruments available which include: command-and-control- i.e., mandatory regulation that enforces certain behaviour; economic incentives; or the promotion of voluntary action (Connelly and Smith 2003:149). Using the word 'diversify' in the strategy description fits in with post-normal language, but it is unclear as to how many and which tools they have at their disposal.

The fifth and final strategy is to use partnerships, which is the most post-normal practice of all of the strategies since it is agreed upon by many[5] that this is one of the ways to works towards sustainability. It remains to be seen how the CWS will carry out this strategy as to be meaningful for those new 'partners'.

[5] See Dale's (2001:123-9) principles for decision making of 'diversity', 'enlarged decision-making contexts', 'information', 'multiple contexts and perspectives', and 'mutuality'. See also the elements of Mitchell's (2002:106) 'human dimension' of the ecosystem approach- specifically 'redistribution of power', 'collaborative approach', and 'consensus'.

4.5. Summary

Operationalizing a post-normal perspective will indeed be a difficult task, further exacerbated for Environment Canada by the fact that environmental concerns are typically only considered after economic and social issues have been addressed (Connelly and Smith 2003:132). Furthermore, many issues often exist in solitude from one another because they are the responsibility of different governmental departments, making it difficult to see and manage the interconnectedness of environmental problems.

It is, however, encouraging to observe that the CWS has acknowledged the inherent uncertainty and complexity within the natural environment. Despite there being many gaps and ambiguities in their strategies for coping with this newfound acceptance, there is at least a certain willingness to adopt a more post-normal way of dealing with issues of policy and hopefully also with science in the near future. Beyond the CWS there are also others, mentioned earlier, successfully implementing a post-normal perspective such as community-based monitoring, the Intergovernmental Panel on Climate Change, and questioning the values behind medicine and health.

5. CONCLUSION

This final chapter summarizes the findings from this case study, which came from the bismuth literature review, four-year wetland study, and the rationale for adopting a post-normal perspective at the Canadian Wildlife Service. Section 5.1 discusses how the original research questions were addressed. In this section it can be seen that science is not sufficiently used by decision makers because the quantity and quality of the information used was lacking. Conversely, it is improbable that sufficient amounts of information will ever be available to cope with the complex and uncertain world that we live in. Therefore, a 'post-normal' approach was deemed necessary in order to achieve a balance between making science- and value-informed decisions. Section 5.2 highlights the contributions of this research and recommendations for further research are noted in section 5.3.

5.1. Research questions revisited

The case study of bismuth shotshells was used to explore broader questions about the use of science in environmental policy making. Three questions, provided in chapter 1.5, provided the focus for this thesis and are now revisited.

First, it was asked, "*Are policy decisions made on the basis of science? This is important to ask because science is the system of knowledge that informs policy makers.*" The case of bismuth shotshells approved by the Canadian Wildlife Service (a program of Environment Canada) as a non-toxic alternative to lead shotshells was selected because it provides an example where only science can supply the answers for policy issues; in this case, it considered if bismuth was toxic or not. Science can inform about the interactions of bismuth with soil, vegetation, animals, and humans. The uncertainties discovered during the process of generating evidence are also informative. Those gaps in knowledge can direct future research as well as point to areas that will remain uncertain for some time and thus require precaution by policy makers.

The literature concerning bismuth was divided into what was known about its environmental effects up to and including 1997 and from 1998 onwards to provide a retroactive view of the information available to policy makers before and after approval. The Canadian Wildlife Service developed a set of toxicity test guidelines that asked important questions about bismuth's toxicity to game birds, as well as to wildlife and humans that may come in contact with it indirectly. Information about the behaviour of spent bismuth shot in the environment was also required. Studies by Sanderson et al. (1997a, 1997b) served as the pivotal research that the Canadian Wildlife Service used to define bismuth shot as non-toxic. The information contained within these studies focused mainly upon the acute and chronic toxicity of bismuth shot to game-farm mallards. The criteria, chosen to measure toxicity, ignored the medical literature on bismuth that mostly classified it as a neurotoxin. Instead, research was modelled on characteristics of lead toxicity by monitoring facets of the game-farm mallard such as blood, kidneys, liver, weight, and egg hatchability. No research was conducted on the neurological aspects of the birds. This lack of research was an oversight because there were thousands of human cases of bismuth-induced encephalopathy in France and Australia in the 1970s and its aetiology is still unknown. Prior to approval, it was known that certain humans are more susceptible than others to bismuth-induced encephalopathy. It was also understood that a host of factors enhance the toxicity of bismuth; factors commonly taking place in conjunction with exposure to bismuth. A critical gap existed in the knowledge of chronic toxicity for game-farm mallards by the pivotal studies avoiding neurotoxic testing.

In addition to the aforementioned data gap, no studies up to and including 1997 had been conducted on effects of bismuth shot on soil, vegetation, or other animals and humans exposed to it. Despite this lack of information and the questionable studies that examined only one facet of bismuth, policy makers decided to approve bismuth shot as being non-toxic. From the perspective of science, not enough was known about bismuth shot before being accepted and promoted as non-toxic. Therefore, it can be concluded that science was not effectively used as a basis for making policy decisions, which leads to the next question.

Second, *"Is it problematic if environmental policy is not made on the basis of science?"* The scientific uncertainty surrounding bismuth solely for medical purposes should have been enough to make researchers and in turn policy makers wary. It may have been possible that bismuth in the form of shot is benign. Nevertheless, the reality is that the scientific work had not been done. This meant that most of the toxicity test guidelines had been overlooked and bismuth's history of inducing encephalopathies had not caused any red flags to go up.

Fortunately, after approval, red flags did go up for a handful of researchers. This led to the initiation of several studies to be conducted on the neurotoxic effects of bismuth shot on animals. It was revealed that bismuth has an affinity for brain tissues as well as nearly mature spermatids, which resulted in decreased serum testosterone levels. This situation is of concern because bismuth could possibly cause some negative impacts upon neurological and reproductive health for animals that received internal exposure to bismuth shot.

Other studies did begin to address the data gap on bismuth behaviour in the environment. Research in this area revealed that background concentrations of bismuth in game birds are largely unknown. It was also found that lead shot is a source of bismuth, which makes it difficult to gauge true background levels of bismuth. A recent study found that bismuth is taken up by trees that have been exposed to bismuth shot via the soil in which they grow (Karagatzides et al. unpublished). In addition, results presented in this thesis (chapter 3) provided evidence of bismuth moving into the soil, on which it is placed, when it is in shot pellet form. Vegetation samples in the bismuth-contaminated soils did not have more bismuth in their tissues than background levels. However, it is possible that the bismuth had accumulated in the belowground biomass of the vegetation. This was not measured in this study, but such uptake is possible since other studies have shown elevated levels of bismuth in vegetation growing in bismuth-contaminated soils. Some researchers have concluded that more work needs to be done in this area as there may be chronic effects for animals that may be difficult to monitor because of their long-term and low-level exposure to vegetation contaminated with metals like bismuth.

After approval of bismuth shot for the purposes of game hunting some of the items in the toxicity test guidelines were re-examined. Closer scrutiny resulted in more focused studies that revealed danger to the long-term health of animals that come into contact with bismuth shot (see chapter 2.4). Some of these studies argued that the pivotal studies, used by the CWS in its approval process, were flawed in their assumptions (e.g., overlooking bismuth's history of causing neurological problems and restricting their studies to mallards only). This discovery demonstrates that it is a problem when science is not used as a basis for environmental policy making because the awareness of certain aspects of new products can only be had after systematic study. However, environmental policy makers must make decisions when staying with the status quo is no longer an option.

Environmental policy is quite different from other types of public policy because the decisions made within it should have regard for sustainability as is commonly advocated by government. Briefly defined, the concept of sustainability requires there to be a focus upon the needs of both present and future generations and to plan and manage with consideration given to social, environmental, and economic perspectives. This includes creating policies, laws, regulations, and institutions that will be able to address the interconnectedness and complexity of the world; blending technical and local knowledge systems. Moreover, it is necessary to recognize and change the values, attitudes and beliefs that are no longer perceived to serve our needs in a complex environment. Therefore, working towards all of this requires attention to massive amounts of information that contains many uncertainties and complexities that somehow must be managed. From here follows the last question.

Third, "*Is science adequate to deal with the uncertainty and complexity found in the domain of environmental policy making? If not, what else is required?*" After approval of the use of bismuth in shot, studies on bismuth confirmed some of the concerns of previous researchers and resulted in more uncertainties. With all of this combined information (see chapter 2), it is still difficult to conclusively state if bismuth poses a heath risk in the form of shot. However, decisions must be made and our primary method of knowledge generation, namely science, provides answers that often omit or misrepresent technical uncertainties, are made untrue by later studies, or ignore broader contextual considerations. This is a problem because ill-informed policy can negatively impact our environment and health. Thus, since science is inadequate to deal with the uncertainty and complexity found in the domain of environmental policy making, a new perspective is required.

This new way of dealing with the interaction between environmental policy and science has become known as post-normal science. Post-normal science is an extension of traditional problem-solving strategies that becomes necessary when the facts about the issues are uncertain; values are disputed; stakes are high; and decisions are urgent (Ravetz 1999:649). It is by no means a replacement for traditional forms of science and is simply an attempt to make science more effective in realms of environment, society, and ethics. In doing so they are causing the decision making process to be more explicit and acknowledging the existence of uncertainty and complexity. This new approach increases the effectiveness of science and gives itself an opportunity to recreate its ability to inform and influence decision makers and the public.

The post-normal perspective provides research with three important tools; 1) Extended peer communities, 2) Acknowledgement and demonstration of uncertainty; and 3) Explicitness of values. It appears to be useful in the realm of ideas, but would it work in a governmental program such as the CWS, in an applied rather than theoretical setting? The existence of several successful examples of these tools in practice seems to answer in the affirmative. These examples would include the Ecological Monitoring and Assessment Network (EMAN), which is a nationwide community-based monitoring initiative. This approach makes room for a variety of interested stakeholders to respond to issues within their community by collecting monitoring data that later helps to inform decision makers. Another example of a post-normal approach is that of the Intergovernmental Panel on Climate Change (IPCC) Working Group I, which has been assessing the science behind climate change. In their reports on the data they have been compactly supplying the technical, methodological, epistemological and ethical uncertainties. Another example is that of the medical profession questioning the value of medicine versus health in terms of individual and community care.

Sections of the Canadian Wildlife Service itself are examples of the utility of a post-normal perspective. In CWS' mission statement, one finds included the concept of sustainability. Of course, achieving sustainability is always a moving target at best in that an individual organization or process can potentially become more and more sustainable. But the value of sustainability is that it acts as a yardstick with which policy options can be compared. Further, the CWS has expressed a desire to adopt a post-normal perspective by publishing their four 'guiding principles' in their Strategic Plan 2000. These principles touch upon ideas from a post-normal perspective and include "building on sound science", "collaborative conservation of biological diversity", the "utilization of the ecosystem approach" and "communication for wildlife". Analysis of the strategies that emerged from these principles revealed points of congruence and conflict with the post-normal perspective literature.

In terms of points of conflict, the CWS may encounter difficulties if it views the adoption of a post-normal perspective as something that gets attached to the organization instead as a paradigm shift. ‘Tacking’ it on may result in accusations of attempts to pay lip-service to mollify the public. Also, the way in which activities take place will not undergo the kind of change that a fresh perspective could provide. In addition, the desire to strengthen their science capacity may conflict with the tool of extended peer communities if that results in a continuation of normal science attitudes that typically view efforts such as community-based monitoring as being illegitimate. Furthermore, such strengthening of science may mean additional resources without adopting post-normal science ideas of accounting for uncertainty and managing it. Another point of conflict is the assertion by the External Advisory Committee on Smart Regulation that Environment Canada (of which the CWS is a part) is doing well in its adoption of Smart Regulation. This has been seen as a movement towards greater governmental efficiency as a form of market-based governance moulded from the corporate model (McCarthy 2003:79). If this style of top-down management is embraced government will be moving away from many of concepts that advance post-normal approaches and in so doing, shift away from working towards sustainability.

In terms of points of congruence, the CWS is strategizing to become an adaptive organization, which is necessary if it is to become responsive to feedback loops and changing values inherent in environmental policy. Additionally, the service’s commitment to partnerships also can help it to “tune into” the values that are important to the stakeholders of various issues.

Upon first glance, it may seem that there are more differences than similarities between the CWS Strategic Plan and a post-normal perspective, but many of these differences stem from the lack of detail associated with each strategy. Nevertheless, the fact that there are similarities gives hope that government is shifting away from solely science-based decision making, to post-normal governance where values are explicitly stated, uncertainties and complexities are addressed instead of downplayed, and extended peer communities are encouraged to flourish. The case study of bismuth shotshells demonstrated that purely science-based decision making is perhaps not an accurate representation of the process because of the influence of stakeholders and the political drive to eliminate lead. It then followed that a few studies were done on the option that would be easiest for hunters in terms of no upgrades in shotguns or technique being required. Little was known about bismuth shot and the preliminary studies assessed it based on the same assumptions as those used for lead shot. As result, the findings suggested that bismuth was non-toxic in comparison. This narrow scientific approach ignored virtually the only information known about bismuth, namely that it is a chronic neurotoxin. It was also stated repeatedly in the literature that the mechanisms for this neurotoxicity are unknown and there is currently no method for determining whether certain levels of bismuth in the body will impact health.

The way in which government copes with the challenges posed by the novel field of environmental policy making must change if sustainability is to take place. Allowing the accumulation of bismuth in the environment at a possible rate of 1700 tonnes per year in the form of shot is unacceptable because bismuth has been shown to do its damage when exposure is chronic and at low levels. The chronic neurotoxic effects that could incur due to ingestion of this shot by animals would be extremely difficult to trace and the consequences of brain damage to behaviour are impossible to estimate. There should, for example, be policy concern with the possibility that birds potentially affected by bismuth are inexplicitly not being able to mate due to behavioural ‘glitches’. In addition to indirect effects of reproductive health, the study that found decreased serum testosterone levels in rats exposed to bismuth subnitrate should not be ignored.

Environmental policy is intimately connected to the notion of sustainability and as such long-term scenarios like the one just mentioned have to be somehow addressed. Post-normal perspectives offer one way of achieving this by increasing clarity of approach and facilitating effective communication among stakeholders as well as maintaining quality and a diversity of information. These are accomplished through revealing the biases and values being adopted and by addressing uncertainties where possible. However, competition between the actors, namely government, civil society, private sector, and planning regime, will always hinder transparency. The tension between competition and collaboration may be the largest obstacle to the effective adoption of post-normal perspectives.

5.2. Contributions of the research

One of the major insights that this research offers is that it is necessary to adopt a post-normal perspective so that science is effectively used in the development of environmental policy. The case study of bismuth shotshells revealed the narrow approach taken to the use of scientific research when making a policy decision and ignoring important related studies. In addition to the examination of bismuth literature that highlighted various risks associated with its unrestricted usage, analysis of a four year wetland study (chapter 3) found that bismuth leaches into soil. Bismuth concentrations are also correlated to those of lead in both soil and vegetation. These two main findings are important because 1) there is demonstration of bismuth entering the soil and then possibly entering higher trophic levels and 2) bismuth and lead are shown to be intertwined as they have been in other studies. This association may offer clues to other behaviours of bismuth.

This thesis did not end with the criticism that governments do not use sufficient science for policy making in situations such as that illustrated by the case study. It continued by presenting a case for the adoption of a post-normal perspective (chapter 4). Such a perspective could help address the shortcomings of a reductionist approach offered by traditional scientific studies that do no take a systems perspective. Such a perspective recognizes the complex interactions of a variety of forces and variables. This perspective exists not only in theory, but is in practice elsewhere (e.g., EMAN and the IPCC).

5.3. Areas for further investigation

Several interesting questions arise from this research. First, in terms of bismuth's behaviour in the environment, more research needs to be done to help establish consumption guidelines. Past studies have shown lead shot pellets to be a chronic source of lead for subsistence hunters. It is reasonable to assume that bismuth will accumulate in the body as lead did. This could result in new cases of bismuth-induced encephalopathies. Whether or not this is an unreasonable possibility can only be found by doing the research.

Second, bismuth-contaminated vegetation is a possible pathway for animals to be exposed to low-level and chronic supplies of bismuth. Research needs to determine if vegetation would take up enough bismuth to be a risk to animals that ingest it. Vegetative uptake of bismuth may also be of concern for those who consume crops that have received night soil amendments. Sewage has been found to contain relatively large concentrations of bismuth due to its popularity as a treatment for gastrointestinal ailments.

Finally, the information collected about the Canadian Wildlife Service's plan to cope with the challenges posed by using sustainability to measure their policy options, was solely obtained from their public documents. It would be illuminating to do a set of interviews with Environment Canada policy makers to help to answer the research question of: *What are the barriers perceived by policy makers to more fully adopting a post-normal perspective?* In the case of the CWS, this analysis could not be done in this thesis because the focus was predominately on bismuth shot. It was thought that this research may have been controversial since some of the work done on the toxicity test guidelines for choosing non-toxic shot was too limited in scope.

REFERENCES

Alloway, B. J. 1990. Heavy metals in soils. Blackie and Son, Ltd., Glasgow.

Berg, T., O. Royset, and E. Steinnes. 1995. Moss (*Hylocomium Splendens*) used as biomonitor of atmospheric trace element deposition: estimation of uptake efficiencies. Atmospheric Environment 29(3):353-360.

Berrow, L., and J. Webber. 1972. Trace elements in sewage sludges. Journal of the Science of Food and Agriculture 23:93-100.

Boddington, C. 1994. Waterfowlers: Bismuth is Coming! Pages 85-98 *in* Guns & Ammo.

Bouchon, J., and D. Cottin-Bouchon. 2001. A dear old lady not so crazy as this... bismuth poisoning (une mamie pas si folle que cela...). La Revue de Medecine Interne 22(Suppl 2):245-246.

Brake, S., R. Jensen, and J. Mattox. 2004. Effects of coal fly ash amended soils on trace element uptake in plants. Environmental Geology 45:680–689.

Bruinink, A., P. Reiser, M. Muller, B. H. Gahwiler, and G. Zbinden. 1992. Neurotoxic effects of bismuth in vitro. Toxicology in Vitro 6(4):285-293.

Canadian Wildlife Service. 1993. Toxicity test guidelines for non-toxic shot for hunting migratory birds. Conservation and Protection Environment Canada.

Canadian Wildlife Service. 2000. Strategic Plan 2000: The Path Forward for Environment Canada's Wildlife Conservation Program. Minister of Environment.

Canadian Wildlife Service. 2004. A review of the environmental impacts of lead shotshell ammunition and lead fishing weights in Canada: Managing the negative impacts of lead shot and lead sinkers. http://www.cws-scf.ec.gc.ca/publications/papers/88/chap4_e.cfm Accessed: [8 March 2004].

Canadian Wildlife Service Waterfowl Committee. 2001. Migratory game hunting regulations in Canada: July 2001. CWS Migr. Birds Regul. Rep. No. 3.

Candelone, J.-P., M. A. Bolshov, S. N. Rudniev, S. Hong, and C. F. Boutron. 1995. Bismuth in recent snow from central Greenland: preliminary results. Atmospheric Environment 29(15):1843-1848.

Canena, J., J. Reis, A. S. Pinto, A. M. Santos, J. Leitao, T. Pinheiro, and M. G. Quina. 1998. Distribution of bismuth in the rat after oral dosing with ranitidine bismuth citrate and bismuth subcitrate. Journal of Pharmacy and Pharmacology 50:279-283.

Carmichel, J. 1997. Heavy metal showdown: Has the space-aged "super shot" finally arrived?" Pages 72-78 *in* OutdoorLife: The sportsman's authority since 1898.

Carter, J. A., R. E. Mroz, K. L. Tay, and K. G. Doe. 1998. An evaluation of the use of soil and sediment bioassays in the assessment of three contaminated sites in Atlantic Canada. Water Quality Research Journal of Canada 33(2):295-317.

Connelly, J., and G. Smith. 2003. Politics and the environment: from theory to practice, 2nd edition. Routledge, London.

Dale, A. 2001. At the edge: sustainable development in the 21st century. UBC Press, Vancouver.

Descartes, R. 1952. Discourse on method and meditations. Prentice-Hall, Inc., New Jersey.

Dresow, B., P. Nielsen, R. Fischer, J. Wendel, E. Gabbe, and H. Heinrich. 1991. Bioavailability of bismuth from ^{205}Bi-labelled pharmaceutical oral Bi-preparations in rats. Archives of Toxicology 65:649-650.

Environment Canada. 2002. The Green Lane: Mandate, Vision and Mission. http://www.ec.gc.ca/introec/mandate.htm Accessed: [25 May 2005].

Environment Canada. 2003a. Facts about lead fishing sinkers and jigs. http://www.cws-scf.ec.gc.ca/fishing/facts_e.cfm Accessed: [9 October 2003].

Environment Canada. 2003b. Where to find lead-free alternatives: manufacturers of lead-free fishing tackle. http://www.cws-scf.ec.gc.ca/fishing/alter_e.cfm Accessed: [9 October 2003].

External Advisory Committee on Smart Regulation. 2003. Compendium for Improving Environmental Regulation: An Environment Canada Perspectives Paper. http://www.smartregulation.gc.ca/en/06/01/su-03.asp Accessed: [19 November 2004].

External Advisory Committee on Smart Regulation. 2004. Smart Regulation: a regulatory strategy for Canada. Ottawa.

Fairbrother, A., and L. Kapustka. 2000. Proposed hazard classification of metals in the terrestrial environment: second discussion paper. *in* International Council on Metals and the Environment, Ottawa.

Feldmann, J., E. M. Krupp, D. Glindemann, A. V. Hirner, and W. R. Cullen. 1999. Methylated bismuth in the environment. Applied Organometallic Chemistry 13:739-748.

Fergusson, J. E. 1990. The heavy metals: chemistry, environmental impact and health effects. Pergamon Press, Oxford.

Ferrari, C. P., S. Hong, K. Van de Velde, C. F. Boutron, S. N. Rudniev, M. Bolshov, W. Chisholm, and K. J. R. Rosman. 2000. Natural and anthropogenic bismuth in Central Greenland. Atmospheric Environment 34:941-948.

Fowler, B. A., and V. Vouk. 1986. Bismuth. Pages 117-129 *in* Handbook on the Toxicology of Metals: Volume 2: Specific Metals. L. Friberg, G. F. Nordberg, and V. Vouk, editors. Elsevier, Amsterdam.

Funtowicz, S., and J. R. Ravetz. 1990. Uncertainty and Quality in Science for Policy. Kluwer, Dordrecht. See also http://www.nusap.net.

Funtowicz, S., and J. R. Ravetz. 1994. Emergent complex systems. Futures 26(6):568-582.

Funtowicz, S. O., and J. R. Ravetz. 1993. Science for the post-normal age. Futures 25(7):739-755.

Gerritse, R. G., R. Vriesema, J. W. Dalenberg, and H. P. de Roos. 1982. Effect of sewage sludge on trace element mobility in soils. Journal of Environmental Quality 11(3):359-364.

Giampietro, M. 1999. Sustainability, the New Challenge of Governance, and Post-Normal Science. Politics and the Life Sciences 18(2):218-221.

Harada, H., and T. Hatanaka. 1998. Natural background levels of trace elements in wild plants. Soil Science and Plant Nutrition 44(3):443-452.

Healy, S. 1999. Extended peer communities and the ascendance of post-normal politics. Futures 31:655-669.

Heinemann, A., G. Strugala, and B. Elsenhans. 1995. Influence of hydroxycarboxylic acids on the water solubility of various bismuth compounds. Arzenimittelforschung/Drug Research 45(1):48-51.

Holdner, J., B. Wainman, R. Jayasinghe, E. V. Spronsen, J. D. Karagatzides, E. Nieboer, and L. J. S. Tsuji. 2004. Soil and Plant Lead of Upland Habitat Used Extensively for Recreational Shooting and Game Bird Hunting in Southern Ontario, Canada. Bulletin of Environmental Contamination and Toxicology 73(3):568-574.

Holling, C. S. 1978. Adaptive environmental asessment and management. Wiley, Chichester.

Hutson, J. 2005. Effects of bismuth citrate on the viability and function of Leydig cells and testicular macrophages. Journal of Applied Toxicology 25:234–238.

Islek, I., S. Uysal, F. Gök, R. Dündaröz, and S. Küçüködük. 2001. Reversible nephrotoxicity after overdose of colloidal bismuth subcitrate. Pediatric Nephrology 16:510-514.

Janatka, J., and P. Moravek. 1990. Geochemical exploration in the Jilove Belt: case history of the Celina deposit, Bohemian Massif, Czechoslovakia. Journal of Geochemical Exploration 37:367-384.

Jayasinghe, R., L. J. S. Tsuji, W. A. Gough, J. D. Karagatzides, D. Perera, and E. Nieboer. 2004. Determining the background levels of bismuth in tissues of wild game birds: a first step in addressing the environmental consequences of using bismuth shotshells. Environmental Pollution 132(1):13-20.

Jickells, T. D., T. D. Davies, M. Tranter, S. Landsberger, K. Jarvis, and P. Abrahams. 1992. Trace elements in snow samples from the Scottish Highlands: Sources and dissolved/particulate distributions. Atmospheric Environment 26(3):393-401.

Jung, M. C., I. Thornton, and H. Chon. 2002. Arsenic, Sb and Bi contamination of soils, plants, waters and sediments in the vicinity of the Dalsung Cu–W mine in Korea. The Science of the Total Environment 295:81-89.

Kabata-Pendias, A. 2004. Soil–plant transfer of trace elements–an environmental issue. Geoderma 122:143-149.

Kalra, Y. P., and D. G. Maynard. 1991. Methods manual for forest soil and plant analysis. Inf. Rep. NOR-X-319. Forestry Canada, Northwest Region, Edmonton, Alberta.

Kawasaki, A., R. Kimura, and S. Arai. 1998. Rare earth elements and other trace elements in wastewater treatment sludges. Soil Science and Plant Nutrition 44:433-441.

Kay, J. J., H. A. Regier, M. Boyle, and G. Francis. 1999. An ecosystem approach for sustainability: addressing the challenge of complexity. Futures 31:721-742.

Kovacs, M., I. Nyary, and L. Toth. 1984. The microelement content of some submerged and floating aquatic plants. Acta Botanica Hungarica 30(1-2):173-185.

Kraabel, B. J., M. W. Miller, D. M. Getzy, and J. K. Ringelman. 1996. Effects of embedded tungsten-bismuth-tin shot and steel shot on mallards (Anas platyrhynchos). Journal of Wildlife Diseases 32(1):1-8.

Krari, N., Y. Mauras, and P. Allain. 1995. Enhancement of bismuth toxicity by l-cysteine. Research Communications in Molecular Pathology and Pharmacology 89(3):357-364.

Kuhn, T. S. 1970. The structure of scientific revolutions, 2nd edition. The University of Chicago Press, Chicago.

Larsen, A., M. Martiny, M. Stoltenberg, G. Danscher, and J. Rungby. 2003. Gastrointestinal and systemic uptake of bismuth in mice after oral exposure. Pharmacology and Toxicology 92(2):82-90.

Leussink, B. T., J. F. Nagelkerke, B. van de Water, A. Slikkerveer, G. B. van der Voet, A. Srinivasan, J. A. Bruijn, F. A. de Wolff, and E. de Heer. 2002. Pathways of proximal tubular cell death in bismuth nephrotoxicity. Toxicology and Applied Pharmacology 180:100-109.

Li, X., and I. Thornton. 1993. Arsenic, antimony and bismuth in soil and pasture herbage in some old metalliferous mining areas in England. Environmental Geochemistry and Health 15(2/3):135-143.

Locht, L. J., L. Munkøe, and M. Stoltenberg. 2002. Bismuth tracing in organotypic cultures of rat hippocampus. Journal of Neuroscience Methods 115:77-83.

Luks, F. 1999. Post-normal science and the rhetoric of inquiry: deconstructing normal science? Futures 31:705-719.

MacNicol, R., and P. Beckett. 1985. Critical tissue concentrations of potentially toxic elements. Plant and Soil 85:107–129.

McCarthy, D. D. P. 2003. Post-normal governance: an emerging counter proposal. Environments 31(1):79-91.

Michie, D. 1992. Back a winner: Bismuth shot beats steel in every way but it's going to need a helping hand. Pages 31 *in* Outdoor Canada.

Mitchell, B. 2002. Resource and environmental management. Pearson Education Ltd., Essex.

Mueller, R. L. 1989. Bismuth- a [sic] environmental problem in [the] future (wismut- ein umweltschadstoff der zukunft?). Zbl. Hyg. 189:117-124.

Nriagu, J. O. 1988. A silent epidemic of environmental metal poisoning? Environmental Pollution 50:139-161.

Office of the Prime Minister. 2004. Prime Minister receives report on smart regulation from the External Advisory Committee on Smart Regulation. http://www.pm.gc.ca/eng/news.asp?id=269 Accessed: [10 November 2004].

Pamphlett, R., G. Danscher, J. Rungby, and M. Stoltenberg. 2000a. Tissue uptake of bismuth from shotgun pellets. Environmental Research Section A 82:258-262.

Pamphlett, R., M. Stoltenberg, J. Rungby, and G. Danscher. 2000b. Uptake of bismuth in motor neurons of mice after single oral doses of bismuth compounds. Neurotoxicology and Teratology 22:559-563.

Pedersen, L. H., M. Stoltenberg, E. Ernst, and M. J. West. 2003. Leydig cell death in rats exposed to bismuth subnitrate. Journal of Applied Toxicology 23(4):235-238.

Pellizzoni, L. 2004. Responsibility and Environmental Governance. Environmental Politics 13(3):541-565.

Polemio, M., N. Senesi, and S. A. Bufo. 1982. Soil contamination by metals: A survey in industrial and rural areas of southern Italy. The Science of the Total Environment 25(1):71-79.

Rapport, D. J., J. Howard, R. Lannigan, and W. McCauley. 2003. Linking health and ecology in the medical curriculum. Environment International 29:353-358.

Ravetz, J. R. 1999. What is post-normal science? Futures 31:647-653.

Ravetz, J. R. 2002. Food Safety, Quality, and Ethics – A Post-normal Perspective. Journal of Agricultural and Environmental Ethics 15(3):255-265.

Reimann, C., H. Niskavaara, P. de Caritat, T. E. Finne, M. Ayras, and V. Chekushin. 1996. Regional variation of snowpack chemistry in the vicinity of Nikel and Zapoljarnij, Russia, northern Finland and Norway. The Science of the Total Environment 182:147-158.

Reimann, C., P. De Caritat, J. H. Halleraker, T. E. Finne, R. Boyd, Ø. Jæger, T. Volden, G. Kashulina, I. Bogatyrev, V. Chekushin, V. Pavlov, M. Äyräs, M. L. Räisänen, and H. Niskavaara. 1997a. Regional atmospheric deposition patterns of Ag, As, Bi, Cd, Hg, Mo, Sb and Ti in a 188,000 km^2 area in the European arctic as displayed by terrestrial moss samples--long-range atmospheric transport vs local impact. Atmospheric Environment 31(23):3887-3901.

Reimann, C., R. Boyd, P. de Caritat, J. H. Halleraker, G. Kashulina, H. Niskavaara, and I. Bogatyrev. 1997b. Topsoil (0-5 cm) composition in eight arctic catchments in northern Europe (Finland, Norway and Russia). Environmental Pollution 95(1):45-56.

Ringelman, J. K., M. W. Miller, and W. F. Andelt. 1993. Effects of ingested tungsten-bismuth-tin shot on captive mallards. Journal of Wildlife Management 57(4):725-732.

Ross, J. F., R. D. Broadwell, M. R. Poston, and G. T. Lawhorn. 1994. Highest brain bismuth levels and neuropathology are adjacent to fenestrated blood vessels in mouse brain after intraperitoneal dosing of bismuth subnitrate. Toxicology and Applied Pharmacology 124:191-200.

Saloranta, T. M. 2001. Post-Normal Science and the Global Climate Change Issue. Climatic Change 50(4):395-404.

Sanderson, G. C., S. G. Wood, G. L. Foley, and J. D. Brawn. 1992. Toxicity of bismuth shot compared with lead and steel shot in game-farm mallards. Transactions of the 57th North American Wildlife and Natural Resources Conference.

Sanderson, G. C., W. L. Anderson, G. L. Foley, L. M. Skowron, J. D. Brawn, and J. W. Seets. 1997a. Acute toxicity of ingested bismuth alloy shot in game-farm mallards. Illinois Natural History Survey Bulletin 35(3-4):183-215.

Sanderson, G. C., W. L. Anderson, G. L. Foley, K. L. Duncan, L. M. Skowron, J. D. Brawn, and J. W. Seets. 1997b. Toxicity of ingested bismuth alloy shot in game-farm mallards: Chronic health effects and effects on reproduction. Illinois Natural History Survey Bulletin 35(3-4):215-252.

Scheuhammer, A. M., and S. L. Norris. 1995. A review of the environmental impacts of lead shotshell ammunition and lead fishing weights in Canada. *in* Occasional Paper 88. Canadian Wildlife Service.

Scheuhammer, A. M. Personal communication. June 7, 2005.

Senesi, G. S., G. Baldassarre, N. Senesi, and B. Radina. 1999. Trace element inputs into soils by anthropogenic activities and implications for human health. Chemosphere 39(2):343-377.

Senesi, N., M. Polemio, and L. Lorusso. 1979. Content and distribution of arsenic, bismuth, lithium and selenium in mineral and synthetic fertilizers and their contribution to soil. Communications in Soil Science and Plant Analysis 10(8):1109-1126.

Serfontein, W. J., and R. Mekel. 1979. Bismuth toxicity in man 2. Review of bismuth blood and urine levels in patients after administration of therapeutic bismuth formulations in relation to the problem of bismuth toxicity in man. Research Communications in Chemical Pathology and Pharmacology 26(2):391-411.

Slikkerveer, A., and F. A. de Wolff. 1989. Pharmacokinetics and toxicity of bismuth compounds. Medical Toxicology and Adverse Drug Experience 4(5):303-323.

Slikkerveer, A., H. B. Jong, R. B. Helmich, and F. A. de Wolff. 1992. Development of a therapeutic procedure for bismuth intoxication with chelating agents. Journal of Laboratory and Clinical Medicine 119:259-537.

Stemmer, K. L. 1976. Pharmacology and toxicology of heavy metals: bismuth. Pharmac. Ther. 1:153-155.

Sterckeman, T., F. Douay, N. Proix, H. Fourrier, and E. Perdrix. 2002. Assessment of the contamination of cultivated soils by eighteen trace elements around smelters in the North of France. Water Air and Soil Pollution 135(1-4):173-194.

Stoltenberg, M., G. Danschera, R. Pamphlett, M. M. Christensena, and J. Rungbya. 2000. Histochemical tracing of bismuth in testis from rats exposed intraperitoneally to bismuth subnitrate. Reproductive Toxicology 14:65-71.

Stoltenberg, M., J. Hogenhuis, J. Hauw, and G. Danscher. 2001. Autometallographic tracing of bismuth in human brain autopsies. Journal of Neuropathology and Experimental Neurology 60(7):705-710.

Stoltenberg, M., A. Larsen, M. Zhao, G. Danscher, and U. T. Brunk. 2002a. Bismuth-induced lysosomal rupture in J774 cells. APMIS 110(5):396-402.

Stoltenberg, M., A. Flyvbjerg, L. G. Søndergaard, and J. Rungby. 2002b. Decreased serum testosterone levels in rats exposed intraperitoneally to bismuth subnitrate. Journal of Applied Toxicology 22:111-115.

Stoltenberg, M., J. D. Schionning, M. J. West, and G. Danscher. 2003a. Bismuth-induced neuronal cell death in rat dorsal root ganglion: a stereological study. Acta Neuropathologica 105(4):351-357.

Stoltenberg, M., L. Locht, A. Larsen, D. Jensen, and G. Danscher. 2003b. In vivo cellular uptake of bismuth ions from shotgun pellets. Histology and Histopathology 18(3):781-785.

Stoltenberg, M., and J. Hutson. 2004. Bismuth uptake in rat testicular macrophages. A follow-up observation suggesting that bismuth alters interactions between testicular macrophages and Leydig cells. Journal of Histochemistry and Cytochemistry 52:1241–1243.

Stone, D. 2002. Policy paradox: the art of political decision making, Revised edition. W.W. Norton & Co., New York.

Tsuji, L. J. S., and E. Nieboer. 1997. Lead pellet ingestion in First Nation Cree of the western James Bay region of northern Ontario, Canada: Implications for a non-toxic shot alternative. Ecosystem Health 3:54-61.

Tsuji, L. J. S., B. C. Wainman, R. K. Jayasinghe, J. D. Karagatzides, E. Van Spronsen, and E. Nieboer. 2004. Tissue-bismuth levels of game birds harvested with bismuth shotshell: policy implications. Bulletin of Environmental Contamination and Toxicology 72(1):128-134.

Walker, K. J. 2001. Uncertainty, epistemic communities and public policy. Pages 262-290 *in* Ecology, uncertainty and policy: managing ecosystems for sustainability. Prentice-Hall.

Waltner-Toews, D. 2000. The end of medicine: the beginning of health. Futures 32(7):655-667.

Whitelaw, G., H. Vaughan, B. Craig, and D. Atkinson. 2003. Establishing the Canadian Community Monitoring Network. Environmental Monitoring and Assessment 88:409–418.

Whitelaw, G. 2005. Presentation on approaches and applications for community monitoring. February 16. *in* Francis, G. 2003. Organizational ecosystems and actor-system dynamics.

Wilkin, P. 2001. The political economy of global communication: an introduction. Pluto Press, London.

Wray, D. S. 1998. The impact of unconfined mine tailings and anthropogenic pollution on a semi-arid environment - an initial study of the Rodalquilar mining district, south east Spain. Environmental Geochemistry and Health 20(1):29-38.

Wynne, B. 2001. Scientific Uncertainty in Public Policy. *in* Biotechnology and Global Governance: Crisis and Opportunity, Cambridge, MA April 26-28. Available online at: http://www.wcfia.harvard.edu/biotech/wynnepaper1.doc.