THE UNIVERSITY OF CALGARY

An Airshed Management Framework for A Selected Area in South Central Alberta

by

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Abstract

"An Airshed Management Framework for a Selected Area in South Central Alberta"

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This project investigated airshed management in south central Alberta. The airshed is an open system controlled by stability factors, wind, precipitation and topography, and can be described as unstable in space and time. These factors cannot be controlled; airshed management must therefore focus on prevention, tracking, and mitigation of pollution. Driving forces include public perception, cost of environmental initiatives now and in the future, and potential liability. South central Alberta's economic focus on petroleum production makes an uneasy marriage between economy and environment. Management tools can be used more effectively in the study area. Environmental assessment can use the Acid Deposition Research Program as a baseline for future studies. The lack of research on long term, low impact deposition of pollutants and the resulting social and ecological significant effects increases the need for cumulative environmental assessment, auditing, lifecycle assessment, and reporting standards. A zonal or regional approach under one political entity is recommended for short to mid term control; cross-jurisdictional control is the ideal for the long term. The study area lends itself to a zonal management approach due to the natural clustering of petroleum production along northwest to southeast trending foothills.

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for mom

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List of Symbols, Abbreviations, and Nomenclature

AEPEA - Alberta Environmental Protection and Enhancement Act

CASA - Clean Air Strategic Alliance

CEE- Cumulative Environmental Effects

CFC - Chloroflourocarbon

CO - Carbon monoxide

CO_2 - Carbon dioxide

EUB - Energy and Utilities Board

GEMI - Global Environmental Management Initiative

HAP - Hazardous Air Pollutant

No_x - Nitrogen oxides

SEA - Strategic Environmental Assessment

So_x - Sulphur oxides

VEC - Valued economic or environmental component

VOC - Volatile Organic Compound

Part One - Conceptualization

CHAPTER 1 -- THE PROJECT

The Project

Introduction

Airshed management is a growing concern in the communities that interact with industry in Alberta.[1] This driving force of public concern -- a public that is at once the consumer, the voter, and the employee -- along with the need to track operating costs, future capital costs, and potential liability, means that airshed management must begin to concern government and industry. This is due to the direct link between Alberta's economy, driven by fossil fuels, and air emissions. Alberta produces over 80% of the conventional crude and natural gas in Canada.[2] More than 60% of the area of the province has directly interacted with the activities of the petroleum industry, whether through test holes, wells, or gas plants.[3] Local stakeholders are organizing action groups, most prominently the Clean Air Strategic Alliance (CASA), which include industry in the search for solutions to the perceived problems.[4] Management strategies are needed that recognize the importance of factors like the influence of atmospheric transport, transformation, and deposition of emissions and the effects on receptors, and that make use of management tools such as environmental audits, economic instruments, environmental and risk assessments, reporting standards, and legislation. Ideally, these policies are created by an interdisciplinary team to make the changes occur. "To effect the necessary changes, scientists must become much better at synthesizing their results with those of other scientists from other disciplines to produce a broad and coherent scientific picture."[5]

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[1] West Central Regional Monitoring Program, July 1994, p. 1.

[2] Alberta Environmental Protection. Alberta's State of the Environment Fact Sheet Vol.2 No. 3.

[3] AccuMap Enerdata Corp., January 26, 1997: Alberta Well Penetrations. Production data to November 30, 1996.

[4] West Central Regional Monitoring Program, July 1994, p. 1.

[5] Thompson, Dixon. *Environmental Management*, in The Environment and Canadian Society. Thomas Fleming, Editor. TTP Nelson, Toronto, 1997. p. 220

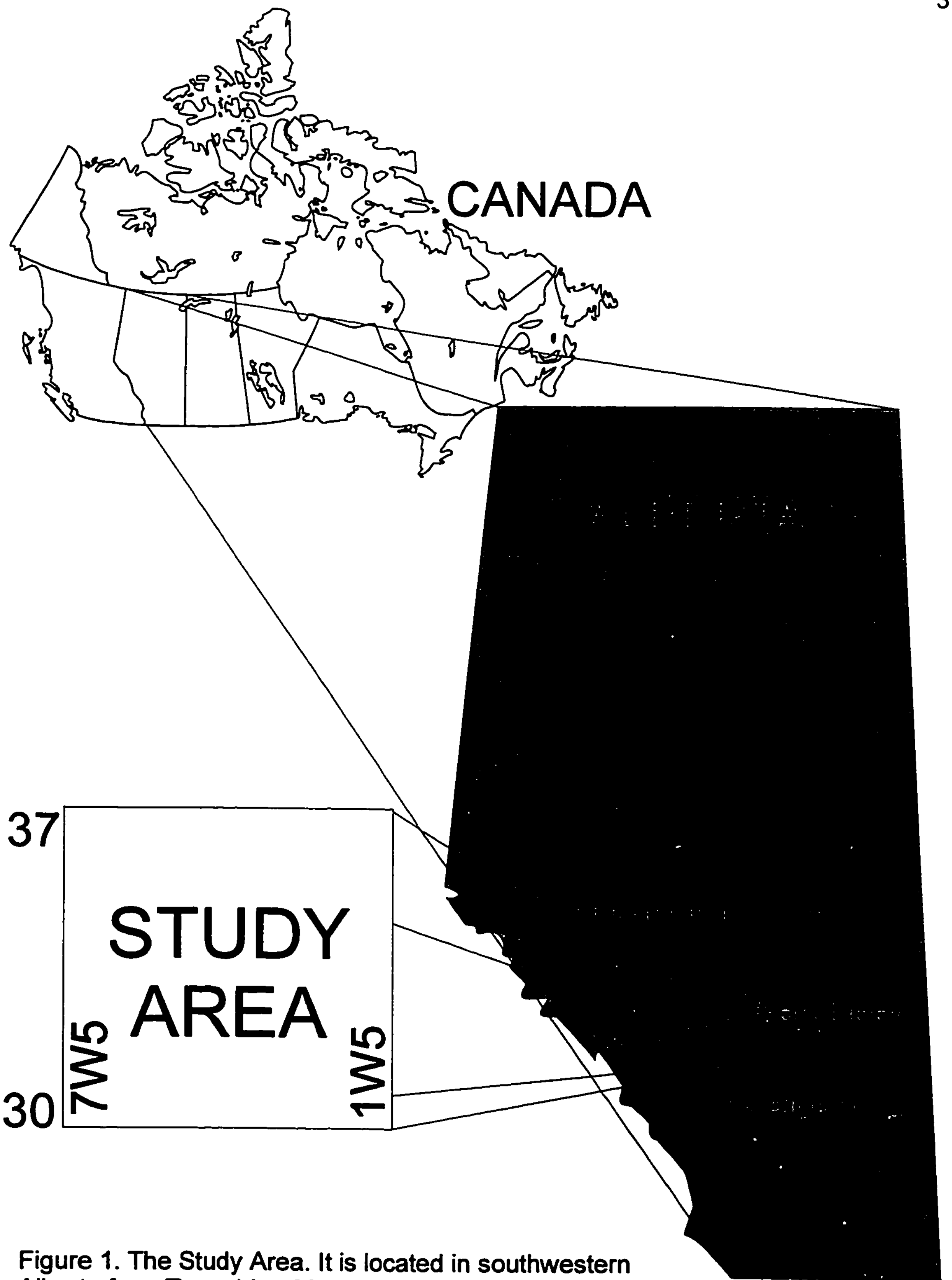

Figure 1. The Study Area. It is located in southwestern Alberta from Townships 30 to 37 and between Ranges 1 and 7 west of the 5th Meridian.

This project will present the emission, transportation, and deposition of pollution; the effects on receptors; and suggest the uses of management tools for effective management strategies.

Goals

The goals of this project are:

- To develop an airshed management framework for the selected study area in south central Alberta that utilizes basic concepts;
- To present the concepts of precaution, cumulative effects, and sustainability as part of a management strategy; and
- To recommend the use of tools such as strategic impact assessments, economic instruments, reporting standards, risk assessment, legislation, lifecycle assessment and environmental audits in a management strategy.

Objectives

The objectives of this research are as follows:

- To describe the role atmospheric processes have in the transportation, transformation and eventual deposition of emissions;
- To accomplish a partial inventory of common (frequently emitted) and significant (a degree of risk or potential risk on health, society and the environment) emissions from petroleum processing in the study area;
- To assess the potential effects that these emissions may have on receptors;
- To explore the legal context of the release of air pollutants;
- To determine what tools exist that can be used to manage apparent problems and are appropriate for the Alberta context; and
- To provide a framework for environmental management to government, industry and other stakeholders.

Given the goals and objectives stated above, a checklist of actions to be taken in the study area has been developed, accomplishing "the separation of the project into manageable parts":[6]

1. Definition of physical attributes:

- Topography;
- Local climatological (wind and weather) patterns;
- Vegetative cover;
- Soils;
- Urban development.

2. Definition of valued ecosystem and economic components.
3. Identification of common emissions, including:

- Emission sources;
- Emission residence times;
- Emissions risk (effects on valued receptors);

4. Identification of tools in existence that may be of use in the region.
5. Recommendation of a regional strategy for the study area for use by government, industry and other interested stakeholders.

Study Area

The study area for this project is in south central Alberta. The area encompasses townships 30 on the south boundary through 37 on the north, and ranges 1 on the east through 7 on the west, west of the fifth meridian. It covers one degree of longitude, from 114 (east) through 115 (west), and forty five minutes of latitude, from 51 degrees, 30 minutes south to 52 degrees, 15 minutes north. It is on the border of the area governed by the Eastern Slopes Policy, but as of 1994 had no Integrated Management Plan.[7]

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[6] Beanlands, G.E. and P.N. Duinker. p. 4

[7] Alberta Energy. Environmental Regulation of Natural Gas Development in Alberta, Canada., undated.

The study area has the following characteristics:[8]

Number of Gas Plants: 29

Oil & Gas Activity Sites: Approximately 2500

Urban Centres: Caroline, Olds, Bowden, Sundre, Carstairs, Didsbury, Cremona

Hamlets: Dickson, Westward Ho, Spruceview, Water Valley

Localities: Crammond, Stauffer, Ricinus, Chedderville, Dovercourt, Evergreen, Congressbury, Bearberry, James River Bridge, Westcott, Harmattan, Eagle Hill, Elkton, Bergen

Natural Areas: Markerville, Chedderville, Clearwater, Bearberry, Snake's Head, Sundre

Provincial Parks: Red Lodge Provincial Park

Natural/Recreation Areas: Red Deer River Valley, Rocky Mountain Forest Reserve, Clearwater River Valley

Other Riparian Environments: Rosebud River, Carstairs Creek, Dogpound Creek, Medicine River, Little Red Deer River, Prairie Creek, Raven River, North Raven River, James River

Muskeg: Charlton Muskeg

Topography: Rolling

Soils: Mostly chernozemic and luvisolic; areas of organic

Ecoregions: Boreal Uplands, Boreal Foothills, Aspen Parkland, Fescue Grasslands

Who Can Use This Information

There are three main groups that have, or should have, a stake in managing the airshed. These are: 1. government; 2. industry; and 3. the public in the form of either individuals or through representation in action groups.

Recommendations in this project will be for the use of these groups, recognizing

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[8] Information from a series of six Provincial Resource Base maps, dated 1986 - 1995 produced by Alberta Forestry, Lands, and Wildlife and Alberta Environmental

that each may have different objectives and priorities. This is especially true given the tight relationship between environment and economy in the production of fossil fuels in Alberta.

Management Tools

The tools that will be referred to throughout this project are: strategic impact assessments, environmental audits, lifecycle assessments, technology, legal and political instruments, economic instruments, risk assessment, and reporting standards. Strategic impact assessment is a proactive, longer–term planning tool. Reporting standards ensure consistency for planning and measurement. Performance indicators measure if performance is meeting or exceeding standards. Economic instruments try to tie environmental performance to economic penalties and incentives; legal and political instruments allow for more centralized control. Technology is an "end of pipe" solution that may be either proactive or reactive.

Driving Forces for Change

A management strategy should take into consideration the external forces that are prompting more effective management or change to occur. Some driving forces are:

- Legislation (current and future);
- Public pressure;
- Future generations (sustainable development);
- Liability;
- Consumer concerns;
- Employee concerns;
- Investors;
- Financiers.[9]

Protection. Map sheets are 82-O-9, 82-O10, 82-O-15, 82-O-16, 83-B-01, and 83-B-02

[9] Thompson, Dixon. p. 225

How This Project is Organized

Following the framework of Beanlands and Duinker, this paper is organized in "a logical progression from chemical--physical to biotic attributes of the ecosystem."[10] Three sections provide the basis for this progression; conceptualization, linkages, and predictors (management tools).

Conceptualization -- The first section of this paper (Chapters 1 to 3) conceptualize the project. These chapters present the goals and objectives, methodology, and context of the project.

Linkages -- In the second section, Chapters 4 to 6 present the linkages between physical and chemical processes and biotic factors. This includes airshed mechanics (physical), emissions (chemical) and receptors (biotic).

Predictors -- Chapters 7 to 10 form the third unit of this project. Here are the tools that can be used to create a framework for environmental management of the airshed.

The approach taken is one that may be termed a "systems approach".[11] The scope taken is broad, which sacrifices depth on any one issue. This reflects the need for an interdisciplinary approach -- biology, environmental geography, management, and chemistry are essential components of finding solutions. Main points are found at the beginning of each chapter. This is followed by the background information used in making these conclusions. A summary is given at the end of each chapter.

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[10]Beanlands, G.E and P. N. Duinker. *An Ecological Framework for Environmental Impact Assessment in Canada.* Federal Environmental Assessment Review Office, 1983. p. 5

[11] Angle, Randy. Head, Air Issues Branch, Alberta Environment. Personal communication.

CHAPTER 2 -- APPROACH

Approach

The following steps were taken in the process of completing the project.

Delineation of Study Area

The study area was chosen because of the following attributes:

- The density of petroleum activity in this region of south central Alberta;
- Proximity of the study area to the base of Calgary;
- The existence of grass roots level airshed management activity in the form of a pre-CASA multistakeholder group;
- It is a large enough area to be considered representative regionally, but small enough to be analyzed on maps.

Identification of Air Management Issues in South Central Alberta

Eight meetings of the pre-CASA multistakeholder group were attended in the role of Secretariat. The issues identified are:

- Human health;
- Animal health, specifically cattle;
- Methods of monitoring (emissions);
- Target loading levels (of emissions);
- Economics (who will pay for monitoring programs);
- Participation by industry;
- Area of proposed management zone;
- Local effects of air pollution.

Identification of Stakeholders

Identification of stakeholders was accomplished through attendance at the pre-CASA meetings in the study area as described above. Identification of stakeholders was necessary to identify and understand the airshed management issues perceived at a local and regional scale in the study area. In addition, it enabled the evaluation of the level of knowledge regarding airshed mechanics among stakeholders. This group became known as the Parkland Air Management Zone (PAMZ), and consisted of representatives from the local ranching industry, the public, the petroleum industry (Amoco, Gulf, Mobil, Home Oil, Shell, PetroCanada, Nova, TransAlta Utilities), and government groups (Alberta Environment Protection, Alberta Energy and Utilities Board, County of Mountainview). Stakeholders fall into three main categories: 1. government; 2. industry; and 3. public persons, either individuals or through action groups.

Formulation of research questions

This step was made in order to give some direction to the research, but were not regarded as the only questions asked during the research. They included:

- How are emissions transported and deposited?
- What factors control transportation and deposition?
- What are the significant emissions in the study area?
- How do these emissions affect receptors?
- What tools are available to use in managing the airshed?
- How can these be applied to the study area?

Analysis of maps

The information required from these maps was:

- Oil and gas activity sites;
- Urban developments;
- Ecoregions;
- Topography;
- Environmental components that are potential receptors.

Maps used in the project are the most recent available.

Literature review

The University of Calgary library was searched using the Dobis system and the new Clavis system. This search included:

- Books on air management;
- Back issues and current issues of Air and Waste Management and Atmospheric Environment journals;
- United Nations publications;
- Government of Canada publications, including the State of the Environment Report and the Emissions Inventory;
- Government of Alberta publications;
- Recent books on airshed mechanics, atmospheric chemistry, and the effects of air pollution of receptors such as plants, soil, and water systems;
- Early airshed modelling from the Alberta Oil Sands;
- The Acid Deposition Research program;
- Conference papers on airshed management (Acidifying Emissions Symposium, 1996);
- CASA publications;
- West Central Regional Airshed Management Zone Technical Report.

This gave initial and detailed knowledge of the issues identified previously.

Identification of Management Tools

Environmental management tools were identified and assessed for use in the study area. Tools included:

- Strategic environmental assessment;
- Cumulative environmental assessment;
- Environmental auditing;
- Lifecycle assessment;
- Reporting standards;
- Economic instruments;

- Political regulations;
- Risk assessment;
- Legal approaches.

Field Reconnaissance

The study area was visited to determine the actual topography, vegetation, and proximity of the petroleum industry to urban developments and other industry such as ranching. Photographs were taken in some locations.

Identification of Current Air Management Techniques

Air modelling programs used in the Alberta airshed, by Alberta Environment, were reviewed for accuracy, capability, and intent. Monitoring, target loading, economic instruments and policy were reviewed. Some information was provided through the Air Issues Branch of the Alberta Government.

Generation of Maps

Generating maps provided information on the extent of oil and gas activity throughout Alberta and identified the sour gas fields in the study area. Accumap, a service provided on campus to students through the Department of Geology, was able to provide the newest available information. This information gives context to the degree of petroleum activity in the province and the study area.

Assessment of Research Findings

Correlation and application of findings to the study area was done through the use of environmental impact assessment, economic instruments, legal and political instruments, reporting standards, and performance indicators.

Limitations of Study

The petroleum industry is only required to report emissions of sulphur dioxide and sulphuric acid. Information on other emissions is considered proprietary and, in most cases, is not released to the public.

A detailed emissions inventory was not done. The information available is comprised of data lists and neither the time nor the money was available for analysis. The current project depends on previous research for its accuracy.

CHAPTER 3 -- CONTEXT

Context: Conceptualizing the Airshed

Main Points

- Control of inputs to the airshed at a regional level where specific industries may be targeted for control and where fewer political jurisdictions are involved should be implemented.
- Use of the precautionary principle when there is lack of full scientific certainty about short, mid, or long term effects is recommended.
- Use of a balanced, central philosophical approach termed "sustainable development" in order to achieve a balance of environmental quality and economic development.

Background

We don't usually think about it. Nor can we see it, smell it, or taste it. Yet air is an essential ingredient of life, a byproduct of the life found in the "primordial soup" billions of years ago. It is an irony that while oxygen, as a byproduct of life (and a major component, at @ 21%, of air), was originally (about 2 billion years ago[12]) toxic to life, most forms of life have adapted so well to it today that life could not exist without it.[13] Byproducts of our own activities are the culprits that threaten the quality of our air today.

> The air around us (the atmosphere) is the most important part of our natural environment. Terminate the supply of breathable air and death follows in short order. Under natural biological conditions, breathing is not at all hazardous, provided the air is of proper and uniform

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[12] Henderson, Dr. C.M. Associate Professor, Department of Geology and Geophysics, University of Calgary, personal communication.

[13] McMenamin, M.and D. McMenamin. *Hypersea*. Columbia University Press, 1994. pp. 37 - 38.

> composition. Human activity, however, has polluted the air with biologically harmful substances and it is only in exceptional cases that this pollution is still insignificant. Recently, there have been occasions when the supply of satisfactory air for breathing has been actually endangered. Unfortunately, our senses cannot adequately evaluate the quality of the air.[14]

The above quote gives a clear idea of why airshed management is important -- the quality of the air influences health and life. Airshed management is an aspect of environmental management that is getting increasing attention on a global, international, and regional level.[15] In Alberta, airshed management has a direct link to our fossil fuel driven economy, making air quality issues economic issues.

The history of anthropogenic air pollution has been around since the first humans discovered fire. Large scale human induced changes to the air around us probably did not occur until the advent of the industrial revolution in the late eighteenth and the nineteenth centuries, when smoke stacks were viewed as symbols of wealth and economic progression. "The industrial revolution, by applying new forms of energy and organization to economic activity, multiplied human productivity many times and gave human beings greater power to transform the environment than ever before. Through industrialization, the influence of human activity on the environment is now on a scale that rivals the forces of nature".[16] It was in the late nineteenth century that the first steps were taken to control the emissions from these stacks (the Alcali Act of 1864 in

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[14]Leithe, W. *The Analysis of Air Pollutants.* Ann Arbour Science Publishers Inc. 1970.

[15] Strosher, M. *Investigations of Flare Gas Emissions in Alberta.* Alberta Research Council, 1996 p. 1

[16]*The State of Canada's Environment Report*, 1991. p. 2-7

England is the first piece of pollution control legislation[17]); we still do not have effective, coordinated control policies.

In Alberta, petroleum processing and other industries have created local and regional concerns about air quality and its effect upon human, animal, and ecosystem health. Project teams consisting of members of the public, interest groups, government, and industry are sprouting at a grass root level to decide what initiatives should be taken and how they can be funded. The Clean Air Strategic Alliance (CASA), sanctioned by the provincial government, acts as an umbrella organization for these project teams.

Industry is becoming increasingly involved as the people in nearby communities are becoming concerned for their health, the health of the animals and the condition of the land. Air quality may be the keyword, as demographics shift and the "baby boomers" are demanding better quality of life just when their impact on the environment may have the greatest potential.[18] Control, at a regional level where specific industries may be targeted by legitimate government, simplifies the process by streamlining the number of stakeholders, controlling costs, gives flexibility in the management response to deal with local and regional factors, and allows the specific targeting of problems with specific actions.[19] At the same time, communities that have regional concerns have easier access to the process.

A regional analysis has the potential to produce better data and ultimately, better information: "The analysis usually covers data from multiple sources, but includes only a single receptor. A regional analysis, combining data from all sources and receptors in the area, has the potential to provide a picture that is

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[17]Leithe, W. p.5

[18] Foot, David. *Boom, Bust, and Echo.* MacFarlane Walter & Ross, 1996. p. 40

both more accurate and more informative than that provided by a method restricted to a single receptor".[20] I am assuming that most receptors are valued most highly at the local or regional level (exceptions may be National Parks or World Heritage sites). A regional analysis allowing for more input from the community as opposed to a provincial or national assessment allows for identification of these valued receptors.

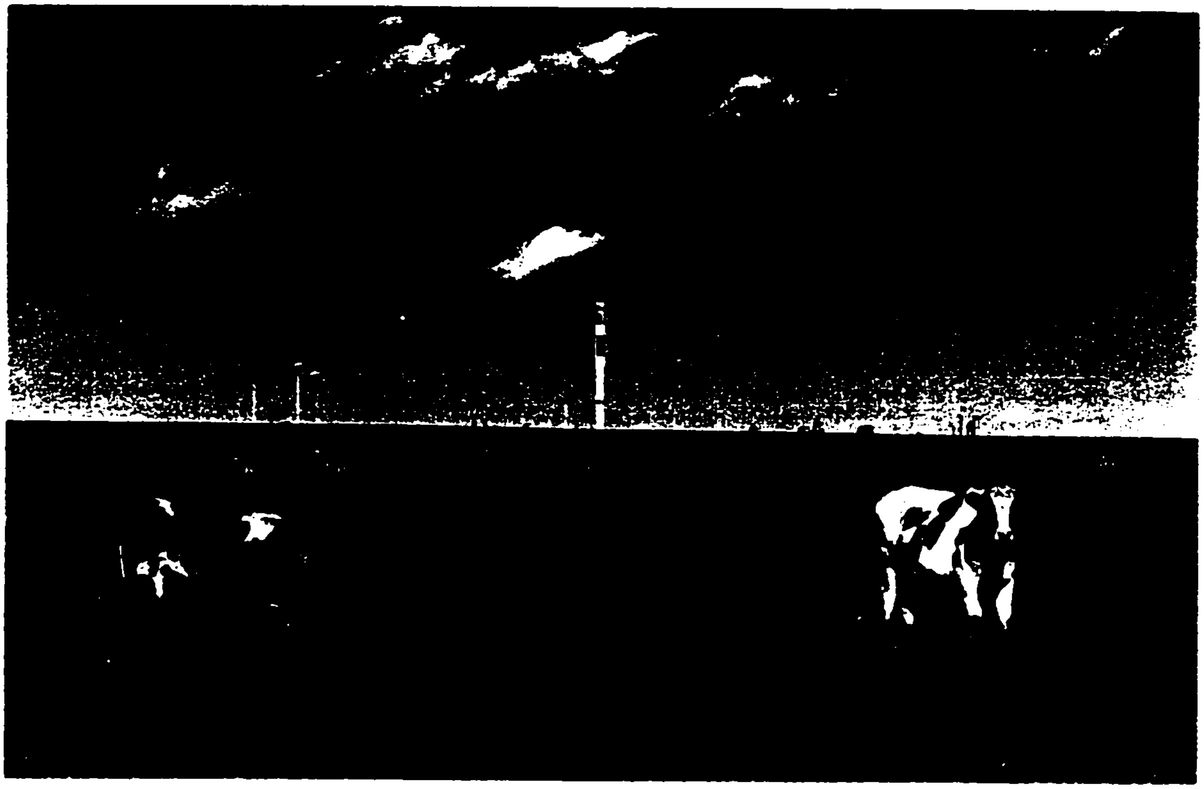

Illustration 1. Cattle Next to Gas Plant: Potential Valued Receptors

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[19] Clean Air Strategy For Alberta. Report of Working Group G-1, Zone Air Quality Management. June 1993. p. iii

[20] Cartright, Hugh and Stephen Harris. "Analysis of the Distribution of Airborne Pollution Using Generic Algorithms" in *Atmospheric Environment* Vol 27 No. 12 August, 1993.

Alberta does not have an air quality problem to the extent that major urban centres such as London (England), Los Angeles, or Mexico City do.[21] The reason for concern is that air pollution goes beyond the locality in which it is produced, and the effects of long term, low impact pollution (chronic or cumulative) are not well known.[22] Air pollution has regional, international, and global effects. The atmosphere is not a very large entity. In the words of a space shuttle astronaut, "For the first time in my life, I saw the horizon as a curved line. It was accentuated by a thin seam of dark blue light -- our atmosphere. Obviously, this was not the 'ocean' of air I had been told it was so many times in my life. I was terrified by its fragile appearance".[23]

The part of the atmosphere that we live in, breathe, and experience weather in is about 6 to 17 kilometres deep[24], with an average of only 10 kilometres.[25] It would take about ten minutes to drive through the layer that provides the entire globe with air, weather, and a global circulation system that transports and distributes heat, water vapour, and any air pollution we may generate.

Precautionary Principle

The concept of "prevention of significant deterioration"[26], also known as the precautionary principle,[27] has a role to play in airshed management. This means simply that it is desirable to stop air pollution from reaching certain (or any) places, even though the air quality in these places is cleaner than what would be required by current air quality standards. The concept of the prevention of

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[21] Campbell, Monica. Our Cities, Our Air, Our Helath: Perspectives on Urban Air Quality and Human Health, in The Environment and Canadian Society. Thomas Fleming, Edtor. ITP Nelson, 1997

[22] Shoemaker, Darryl.Cumulative Impact Assessment. Department of Geography Publication Series Number 42, University of Waterloo. 1994. p. 1

[23]Merbold, Ulf. as quoted in *The State of Canada's Environment Report*, 1991.

[24]*The State of Canada's Environment Report*, 1991. p. 2-4

[25]Oke, T.R. *Boundary Layer Climates. Second Edition*. Routledge,1990. p.3

[26]Stern, A.C. et al. *Fundamentals of Air Pollution, Second Edition*. 1984. p.33

significant deterioration is an underlying element of this project. The essence of the precautionary principle, as seen in the Rio Declaration on Environment and Development, is that lack of full scientific certainty of cause and effect relationships should not be used as a reason to prevent the implementation of preventative measures.[28] This approach has the core elements of the following:

- Proaction in the willingness to take action in environmental management without scientific proof;
- Intrinsic value of non--human elements of the airshed;
- Concern for future generations; and
- The view that regulatory inaction is unjustified.[29]

Prevention of significant deterioration is, unfortunately, not often heeded, especially when there are economic interests involved, as the following story suggests:

> It was in 1974 that University of California, Irvine, chemists F. Sherwood Rowland and Mario Molina discovered that chloroflourocarbons -- the ubiquitous household chemicals that make up a billion dollar worldwide industry -- could rise slowly to the upper atmosphere and destroy the earth's fragile ozone shield. Ozone is a pungent, poisonous gas. Wafting some 15 miles above the earth's surface, it helps shield living things from the sun's searing ultraviolet light. If ozone is lost, more ultraviolet light reaches the earth. This can lead to increasing rates of skin cancer, the death of some microorganisms, and the failure of crops and plants.

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[27]VanderZwaag, David. *CEPA and the Precautionary Principle/Approach. Reviewing CEPA, The Issues, #18.*, 1994. p. 1

[28]VanderZwaag, D. p. 7

> Rowland and Molina hurried to alert the world of their findings. But they were naive. Although their theory was judged to be correct in 1976, they were to discover that billions of dollars in profits would outweigh a potential environmental problem whose onset and magnitude were unknown.[29]
>
> In their quest to rid the world of these chemicals ... Rowlands and Molina faced a curious dilemma. Since CFCs take a hundred years or more to decompose in the atmosphere, damage to the ozone layer takes place long before it becomes apparent. Prudence would suggest that the chemicals be banned before any damage was done. But prudence was misplaced in the case of the ozone crisis.[30]

I am not suggesting that the entire oil and gas industry in Alberta or elsewhere be shut down -- the industry is essential to our way of life. However, as a participant at the Acidifying Emissions Symposium in Red Deer, Alberta (April 1996) states: "As a province built on energy resources, whose prosperity depends not only on accommodating but anticipating changes in the demand for energy, Alberta cannot afford to neglect air quality. This connection between air quality and fossil fuels is too direct and too important for Alberta to ignore."[31] I am suggesting that effects of and interactions between emissions on receptors be monitored carefully and the negative effects reduced by industry and government, using a portfolio of management tools, both proactive and reactive.

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[29] VanderZwaag, D. p. 7

[30] Roan, S. *Ozone Crisis: The 15 Year Evolution of a Sudden Global Emergency.* Wiley Science Editors, 1989. p. vii

[31] Guidotti, Dr. T. "Air Quality Studies in Alberta: Past and Future". *From The Acidifying Emissions Symposium 96 in Red Deer Alberta*, April, 1996.

These tools may include the maximum available control technology, legislation, economic instruments, environmental auditing, performance indicators, strategic environmental assessments, and concepts of precaution in conjunction with an interdisciplinary approach to problem solving.

Identification of Valued Ecosystem Components

Valued environmental (ecosystem) components, or VECs, is the term used by Beanlands and Duinker.[32] For this project, the valued ecosystem components will be considered to be clean air, clean water, non-acidified soil, vegetation (both natural and crops), healthy animals, healthy humans, and other parts of the ecosystem that have an aesthetic, human, economic, or emotional significance . The West Central Project team under CASA, for comparison, has identified the issues in their zone as "soil acidification, pollution stress on vegetation (agricultural crops and forests), human health, visibility, odour, and livestock health".[33] Each of these is influenced by the degree to which we can achieve the valued atmospheric components that constitute clean air.

Towards Sustainability

Views about environmental management lie on a continuum. This continuum is discussed in the State of Canada's Environment report for 1991, the source for the following discussion.

On one extreme lies the concept of "frontier economics". The environment is seen as being infinite, and the focus is on a resource-based economy. Moving towards the centre is a philosophy of resource management. This view includes the environment in its calculations, but only as a secondary consideration to economics. Here we see the concept of polluter pays, and environmental mitigation and assessment. Assessment and mitigation are largely an

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[32] Beanlands, G.E and P.N. Duinker. p. 8

[33] West Central Regional Airshed Monitoring Program Technical Design. July 1, 1994 p. iii

afterthought, after the planning for the project has been completed. Moving to the other extreme lies the realm of the "deep ecologists", or of deep environmentalists. The economy is given the back seat to the environment. The environment itself is viewed as limited and fragile. Moving towards the centre, from this extreme, is the philosophy of what the State of the Environment Report calls "selective environmentalism". The economy again takes a back seat to the environment as a plethora of environmentally friendly products are produced, and environmental preservation and planning take place.[34]

This brings us to the "central" philosophy on the spectrum, termed "sustainable development". This philosophy is a balanced approach between environment and economics. Here the long term health of the environment is seen as the cornerstone of a healthy economy, a symbiotic relationship. The environment is taken into account before decisions are made, allowing the mitigation approach common in many environmental impact assessments (EIAs) to blossom into the preventive approach championed by SEA philosophy. The view of this project is that sustainable development is the best mix of environment and economy, given the tenets of the theory and the relationship between Alberta's fossil fuel driven economy and the environment. The concepts of the prevention of significant deterioration and of a strategic environmental assessment are consistent with sustainable development.

Summary

The importance of air quality to life and the fragility of the atmosphere are essential concepts. To aid in the environmental assessment of an airshed, a checklist of factors including the physical attributes of an area, the valued ecosystem components (VECs) within that area, common emissions, and policy tools available should be compiled. There is a need for regional analysis to give better information about the effects of air pollution and to aid in making better

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[34] *The State of Canada's Environment*, 1992. pp. 1-5 to 1-7.

decisions. The selected study area will provide a case study for a regional analysis. The use of a strategic environmental assessment (SEA) can help in predicting and preventing the effects of potential cumulative impacts, and reducing potentially expensive mitigative efforts later. The concept of the prevention of significant deterioration, or the precautionary principle, can be used in the quest for sustainable development and the movement from mitigation to prevention on a philosophical basis.

Part Two : Linkages

CHAPTER 4 -- AIRSHED MECHANICS

Airshed Mechanics

Airshed management should consider the complexities of the transportation and deposition of pollutants, because "sound and objective scientific descriptions of environmental problems and ways to solve or avoid them are the first steps in effective environmental management."[35] Therefore, an airshed management strategy must first address the nature of these complexities, which will be addressed in this chapter.

Main Points

- The factors controlling emission deposition are complex, and may involve a very large geographical area. Because of this, airsheds may cross political boundaries. For purposes of effective control, an area should be designated as an "airshed" under one political unit to reduce the level of political complexity involved, but not to the exclusion of intergovernmental cooperation.
- Wind data, in the form of wind roses and pollution roses, are useful in the placement of monitoring devices.
- Topography that has the potential to encourage deposition (hills, terraces, river valleys) can be used in the placement of monitoring devices.
- Consideration should be given to modelling specific plumes in specific localities to learn of potential zones of deposition and if they contact valued receptors.
- The need for prevention as well as mediation is emphasized by the "surge effects" -- a sudden release of pollutants trapped in snow -- encountered during common chinook events.

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[35] Thompson, Dixon. p. 220

Background

A study of airshed management presupposes undesirable inputs into the airshed, otherwise the need to manage it disappears. Traditionally, undesirable inputs have been termed pollution. "Air pollutants are substances which, when present in the atmosphere under certain conditions, may become injurious to human, animal, plant or microbial life, or to property, or which may interfere with the use and enjoyment of life and property".[36] Similarly, the World Health Organization (WHO) has defined air pollution as: "Air pollution occurs when one or several pollutants are present in such amounts and for such a long period in the outside air that they are harmful to humans, animals, plants, or property, contribute to damage or may impair the well-being or use of property to a measurable degree".[37] The immediate, or local, effect of these pollutants is determined by the nature of the emissions and the state of the atmosphere.[38]

A Leaky Box

"Airshed" is an unfortunate term. It implies the same certain geographic boundaries of a watershed, where it is possible to locate and map all of the inputs to the water regime of a certain area, and call this unit a watershed. Plotting the inputs to a certain geographic area designated as an airshed would include not only those sources in that specific area, but those emissions transported there from other regions. This long range transport could involve sources worldwide, yet it is not effective, in the short to mid term, to manage it globally. An airshed, in the words of R.E. Munn, "is a very leaky box indeed."[39] The term airshed was coined by someone who knew little about the actual workings of such a leaky box; President Kennedy of the United States used the term in a speech to the United Nations in the 1960's, and it has, for better or for

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[36] Oke, T.R. p. 304
[37] Leithe, W. p. 4
[38] Oke, T.R. p. 304
[39] Munn, R.E. p. 125

worse, stuck.[40] Two other terms used to describe an airshed are air basin and air quality control region. The latter is used to describe "the geographic area including the sources significant to production of air pollution in an urbanized area and the receptors significantly affected thereby."[41] This definition is close to what is meant by the term "airshed" in this paper, except that the definition in this paper is necessarily broader to include rural areas as well.

An airshed has no fixed boundaries; it is able to be manipulated by local weather, prevailing winds, and topography, as well as by the properties of the emissions themselves, such as lifetimes. Chemicals have various known lifetimes, ranging from seconds to minutes to years or centuries (see Chapter 5). The length of time each input remains in the air, and therefore in circulation, will determine the affected "airshed". An airshed, therefore, can in theory be as small as local fallout and as large as the global air circulation, depending on the lifetime of each input, the state of the atmosphere, and the controlling topography. In practice, the "airshed" is governed by the political boundaries or affiliations of the emitting region. It has been suggested by others that the boundaries of a zone, or airshed, be dependent on topographic, meteorological, emission, jurisdictional, and management factors.[42] For control purposes, airsheds can be designated arbitrarily within political or other units that are not related to science; I have selected the study area in this arbitrary manner, as the "physical bounds of open systems such as oceanic or atmospheric"[43] are more difficult to set. Setting the airshed boundaries within a single political unit is not meant to exclude the cooperation between governments on this clearly cross-jurisdictional problem. Another way to cross political boundaries without the cooperation of governments is through multinationals. Technology, information,

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[40] Munn, R.E. p. 125
[41] Stern, Arthur et al. p. 379
[42] Clean Air Strategy for Alberta. Report of Working Group G-1. p. iii
[43] Beanlands, G.E. and P.N. Diunker. p. 50

and systems transfer within these corporations could bring an element of consistency to environmental management solutions on a global level.

Setting the Stage -- Scientific Bases of Environmental Problems

Energy Balance of the Earth, Atmosphere, and Sun

The energy balance of the earth, atmosphere, and sun may seem only remotely connected to the topic of air pollution. However, the connection is direct. First, it is the energy balance between the sun and the earth that directly affects the motion of the atmosphere, which in turn controls the distribution of pollutants. Second, the concentration of air pollutants affects the energy balance in the earth - sun system itself.

Radiation from the sun is transferred to the earth in the form of energy, each unit with a particular wavelength. The earth - atmosphere system absorbs some of this energy and re-emits some of it. The atmosphere can absorb incoming solar radiation, as well as outgoing radiation from the earth's surface, but is open to some radiation loss to space. This is necessary to maintain the constant average temperature of the earth, and is called the "atmospheric window".[44] It can be partially closed by atmospheric pollutants, creating what is popularly known as "the Greenhouse Effect."[45]

Atmospheric Mechanics

The airshed is a part of the atmosphere, and is affected by atmospheric processes. Any understanding of an airshed and the control of inputs into it must include an understanding of these atmospheric processes. This includes solar heating; cooling of the earth's surface and the related concepts of mixing

[44] Oke, T.R. p. 15

[45] Hare, Kenneth F. Global Warming, in The Environment and Canadian Society. Thomas Fleming, Editor. ITP Nelson, 1997. p. 135

and inversions; winds and local wind systems; and the Earth-Atmosphere radiation balance, discussed above.

The Earth's atmosphere consists of layers. These layers are known as the troposphere, mesosphere, and stratosphere. The troposphere affects the earth's surface the most intimately. It is a layer about ten kilometres thick, in which all weather occurs. The atmosphere can be subdivided further into the boundary layer, which itself can be subdivided into turbulent surface layer, the roughness layer, and the laminar layer.[46] These layers come into play in airshed management; the turbulent surface layer plays a part in the transport of pollutants, the roughness layer in the deposition, transport, and creation of pollutants, and the laminar layer on the receptor, or sink. The turbulence associated with these layers, surprisingly, also controls the number and quantity of pollutants emitted into the airshed from burning, such as oil and gas field flares.[47] This will be discussed in Chapter 5.

The turbulent surface layer consists of about 10% of the entire planetary layer[48], and is generated by movement over uneven topography. The roughness layer lies below the turbulent surface layer, and extends from one to three times the height or spacing of objects (buildings, hills, trees, etc.) on the surface.

The laminar layer, by contrast with the other two layers above, is in direct contact with the surface of the object (a leaf, blade of grass, etc.). "It is the non-turbulent layer, at most a few millimetres thick, that adheres to all surfaces and establishes a buffer between the surface and the more freely diffusive environment above."[49] This buffering capacity is important in the pollutant uptake of plants. No convection takes place in this layer, and all non-radiative transfer between the

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[46]Oke, T.R.
[47] Strosher, M.
[48]Oke, T.R. p. 40

plant and the atmosphere is by molecular diffusion.[50] The laminar layer and molecular diffusion will be referred to again in Chapter 6 - Receptors. Laminar flow is also a critical factor in the burning efficiency of oil and gas field flares.[51]

The boundary layer as a whole is what affects the earth's surface on a day to day basis. It is influenced by the sun and the nature of the surface it flows over, resulting in convective mixing. Convective mixing occurs as the sun heats the surface of the earth. This heat rises into the cooler atmosphere as a buoyant package of air and mixes with it. This is known as free convection.[52] Forced convection occurs as packages of air pass over the irregular surface of the earth and are forced into motion by these features -- for example, hills, buildings, or valleys.[53] The resulting eddies (turbulence) play a role in the dispersion and deposition of effluents.[54]

Stability and Instability

Two terms are used in describing atmospheric conditions -- stability and instability, although the terms are often found confusing.[55] If the conditions are conducive towards free convection (sunny, warm surface), the atmosphere has a high degree of instability.[56] If conditions do not promote convection -- for example, at night when there is no sun and cooling is occurring -- the atmosphere is stable.[57] Stability implies a compression of the boundary layer, and instability implies an expansion. Neutral stability implies neither is occurring. This is typical of cloudy, windy conditions where there is little surface heating,

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[49] Oke, T.R. p. 6
[50] Oke, T.R. p. 38
[51] Strosher, M. p. 107
[52] Oke, T.R. p. 16
[53] Oke, T.R. p. 17
[54] Oke, T.R. pp. 186 - 187
[55] Angle, Randy. Head, Air issues Branch, Alberta Environment, personal communication.
[56] Oke, T.R. p. 52
[57] Oke, T.R. p. 53

and therefore little cooling at night. For the purpose of diluting (a strategy that is used but is not necessarily desirable) inputs into the atmosphere, a highly unstable boundary layer is needed.

Winds

Winds are a product of solar heating. As air warms, it expands and loses pressure. As this warm air meets colder and denser air, a front forms and winds are created by the pressure difference.[58] The wind speed controls dispersion, turbulence controls dilution, and wind direction controls the path of the effluents and determines the area of deposition. Wind is the primary agent of dilution and transport of effluent. Evaluating local wind patterns seasonally and daily is an important component of airshed management. Monitors can be placed in areas where local fallout may tend to occur; while this will not guarantee accurate measurements[59], it could increase the probability of accuracy.

Mixing Depth

The depth of the boundary layer is inconstant, depending on the strength of the mixing generated. In the daytime and particularly in the summer in Alberta, the depth of the boundary layer may reach one to two kilometres due to strong surface heating. At night this layer shrinks as the earth's surface cools much more rapidly than the air. As a result, heat is transferred downwards, repressing mixing. This process has a significant effect on pollution sources. During the daytime, in particular late morning to late afternoon, strong mixing is likely to occur, taking emissions out of the local area and diluting them. At night, the lack of mixing allows for higher local emission concentrations and fallout; early morning can provide low level mixing underneath a stable layer, which results in a fumigation (a dense concentration of effluent) at ground level.

Table 1 presents typical mixing height in Alberta:

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[58] Oke, T.R. p. 27

Table 1. Mean Seasonal Mixing Heights (metres) in Alberta[60]

Month	Morning	Afternoon
Dec., Jan., Feb.	400	500
March, April, May	500	1750
June, July, August	450	2500
Sept., Oct., November	425	1200

During the warmer months, the mixing height by day is much greater (up to four times) than during the winter, resulting in higher potential levels of dilution.

This known shift of stability by seasonal and diurnal patterns potentially could be used to advantage when planning scheduled down time for industry. Any likely periods of stability could be considered for this purpose to decrease the concentration of emissions at local or downwind sources. For example, nighttime in the winter tends to be extremely stable and may be viewed as a good time to plan maintenance. Science supports this: a study of average ground concentrations of certain compounds found that concentrations were higher in the winter due to higher incidence of ground based inversions.[61] However, logic and economics do not -- shutting down on a cold winter night is not an effective economic or social solution. Management solutions for industry must therefore forego prevention and use other tools in the management portfolio such as the maximum available control technology.

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[59] Strosher, M. p. 113

[60] Legge, A.H. *The Present and Potential Effects of Acidic and Acidifying Air Pollutants on Alberta's Environment*. The Acid Deposition Research Program, Critical Point 1 Final Report. p. 513

[61] Leahey, D.M. "Estimated Ground Level Concentrations of Products if Incomplete Combustion (PIC)Associated With Flaring Activities at Two Sites in Alberta", in *Investigations of Flare Gas Emissions in Alberta*. Alberta Research Council, 1996. page 2

Topography and the Movement of Air

Regional topography controls the movement of air. For example, in the winter in Alberta, cold air "ponds" itself up against the mountains, which may result in long periods of cold weather. This ponding effect concentrates emissions because mixing is severely repressed at a regional scale. Another example of topographically controlled air can be seen in California: "In 1542, the Spanish explorer Juan Cabrillo entered what is now Los Angeles' San Pedro Harbor. In his diary, he wrote not only of the magnificence of the Los Angeles basin with its ring of mountains, but also of the smoke from the Indian fires that rose straight up a few hundred feet and then, as if encountering an invisible barrier, spread horizontally over the valley. He named the harbor the Bay of Smoke."[62]

The Los Angeles Basin today is renowned for its pollution problems, and for being the type area for photochemical "Los Angeles type smog". Topography and air movement within the basin is largely responsible for the extent of the problem -- although the large number of sources is of course the ultimate cause.

The role of topography is further explored later in the chapter. The following discussion on plume types explores the linkages of stability patterns to wind and topography.

Plume Types

Sources of air pollutants can be of different types. For example, a volcano spouting ash would be considered a point source. A city is an area source. A whole gaggle of dragons driving up and down the Trans Canada highway in their Porsches is a line source. The simplest source to consider is the point source, as it remains stable in space. Petroleum industry sources are typically point sources -- for example, a gas plant or a gas flare. The plume emitted from the

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[62]Greyson, Jerome. *Carbon, Nitrogen, and Sulphur Pollutants and Their determination in Air and Water.* 1990. p. 6

point source is then manipulated by local weather patterns. The plume assumes a variety of forms, depending on these patterns. The important aspect of the plume is the point when it comes into contact with a receptor and the length of time the receptor is then exposed.

Looping

This plume is most often seen in the daytime under strong instability, conditions that are unusual in Alberta[63]. The large eddies of air associated with free convection carry the plume up and down like a rollercoaster. This type of plume will contact the ground relatively rapidly. [64] Hot and sunny conditions may indicate that receptors close to the point source may be vulnerable – people, vegetation, or cattle. In the study area, this type of plume would be worst case scenario in the summer time. Lack of time before the plume contacts the ground means that the emission has not been diluted by mixing with surrounding air. [65]

Coning

This type of plume occurs usually under windy conditions and a neutral atmosphere. The plume forms a cone shape around its centreline, as it is being forced neither up nor down. As the width of the plume grows only by diffusion, it will contact the ground only at a point when the plume is wide enough. This indicates that receptors downwind of the source will be affected, but also that the effluent is likely to be diluted by diffusion.[66] This type of plume is common in Alberta.[67]

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[63] Leahey, D.M. p. 16

[64]Erbrink, Hans J. "Plume Rise In Different Atmospheres: A Practical Scheme and Some Comparisons With Lidar Measurements" in *Atmospheric Environment* Vol. 28 No. 22 December 1994 p. 3628

[65] Oke, T.R. p. 323

[66] Oke, T.R. p. 325

[67] Leahey, D.M. p. 16

Fanning

Fanning is likely to occur under strongly stable conditions (at night or under an inversion). There is little motion to act on the plume in a vertical direction, although winds may allow it to fan out laterally. This type of plume is very common in Alberta, particularly in the winter time when cool air ponds up against the Rocky Mountains and a long term, regional inversion occurs.[68] It also happens frequently at night when radiative cooling inversions occur. It indicates that receptors downwind from the point source will be affected.[69]

Lofting

Lofting is viewed as a very favourable type of dispersal plume because of its ability to dilute effluent but it is short lived. It occurs in the early evening when the inversion common at night is building up from the surface. As long as the inversion is lower than the stack height, the plume is forced upwards in the still unstable layer above the inversion. This allows the effluent to be dispersed and diluted before it reaches ground level.[70]

Fumigation

Fumigation is the worst-case scenario type of plume. Unfortunately, fumigation happens frequently in Alberta in the winter.[71] It occurs as the nocturnal inversion erodes, for example, just after sunrise. Before the inversion erodes, a zone of instability under a stable cap is created. This forces the plume downward, causing a fumigation at ground level. This situation may become particularly unpleasant when a fanning plume has occurred during the night. Fanning plumes can be carried for a hundred kilometres without touching the ground.[72] As the inversion erodes, the plume is forced downwards along its entire length. This scenario is common, as well, along river valleys. Trail, British Columbia,

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[68] Leahey, D.M. p. 16
[69] Oke, T.R. p. 325
[70] Oke, T.R. p. 325
[71] Leahey, D.M. p. 16

provides a real example of this happening. A source released large amounts of sulphur dioxide in a river valley. At night, this plume travelled down the valley with the local wind system. In the morning, a fumigation occurred along the entire valley.[73] This effect was described as:

> The presence and properties of an inversion layer are critical to the dispersion of hot fumes. When a rising buoyant plume is able to penetrate an inversion layer, the stability of the layer prevents the plume from mixing downwards and the ground concentration of the fumes remains low. On the other hand, if the plume cannot penetrate the layer, upward dispersion is prevented, and the plume material is trapped beneath the inversion, leading to a high ground concentration of the fumes.[74]

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[72] Oke, T.R. p. 325

[73] Oke, T.R. Boundary Layer Climates. p. 323 - 325

[74] Zhang, Xiaoming and Ahmed F. Ghoniem. "A Computational Model for the Rise and Dispersion of Wind-Blown, Buoyancy-Driven Plumes - III. Penetration of Atmospheric Inversion". in *Atmospheric Environment* Vol. 28 No. 18 October 1994. p. 3019-3020

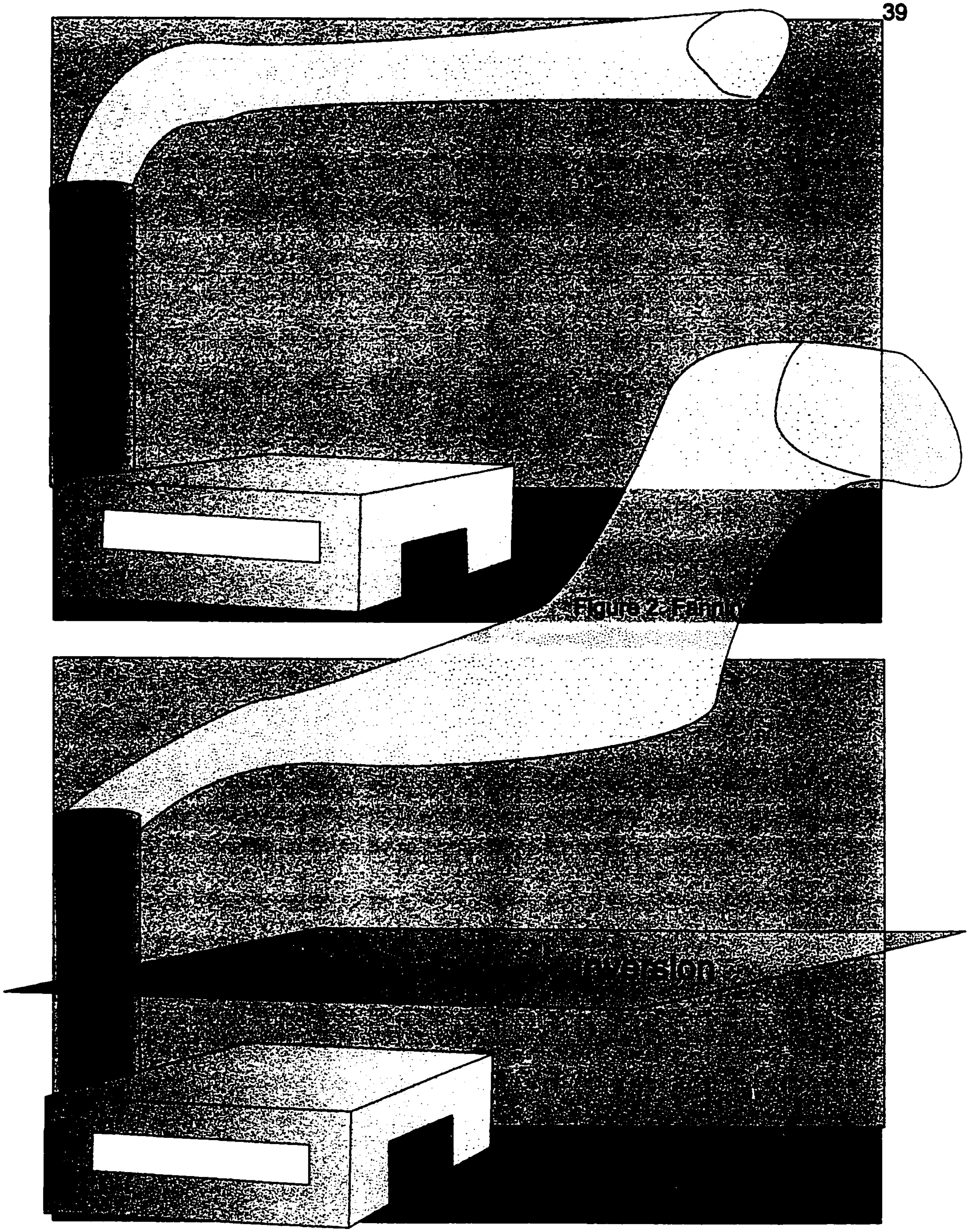
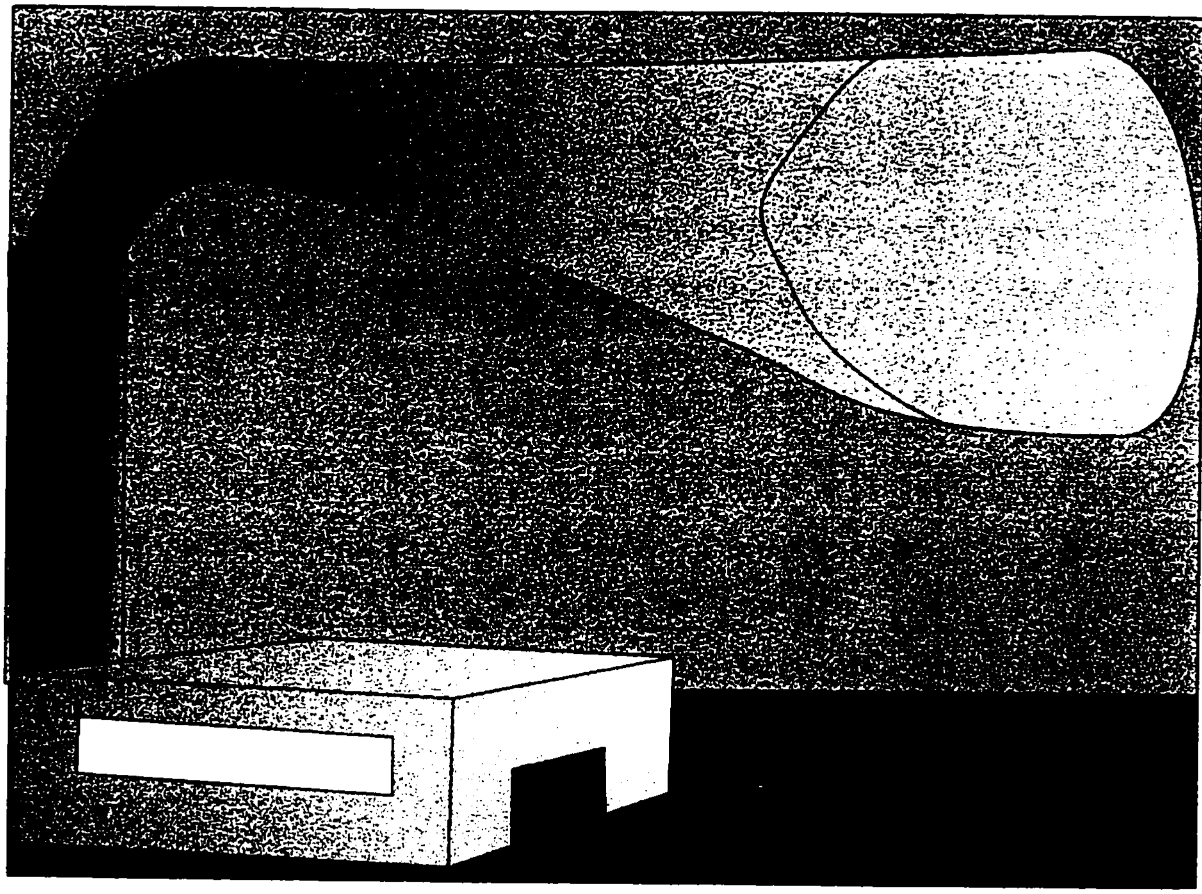
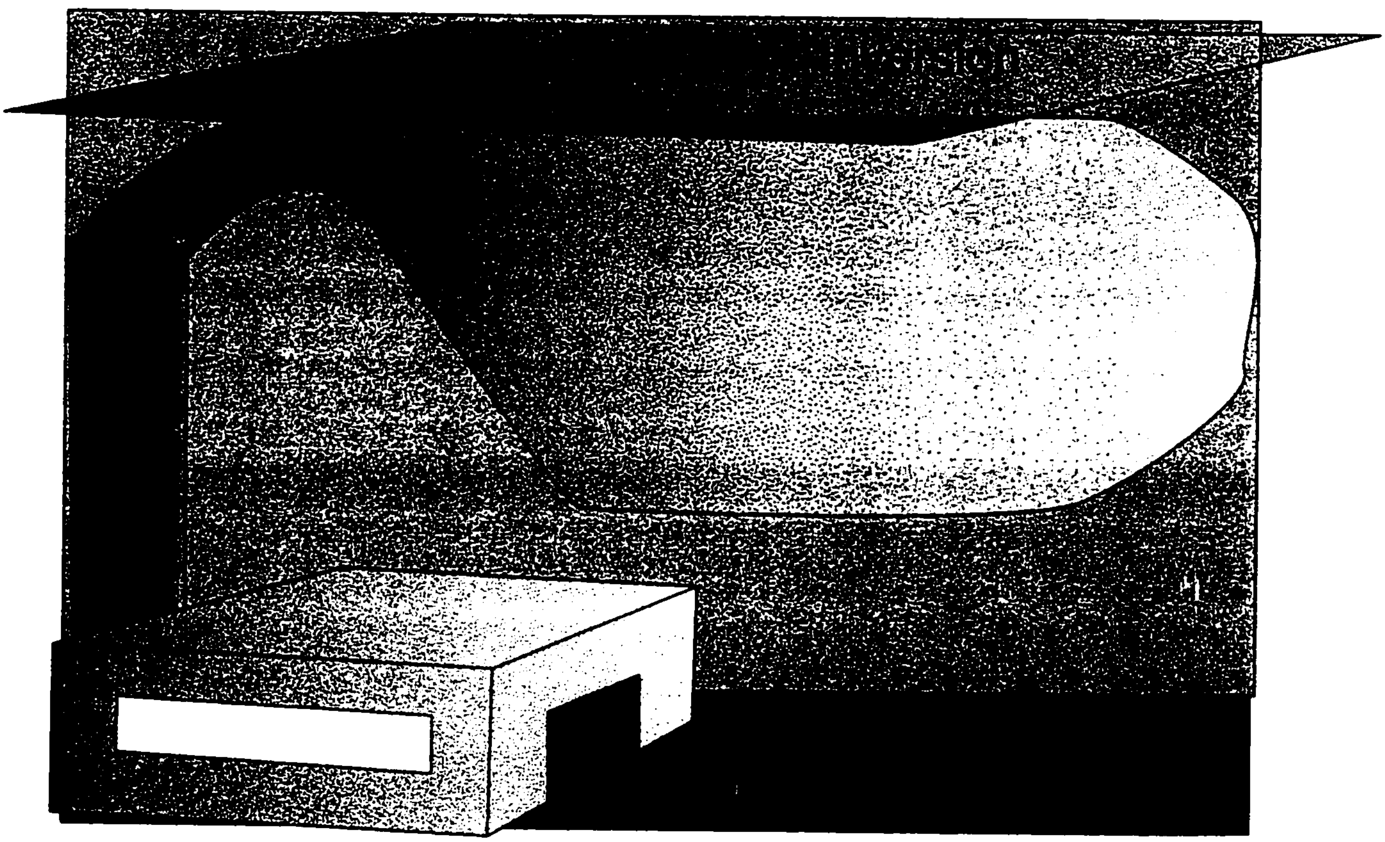
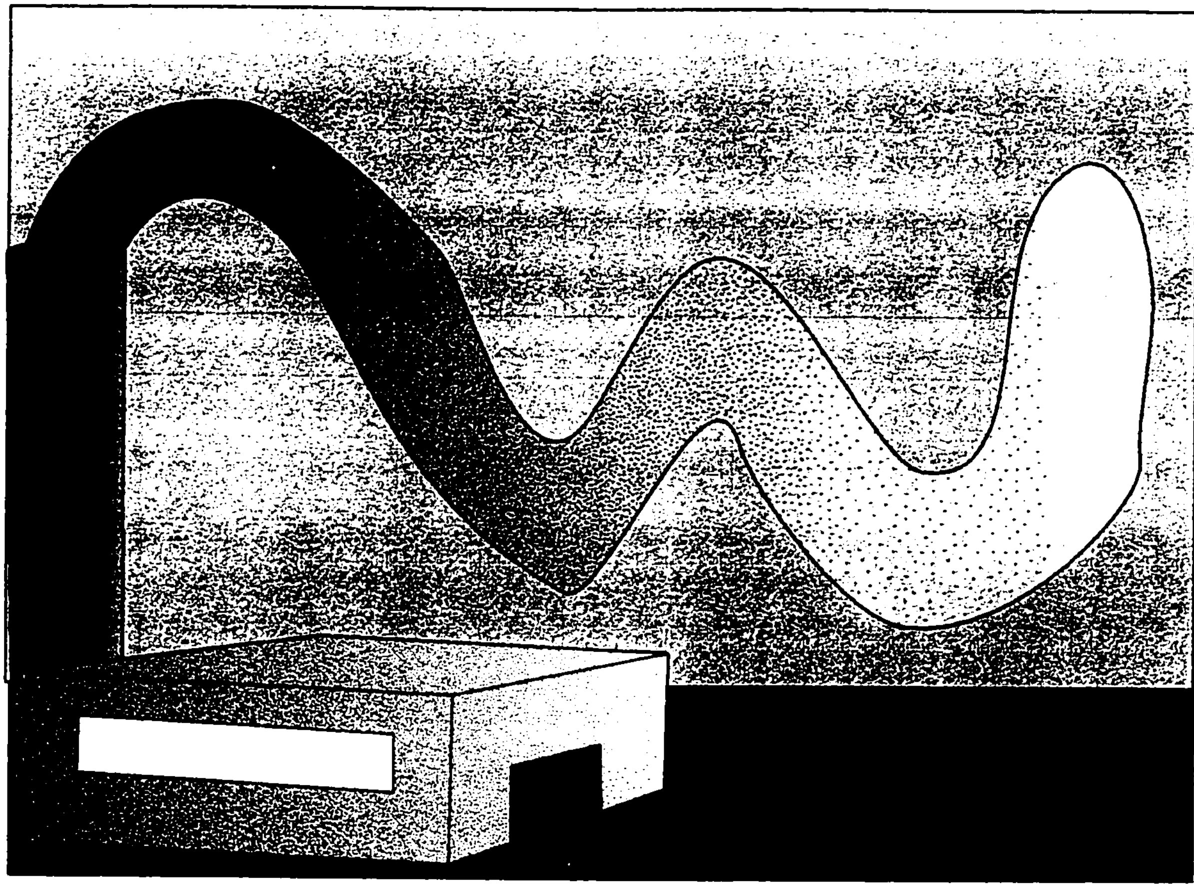


Figure 2: Fannin
Inversion







Other depressions, such as old river terraces in river floodplains, may also collect this type of effluent. It is possible for topography to block the downstream passage of the effluent, creating a much higher concentration at this locale. The placement of monitoring devices should take into account the influence of topography.

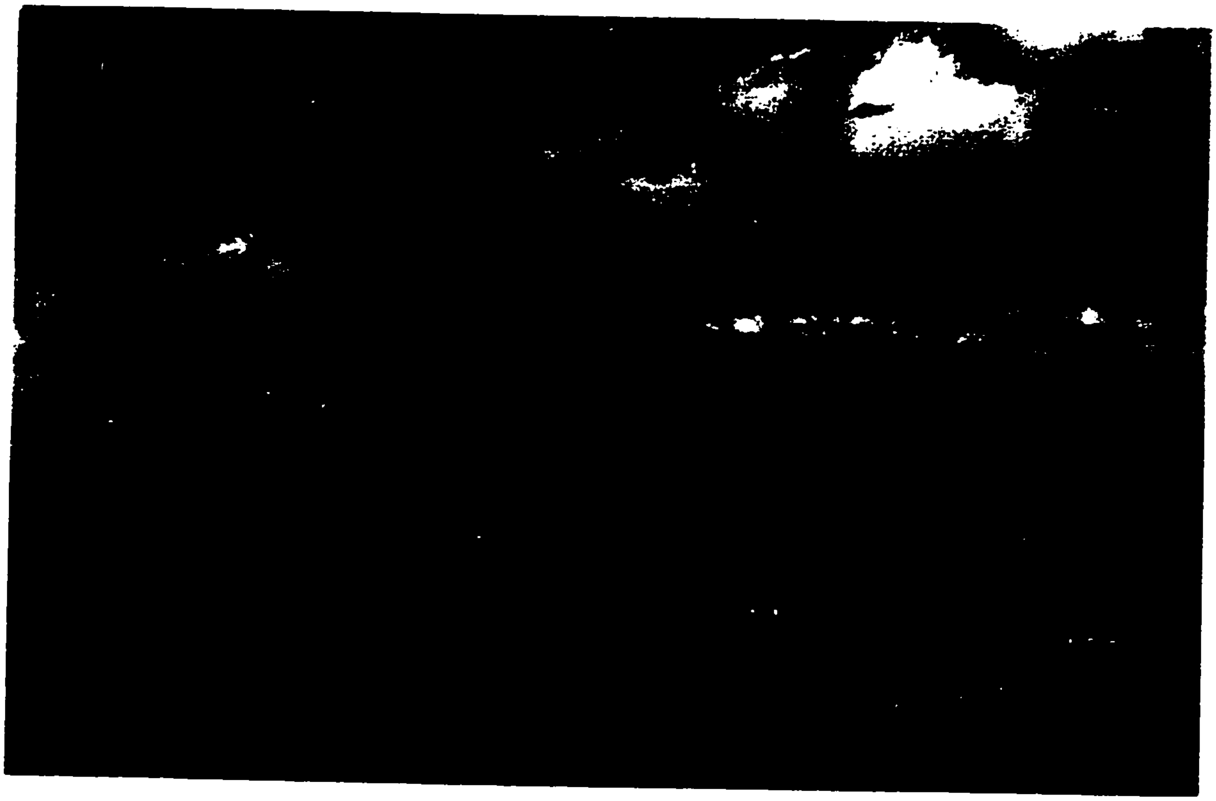


Illustration 2. Gas Plant in River Terrace

Management Responses to the Environmental Situation

The above descriptions of plume types illustrate the intimate connection between sources of pollution, atmospheric mechanics and topography. Each should be taken into account in a comprehensive airshed management program, and the appropriate preventative or responsive management tool used. Diffusion modelling can be done to indicate where a plume will touch down in a given wind and weather situation (see Chapter 9). Use of this type of modelling should be considered in the placement of monitors. It may result in the development of mobile monitoring stations or simply more stationary monitoring systems, or identification of components in the region that have value and need to be monitored. Also, because concentrations of a pollutant are directly porportional to its emissions rate[75], the volume of product the plant is able to process should (scientifically) be proportional to the stability of the atmosphere to alleviate high local concentrations of compounds. For example, high levels of fossil fuel production could be considered during windy, neutral periods but not during inversions. Logically, this may not be practical for marketing the product or for cycles of demand, and would probably drive the price of the product up. Methods of storage could alleviate these problems. Technology more efficient at removing emissions is another, more practical answer, but again, probably would drive up costs of the product due to greater capital investment on the part of the producer. Wind as an agent of atmospheric motion is discussed below.

Wind and the Effect on Plumes

Wind can both dilute and transport a plume. Small eddies in the wind will dilute the plume; eddies larger than the plume will transport it. This affects the plume both along its path and across it. Eddies are influenced by surface roughness, including hills and buildings. An eddy against a building, hill, or in a depression may encourage the deposition of effluents. This process is illustrated on the following pages.

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[75] Leahey, D.M. p. 16

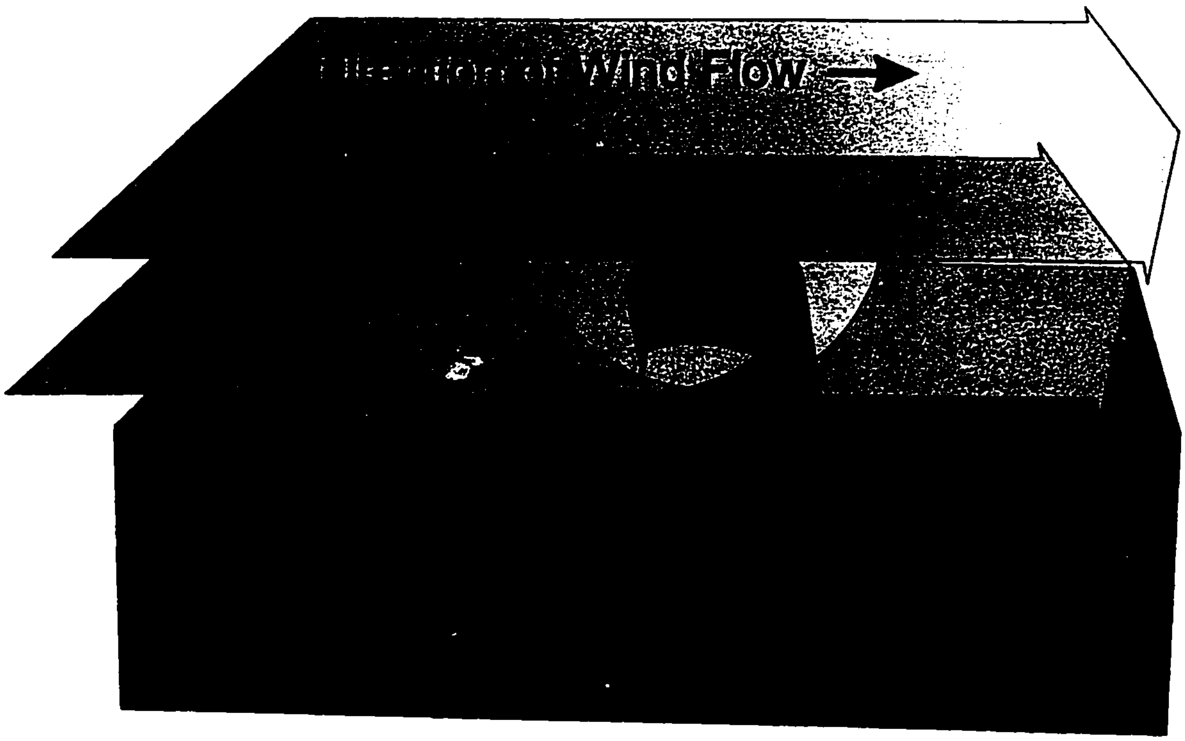

Figure 7. Eddy creation and potential pollution deposition zone-narrow valley scenario. Adapted from T.R.Oke, Boundary Layer Climates, page 185.

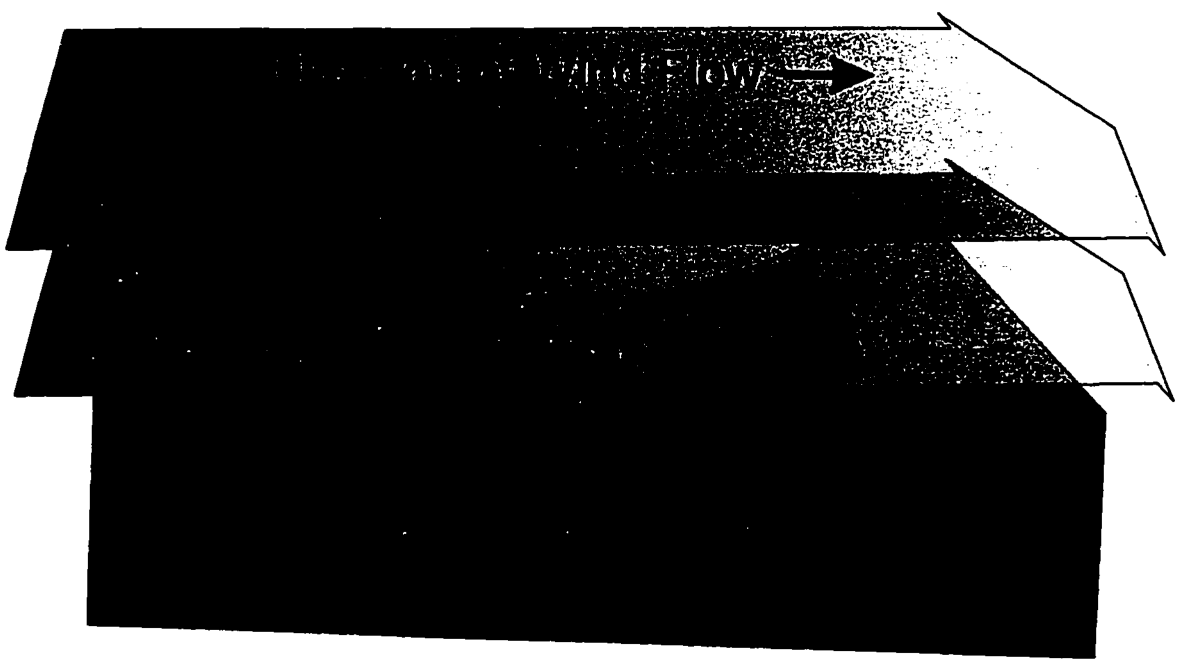

Figure 8. Eddy creation and potential deposition zone - wide valley scenario. Adapted from T.R.Oke, Boundary Layer Climates, page 185.

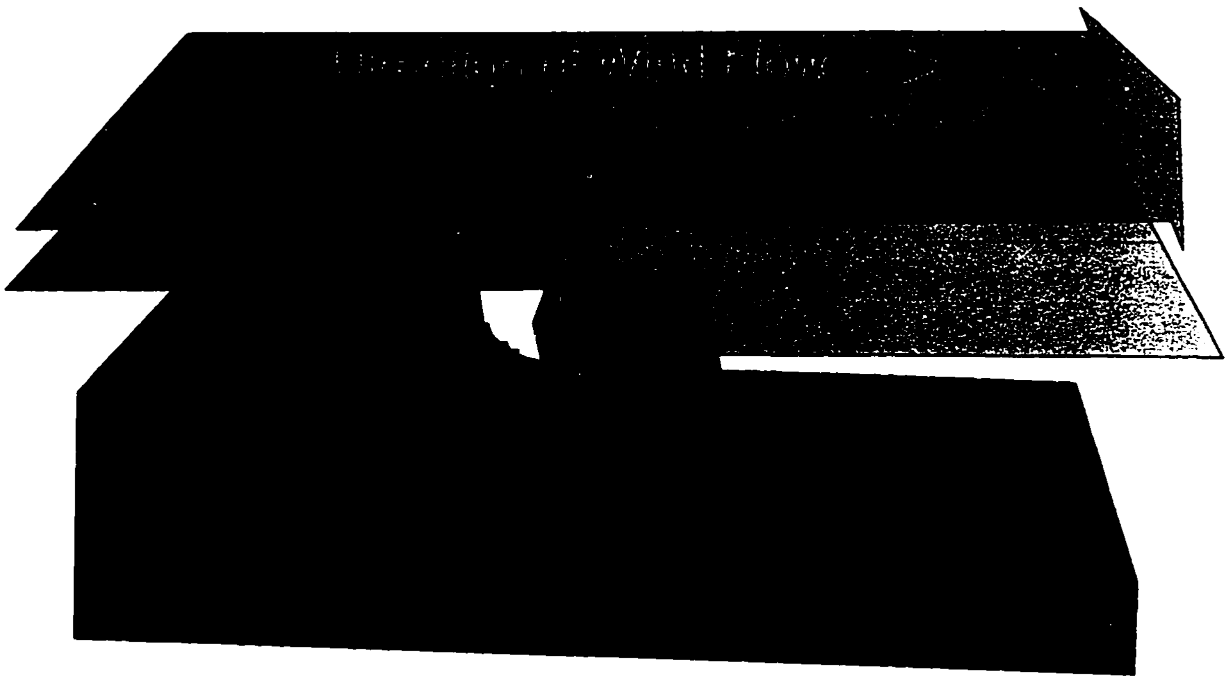

Figure 9. Eddy creation and potential deposition zone - river terrace (down) or escarpment. Adapted from T.R.Oke, Boundary Layer Climates, page 185.

Figure 10. Eddy creation and potential deposition zone - river terrace (up) deposition area. Adapted from T.R.Oke, Boundary Layer Climates, page 185.

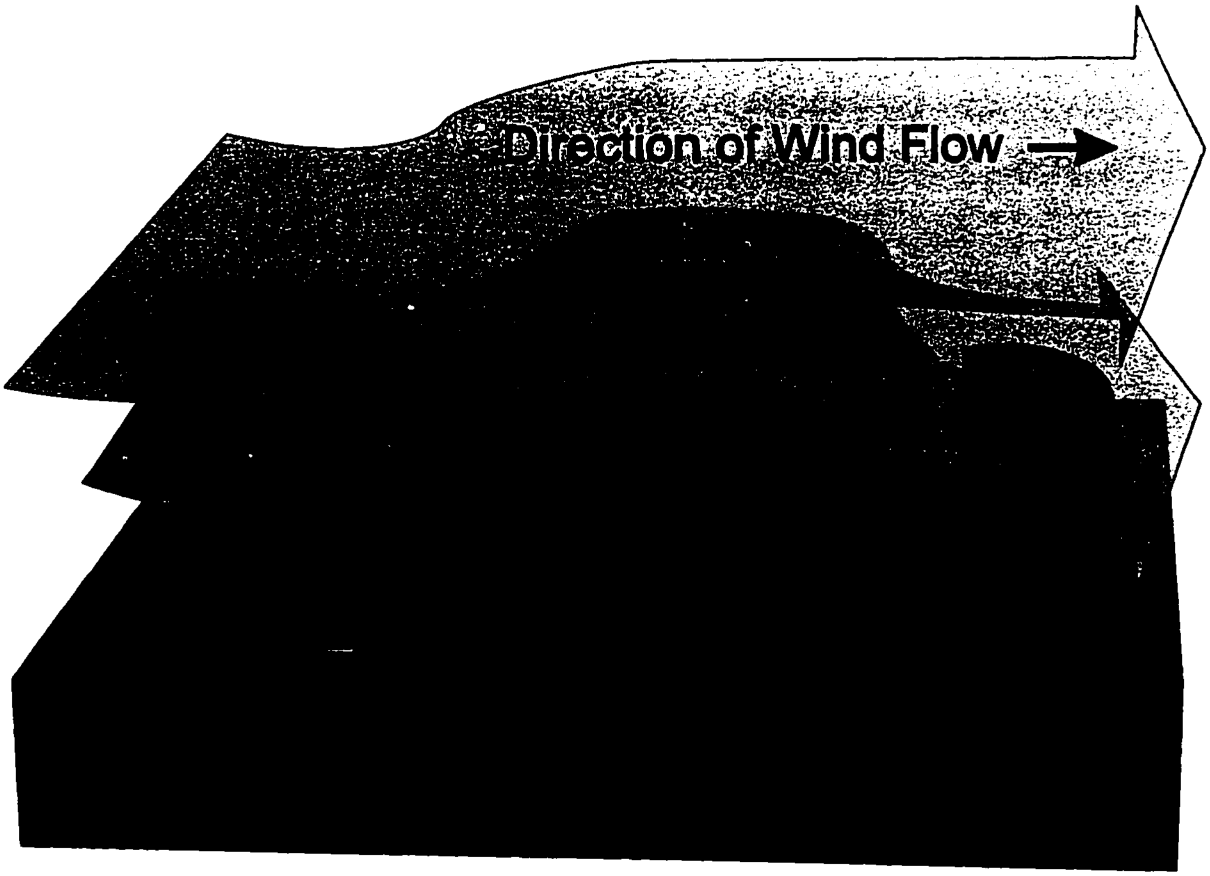

Figure 11. Eddy creation and potential deposition windward and leeward of a hill . Adapted from T.R.Oke, Boundary Layer Climates, page 185.

The higher the wind speed, the more air there is to dilute the plume. "This is the concept of dilution by forward 'stretching' and is directly related to wind speed."[76] Turbulence involves movement of the wind in various directions and will dilute the plume.

Pollution Roses - A Management Tool for a Strategic Assessment

Wind direction is important in the transport of emissions. As wind directions shift continuously over time, emissions "spray" through these directions. This concept is illustrated in the phrase that "wind is circular"[77]; in effect, wind does not come from one direction but over all directions over time, making a rough circle when viewed in plan. This spraying of pollutants has led to the concept of "pollution roses" that are based not only on prevailing winds on a seasonal basis but also the concepts of secondary reactions in the atmosphere based on season (i.e., amount of daylight).[78] "Pollution roses are constructed by plotting either the average concentration [of pollutant] for each [wind] direction or the frequency of concentrations above some particular concentration [for example, above an arbitrary ambient standard] [my brackets]."[79] This is then done for various times of the year, at any elevation thought to be significant -- ground level, at 25 metres, or other arbitrary level.

Wind roses, as a component of a strategic environmental assessment, can act as a basis for constructing a regional or local pollution rose. Pollution roses represent one example of an available and inexpensive tool to be used in the strategic environmental assessment of the Alberta airshed. Roses constructed for a number of pollutants by time of year could help target vulnerable receptors, aid in tracking potential secondary reaction emissions, and in the assessment of cumulative effects. Another implication of pollution roses is in the use of an

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[76]Oke, T.R Boundary Layer Climates. p. 314
[77]Stern et al. p. 333
[78]Stern et al, p. 333
[79]Stern et al., p. 333

economic instrument, the emissions trading zone. Trading zones have been used in the United States and will be discussed in Chapters 9 and 10.

Depositional Processes

At some point in time and space, airborne pollutants must be deposited. The three main processes are: gravitational settling, dry deposition, and wet deposition or precipitation scavenging. On a sunny day, deposition will be by gravitational settling and by dry deposition; if it is raining or snowing, wet deposition will play a role.

Gravitational Settling

Gravitational settling removes most of the larger particles, with the largest particles settling out close to the source.[80] Small particles are carried by turbulent eddies and are eventually deposited by one of the two other forms of removal, dry deposition or precipitation scavenging.

Dry Deposition

Dry deposition is a transfer process depending upon the state of air turbulence and the stomatal aperture (opening in the leaf that exchanges gases with the atmosphere) over vegetation. Surface moisture will also play a role. Over water, deposition is affected by surface tension; over soil, by microbial activity.[81]

Wet Deposition

The most effective method of removing pollutants from the air is wet deposition (precipitation scavenging). Precipitation can refer to both rain and snow; it has been suggested that snow is a more effective scavenger due to its larger surface area.[82] , However, in most diffusion models, snow is regarded as a poor scavenger – at least an order of magnitude smaller than for rain.[83] Some

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[80]Oke, T.R. p. 321
[81]Oke, T.R. p. 322
[82]Oke, T.R. p. 321
[83] Angle, Randy. Head, Air Issues Branch, Alberta Environment, pers. comm.

particles in the air complement the scavenging process by acting as condensation nuclei to aid in cloud formation. These condensation nuclei then capture other particles, making the scavenging process more effective. When the nucleus becomes large enough, it falls out of the cloud as precipitation (a raindrop or snowflake) and brings the pollutants it carries to earth in a process called rainout or snowout.[84] As the raindrop or snowflake moves through the air downward, it also scavenges particles out of the air. This process is called washout and is more effective than rainout in removing particles from the air, although rates of removal depend upon the rate of fall, the sizes of the drops, and the types of pollutants in the air.[85]

Despite the effectiveness of wet deposition, according to a study done by Alberta Environment, "in most areas of Alberta, dry deposition is the dominant means of SO_2 removal from the atmosphere".[86] The Acid Deposition Research Program also states this: "on average, the dry deposition of sulphate is 1.86 times greater than the corresponding wet deposition."[87] This difference is because of Alberta's low amounts of precipitation. I am assuming that, although this study used sulpher dioxide, the dominance of dry deposition holds true for many other pollutants in Alberta.

Surge Effects

However effective precipitation may be as form of scavenging, Alberta's low amounts of it would make this an inefficient form of atmospheric cleaning. Relying on precipitation has other problems: if snow were the primary agent of atmospheric cleansing, a surge effect would be noticed during melting as trapped pollutants were suddenly released. In southern Alberta this could,

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[84] Oke, T.R. p. 321
[85] Oke, T.R. p. 321
[86] Alberta Environment. *An Analysis of Techniques for Measuring the Dry Deposition Rate of SO2.*, 1981. p. 1
[87] Legge, A.H. p. 14

speculatively, happen several times a winter as the chinook winds raise temperatures quickly. This scenario serves to reinforce the interdependence of the atmosphere with other environmental factors and the need to prevent the problem, if possible, rather than mediate it once it has already happened.

Deposition - A Management Response

The potential effect that topographic eddies can produce was illustrated above. Dry deposition would be enhanced by topographically induced eddies, as components of these eddies are more likely to drop out as the air is recirculated here. A topographically produced eddy in a dominant wind direction downwind from a source would therefore be a prime target for a monitoring station, especially if the area acted as shelter for livestock, wildlife, or human habitation.

Type of deposition would be able to affect the final form of a pollution rose from year to year. This could vary by season -- for example, if the area had a particularly wet spring or summer or extensive snowfall in the winter, pollutants are more likely to be deposited in the local area rather than be transported. Dry deposition would enhance the likelihood of longer range transport. Not only the increased wet or dry deposition would affect the pollution rose, but the resulting cloud cover could reduce the amount of direct sunlight, and thus control any secondary emission formation.[88]

The higher incidence of dry deposition in Alberta and the related higher chance of transport makes a strategic assessment at a regional level necessary for an attempt to assess cumulative impacts and monitor those receptors that could be affected by these pollutants, but which are not in locality of the emissions.

Airshed Volatility and Monitoring - Management

Airshed deposition is controlled by wind, stability factors, and topography. These are all complex factors and difficult to predict. While industry or action group monitoring efforts should use wind direction and topography as guidelines for placement, this will not ensure that the monitors will actually measure anything at all. During studies of test flares, it was found that: "Weather conditions and access constraints were the main reasons for the inability to collect meaningful data. In the majority of cases, instruments could not be strategically positioned and/or samples collected for sufficient periods of time, resulting in downwind concentrations no higher than background levels."[89] The implication is that long range monitors are ineffective. Monitoring at the point of release is most effective for accurate measurements of what is being released. Monitoring of specific receptors over the long term would ostensibly provide samples over a sufficient period of time, and would provide valuable information in the tracking of cumulative effects. In order to do this effectively, consistent reporting standards must be imposed by government and adhered to by industry. Reporting standards are a necessary management tool to ensure consistency of information in decision making.

Summary

Pollution is an undesirable input into the airshed or atmosphere. Each emission has a source that is then transported and deposited. The airshed, unlike a watershed, has no certain geographical boundaries and, for the purpose of control, often takes on the political boundaries of the region. Airshed mechanics are governed by the connection between the earth, atmosphere, and solar radiation.

The airshed is a part of the atmosphere and is affected by atmospheric processes. The atmospheric layers of the turbulent surface layer, roughness layer, and laminar layer play roles in the transport and deposition of inputs to the airshed. The stability and instability of the atmosphere affects mixing and air

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[88] Please see Chapter 5, Emissions: Signifiance and Scale
[89] Strosher, M. p. 113

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CHAPTER 5 -- EMISSIONS: SIGNIFICANCE AND SCALE

Emissions: Significance and Scale

Main Points

- Identification of common (frequently emitted) and significant (have an element of risk or potential risk to receptors) emissions in the airshed is a necessary step in environmental assessment.
- The recognition of oxides of sulphur, nitrogen, and carbon, volatile organic compounds (VOCs), hazardous air pollutants (HAPs), and potentially secondary reaction emissions as common and significant emissions in the airshed should make the monitoring and study of long term effects of such emissions mandatory.
- Pollution roses are valuable as a local assessment tool because of ease of access to the needed information and cost effectiveness.
- Use of precautionary approach must be considered when dealing with emissions of unknown long term effects to adequately plan for sustainable development.
- The use of a strategic environmental assessment (SEA) is important to plan for sustainable development and the prevention of cumulative effects.

Background

It is important to identify inputs so an assessment can take place. Pollutants can enter the air from a variety of sources. In southern Alberta, these sources may include cars, petroleum processing, electricity generation, and chemical production.[90] The most common pollutants from these sources have components of sulphur, nitrogen, and carbon, including oxides.

The basis of classifying these substances as air pollutants is not because of what they are, because all of these substances occur naturally in the

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[90] Picard, D.J., D.G. Colley and D.H. Boyd. *An Overview of the Emission Data: Emission Inventory of Sulphur Oxides and Nitrogen Oxides in Alberta*. The Acid deposition Research Program, 1987. p. 14

environment. Carbon, nitrogen, and sulphur are essential parts of the atmosphere, geosphere, and hydrosphere and can move freely between them. Classification as a pollutant is instead based on their concentration in the atmosphere. These substances can react with other substances in the atmosphere to form secondary pollutants.

Significance

Carbon, nitrogen, and oxygen all share a common quality at the element level. As the outer shells containing electrons are not full, they can either share, donate or receive electrons. Each may assume multiple oxidation states, meaning that each can act as an electron donor or an electron receptor, giving the ability to react with a variety of other substances. The important point here is that, as well as the ability to react easily, each of these compounds that result from a reaction have a further common quality -- they are all gases, giving them an ability to circulate freely in the atmosphere.[91] These gases may be affected by light, water and water vapour to produce acids or aerosols. Their significance depends on the effects they may have on valued components. This value system is man-made: Any consideration of the significance of environmental effects must acknowledge that environmental impact assessment is inherently an anthropogenic concept. It is centred on the effects of human activities and ultimately involves a value judgement by society of the significance or importance of these effects[92]. Their significance as a pollutant may be considered socially, statistically, ecologically, or on the basis of effects to a specific project.[93] This project considers risk in terms of ecological risk, which may in turn imply long term social risk (future generations), and statistical risk, when considering long term trends in a "negative" direction.

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[91] Greyson, Jerome. p. 27
[92] Beanlands, G.E. and P.N. Duinker. p. 44
[93] Beanlands, G.E. and P.N. Duinker. pp. 8, 43-45

Carbon Dioxide

The most common anthropogenically generated carbon based air pollutant is the carbon in hydrocarbons. When heated in an oxygenated environment, carbon burns and forms carbon dioxide (CO_2). Carbon dioxide is also a common element of the natural atmosphere. Man made sources have increased the proportion of carbon dioxide in the air. This has implications for global warming, one of the major topics of the United Nations Committee on Environment and Development (UNCED) meeting in Rio de Janeiro in 1992. This meeting led to the Framework Convention on Climate Change.[94] As Jerome Greyson writes: "...fossil fuel combustion gas released enormous additional quantities of the gas to the atmosphere, with estimates of upwards of 180 billion tons being released since the beginning of the industrial revolution....In that sense, CO_2 is a pollutant; and it is argued that its enormous releases have led to a rise of about 1 (degree) K in the Earth's average temperature."[95] As another author states, "Human society...has become a force capable of influencing our global environment...we have begun playing with the climate on a planetary scale."[96] Climate change holds great social significance. It may endanger human health and safety through flooding or changes in weather patterns. It could change the status of land currently capable of agricultural production, or change ecosystems of recreational and aesthetic importance. It has environmental significance as well, as climate change could have the potential to change entire ecosystems.

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[94]Nilsson, Lars and Thomas Johansson. "Environmental Challenges to the Energy Industries" in *Sustainable Development and the Energy Industries.* Ed. Nicola Steen. 1994 p. 53

[95]Greyson, Jerome. p. 13

[96]Columbo, Umberto. "Development and the Global Environment". in *The Energy-Environment Connection.* Jack Hollander, ed. 1992 Island Press p. 5

Alberta is responsible for 30% of the total carbon dioxide released in Canada.[97] Carbon dioxide is released during petroleum processing and is a common compound in the study area. However, in my opinion, carbon dioxide emissions are truly a planetary scale problem. While emissions can only be controlled effectively regionally, it is the global community that must agree to limits on production. One author describes the carbon dioxide issue as "Una fuga in avanti", an attempt to conceal the resistance to solving one problem by pointing out other, less solvable, ones -- a kind of red herring.[98]

Nitrogen Oxides

Nitrogen is emitted in several forms of oxides, which are collectively referred to as NO_X. It is produced by high temperature combustion, which allows nitrogen to combine with oxygen (both of which are natural, and major, components of air). Nitrogen is also supplied from burning fossil fuel. Transportation (the internal combustion engine) is considered to be the largest source worldwide.[99]

Nitrogen oxides have direct and combined (with other emissions) effects on vegetation[100]. Nitrogen oxides contribute to acid deposition and thus affect not only vegetation, but soils, water systems, and organisms.[101] On humans and presumably animals, nitrogen oxides cause headaches, increase susceptibility to viral infections, irritate respiratory tracts, and increase response to allergies.[102] Nitrogen oxides are precursors of photochemical oxidants such as ozone, which can lead to ground level ozone creation (an irritant). Nitrogen oxides, therefore, have both social and environmental significance; they may contribute to

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[97] Clean Air Strategic Alliance. *A Better Way* (pamphlet). July 1996

[98] Colitti, M. "Economic Stagnation and Sustainable Development" in *Sustainable Development and the Energy Industries*. Nicola Steen, Editor 1994 p. 43

[99]Hollander, J. and Duncan Brown. "Air Pollution", in. *The Energy -Environment Connection*. Jack Hollander, ed 1992 p. 39

[100]Nilsson, Lars and Thomas Johansson, p. 53

[101]Nilsson, Lars and Thomas Johansson, p. 54

[102]Nilsson, Lars and Thomas Johansson, p. 53

endangering human health, degrading commercially viable agricultural land, or endangering the health of animals (either livestock or wildlife).

Alberta is responsible for 24.8% of the nitrogen oxide released in Canada.[103] This results despite the fact that Alberta's relatively low population compared with the total population of the country means that transportation could not be the primary source of this emission. According to the Acid Deposition Research Program, transportation is third in Alberta at 15.9%, whereas petroleum is first at 38%of the Alberta total[104], which translates into ten percent of the Canadian total. Nitrogen oxides, as agents of direct effects on plants, animals, and humans, and indirect effects on soils, water (through acid precipitation) humans, plants, and animals (precursor to ozone and photochemical oxidants), as well as being an emission produced in petroleum processing, are both common and significant emissions in the study area.

Sulphur

Sulphur is a component of many common air pollutants. It is produced both by natural sources (volcanoes, sea spray) and by the burning of fossil fuels. Its most common reincarnation is as sulphur dioxide (SO_2), although elemental sulphur can play a role in deposition when it is removed from emissions and stored in solid form. In Alberta, it is released in the processing and flaring of sour gas (high H_2S). In newer processes, much of this sulphur is recovered and sold or stored in solid form.

Sulphur compounds have direct effects on receptors including plants, animals, and water systems. The effects may be synergistic when combined with oxides

[103] Clean Air Strategic Alliance. *A Better Way* (Pamphlet). July 1996

[104] Picard, D.J. et al. *Overview of the Emission Data: Emission Inventory of Sulphur Oxides and Nitrogen Oxides in Alberta* for the Acid Deposition Research program, November, 1987

of nitrogen and with ozone.[105] Sulphur is considered, along with oxides of nitrogen, an element of acid rain, or, more descriptively, of acid precipitation, since other forms of precipitation such as snow can also deposit sulphur collected from the atmosphere. Effects of sulphur compounds may include reduced plant growth, irritation of human and animal respiratory tracts, and acidification of soils and water.

Sulphur dioxide is the precursor of other sulphur based entities, such as sulphuric acid (H_2SO_4). The primary reaction to form sulphuric acid involves the oxidation of SO_2 to SO_3, which reacts with water vapour (H_20) to form sulphuric acid mists[106]. Sulphuric acid is a major component of acid rain. The hydrogen is generally supplied from atmospheric water vapour or cloud water. According to one source, "Recent estimates are that 30 to 50% of the sulphur resident in the atmosphere is anthropogenically generated as SO_2."[107] High concentrations of SO_2 in the atmosphere are responsible for "London type" smogs, not common in Alberta.

Flares are used at many oil and gas sites to handle waste gases. If there was 100% efficiency during the flaring process, the only byproduct of sour gas would be sulphur dioxide.[108] However, the burning efficiency is affected by the design of the flare system, in which fuel and oxygen are not premixed to ensure maximum burning efficiency.[109] The efficiency of the flare is also affected by turbulence[110], cross winds [111], and co-flowing liquid and gaseous fuel[112]. Incomplete combustion produces volatile and non-volatile hydrocarbons,

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[105]Nilsson, Lars, and Thomas Johansson, p. 52
[106]Oke, T.R. p. 318
[107]Greyson, Jerome. p. 112
[108] Strosher, M. p. 3
[109] Strosher, M. p. 5
[110] Strosher, M. p. 48
[111] Strosher, M. p. 51

including benzenes and lighter aromatics (considered a volatile organic compound -- see next section, Volatile Organic Compounds).[113]

Alberta emits 23.7% of the sulphur dioxide generated in Canada.[114] Approximately 82% of this is from petroleum -- about 20% of the Canadian total.[115] The study area is located in one of eight areas of high sulphur dioxide concentration as predicted by the regional model in use today (RELAD).[116] The study area is also one of eight areas in the province with high levels of sulphur deposition as predicted by the same model.[117] Sulphur oxides, through their direct and indirect effects on organisms and support systems such as water and soil and their production in petroleum processing, are considered a significant emission in the study area and should be considered in an environmental management program.

Volatile Organic Compounds (VOCs)

Volatile organic compounds, or VOCs, have known carcinogenic effects[118] and so are significant from a health (social) standpoint. They are produced by the incomplete burning of fossil fuels and include the following compounds: alkanes, alkenes, alcohols, ethers, esters, aldehydes, ketones, aromatics, and methane.[119] VOCs are precursors to photochemical oxidants such as ozone. Their role as a carcinogenic and a precursor to photochemical oxidants as well as their release during petroleum processing make VOCs a socially significant emission.

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[112] Strosher, M. p. 57
[113] Strosher, M., p. 86
[114] Clean Air Strategic Alliance. *A Better Way* (pamphlet) July 1996
[115] Picard, D.J. et al. p. 14
[116] Cheng, Lawrence. *Concentration and Deposition of Anthropogenic Air Pollutants in Alberta (Summary Report).* April 1994
[117] Cheng, Lawrence.
[118] Nilsson, Lars and Thomas Johansson, p. 55
[119] Nilsson, Lars and Thomas Johansson, p. 55

Volatile hydrocarbons are also a common release from oil and gas flares; their abundance depends on several factors (aside from absolute volume of flaring), including wind speed and direction and presence of condensates in the flare.[120] A recent study by the Alberta Research Council details these emissions.[121]

Hazardous Air Pollutants

The Organization for Economic Co-operation and Development (OECD) defines an hazardous air pollutant as "gaseous, aerosol, or particulate contaminants present in the ambient air in trace amounts with characteristics (e.g. toxicity, persistence) that present a hazard to human health, animal, or plant life."[122] These hazardous air pollutants may include substances such as ammonia compounds, arsenic, cadmium, lead, copper, nickel, vanadium, and zinc.[123] Hazardous air pollutants emitted from petroleum processing plants are not monitored or reported. Shell estimates that up to 200 trace substances are emitted and not monitored from its Caroline gas plant, possibly including heavy metals.[124] There is little research on long term effects of these substances on valued ecosystem or economic receptors. This may be because they are viewed as expensive to conduct and only of local interest.[125] However, I believe that it is the local nature of these emissions that makes research necessary in Alberta, given the close ties between industry and environment. The people who live in the communities also work for the industry, and they may start to act as a driving force to demand more accountability. The Commission for Environmental Co-operation reported in 1994 that Alberta was among the top 20 producers of toxic pollutants in North America, although the method of ranking was unreported.[126]

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[120] Strosher, M.

[121] Strosher, M.

[122] OECD. *Hazardous Air Pollutants The London Workshop*. OECD 1995. p. 26

[123] OECD p. 27

[124] The Calgary Herald. "Many Flare Emissions Unmeasured, Says Shell". October 3, 1996

[125] Leahey, D.M. p. 2

[126] "Air Pollution Wreaking Havoc" in the Calgary Herald, September 5, 1997.

A recent NAFTA report has, in addition, concluded that cross border air pollution is "wreaking hoavoc on human health and the environment."[127]

Secondary Pollutant Processes

A common secondary pollutant process is that of photochemical oxidants. They are formed "under the influence of sunlight by complex photochemical reactions in air that contains nitrogen oxides and reactive hydrocarbons as precursors."[128] Most reactions in the atmosphere are initiated by light, as substances absorb photons and are excited to a higher energy state. They can use up this "extra" energy by participating in other chemical reactions. This means that the ingredients for secondary photochemical reactions are, basically, sunlight, and the burning of fossil fuels, both of which are easy to find in Alberta, particularly in the summer. Secondary pollutants that evolve from this include ozone (toxic in the lower atmosphere), peroxyacetyl nitrate (PAN), higher oxides of nitrogen, and aldehydes (a VOC).

Secondary pollutants generated by sunlight may be common, due to the high incidence of sunlight in Alberta. However, after extensive library research, I am unaware of available research on secondary pollutants in Alberta, so this is speculative.[129] On the other hand, secondary pollutants generated by reaction with water vapour would probably not be common, due to the low incidence of fog, mist, or wet precipitation. The control of secondary pollutant precursors such as NO_X can control the creation of these emissions. There is a need for research into secondary reactions in Alberta and the study area to determine if they are socially, environmentally, or statistically significant.

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[127] "Air Pollution Wreaking Havoc" in the Calgary Herald, September 5, 1997.

[128] Guderian, R. Editor. *Air Pollution by Photochemical Oxidants.* Springer Verlag Berlin Heidelberg, 1985. page 1

[129] Randy Angle, Head of the Air Issues Branch of Alberta Environment, informs me that there are papers available by himself and by H. Sandhu on this subject.

Significant Emissions - Management Response

The recognition of oxides of sulphur, nitrogen, and carbon, volatile organic compounds, hazardous air pollutants and the potential creation of secondary reactions in Alberta and the study area as common and significant (either socially, environmentally, or statistically) emissions should make the monitoring of these emissions mandatory. Studies of the long term effects of these emissions should be initiated to avoid potential health problems or the loss of commercially viable land. The cost of these studies could be justified on the basis that prevention is less expensive than a potential mitigation of effects. Use of the precautionary principle should be invoked and the absolute amounts of these substances emitted should be reduced using the most effective technology and legislation. Studies of long term effects can be effective only if the amounts of pollutants currently being emitted are known, reinforcing the need to use reporting standards as a management tool.

The high incidence of sunlight and the burning of fossil fuels in Alberta, and therefore the potential for secondary chemical reactions, leads to the necessity of creating pollution roses for time of day as well as by season as part of the predicting phase of a strategic impact assessment. This holds especially true for those areas with potentially high local effects of petroleum burning and processing, such as around gas plants.[130] Use of such a tool is a positive thing for all stakeholders. The petroleum industry can benefit by using all available tools by this illustration of due diligence (if available as a defense) in any legal challenge.

Flaring

In 1996, the Alberta Research Council released a report on flaring that detailed emissions from various types of flames (methane, pentane, natural gas, pure and with liquid and with condensates) under various conditions -- in a lab with laminar flow, with simulated cross winds, in open atmosphere, and with two actual flares, one sweet and one sour.

Emissions from each type of flare were found to increase with turbulence, crosswinds, amount of liquid gas introduced, and amount of condensate. A natural gas flame in an open atmosphere cross wind produced 61 volatile hydrocarbons and 58 non-volatile hydrocarbons[131], as compared with 41 total compounds in a turbulent laboratory setting.[132]

In addition, sampling of actual flares indicates that efficiency of the flame, which governs the amount of products emitted, varied widely depending on the circumstances. The sweet flare experienced reduced combustion efficiency when the flow rate increased, from 70.6% efficiency at a flow rate of one to two cubic metres a minute to 66.1% when the rate increased to five to six cubic metres a minute.[133] This increased the carbon content by approximately five times, the volatile hydrocarbons by 33%, and non volatiles by five times.[134] When the level of liquid hydrocarbons in the processing system was increased, the combustion efficiency went from 71% to 63.9%. [135] Carbon particulates accordingly increased 40% at the lower efficiency, and hydrocarbons increased also by 25%.[136]

The most common compounds found in sweet gas flare testing were benzene, styrene, ethynyl benzene, naphthalene, ethyl-methyly benzenes, toluene, xylenes, acenaphthylene, biphenyl, and fluorine, accounting for between 100

[130] Leahey, D.M. p. iv
[131] Strosher, M. pp. 79, 82
[132] Strosher, M. p. 44
[133] Strosher, M. p. 85
[134] Strosher, M. p. 111
[135] Strosher, M. p. 97
[136] Strosher, p. 111

and 150 different hydrocarbons.[137] None of these compounds are required to be monitored or reported under current regulations. The effect of these compounds are likely to be local, as it was found "concentrations initially drop off very rapidly with distance and are generally about 20 percent of the overall maximum concentrations of about 3 km from the flare site".[138] The proximity of cattle ranching to processing facilities leads to concern about animal health in the region.[139]

Flaring - Management Response

Since it is impossible to control the weather, other solutions must be devised. To control emissions from flaring, either the absolute amount of emissions can be reduced, or control technologies can be implemented. Many effects of flaring are local, in and around the communities in which workers and consumers live. The potential health significance of flare emissions and the potential impact on agricultural systems, both land and wildlife, may demand research into effects of these substances. It is more cost effective to invest in maximum available end-of pipe- technology now as a part of the management portfolio than be required to clean up contaminants later. Research into local effects may eliminate concern or point to other possible solutions.

Emission Lifetimes and Scale

It was mentioned above that the boundaries of an airshed are influenced by emission lifetimes, that is, the length of time an emission is expected to stay in the atmosphere. This is also referred to as the residence time or the turn-over time.[140] These residence times vary by compound and may be complicated by secondary chemical reactions occurring in the free atmosphere. The following

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[137] Strosher, p. 111

[138] Leahey, D.M. p. 24

[139] Proceedings of an International Workshop: Effects of Acid Forming Emissions in Livestock. AECV92-P2

[140] Meszaros, E. *Atmospheric Chemistry Fundamental Aspects*. Elsevier Scientific Publishing Company 1981. p. 1

table is adapted from Stern et al, The Fundamentals of Air Pollution, Table 2-5. To compare with this information, the residence times for the same constituents as provided by another source are presented as residence time (B):[141]

Table 2. Residence Times for SO_2, NO_x, CO_2, and N_xO_x

Emission	Major Sources	Residence Time (A)	Removal Mechanisms	Remarks	Residence Time (B)
SO_2	Combustion	1-4 days	Photochemical	high reaction rates in summer	2 days
NO_x	Combustion	2-5 days	Oxidation		8 - 10 days
N_xO_x	Combustion	20 - 100 years	Photochemical in stratosphere		25 years
CO_2	Combustion	2 -4 years	Photosynthesis , absorption in oceans	deforestation may add to background levels	5 - 6 years

From this comparison it can be seen that there is a difference between the stated residence times. This illustrates the difficulties encountered when trying to quantitatively describe an airshed and measure what is happening there. Environmental managers will face this problem and should use the appropriate tools to moderate the uncertainty.

An additional problem that can be seen from the above table is that many emissions -- for example, carbon dioxide or nitrous oxides -- have an extremely long residence time in the atmosphere. This could mean that the full effects of these pollutants are yet to be discovered. A similar problem that has attained

[141]Meszaros, E. p. 12

world wide attention is the residence times of CFCs, and the unique abilities attached to each of these long-lived molecules in the atmosphere. A CFC has a residence time of up to 120 years in the stratosphere, and has the ability to destroy ozone, which in the stratosphere blocks damaging solar radiation from reaching the earth. This example illustrates one aspect of why a precautionary approach is necessary when dealing with substances of unknown properties. Residence times in the atmosphere are affected by the processes described earlier -- diffusion, precipitation scavenging, and weather (including wind speed and atmospheric stability and instability) -- as well as topography.

Mesoscale Emissions

Residence times in the atmosphere leads to the concept of scale -- that is, if a particular substance can exist in the air for a given period of time, then on what scale of distance can that substance affect receptors? William C. Clark has devised a system that uses residence times as a parameter. Under this system, mesoscale constituents "have atmospheric lifetimes of a few hours or less, and transport distances of tens to hundreds of kilometres".[142] This means that they are heavily influenced by local weather systems, wind speed, and topography.

Clark points out that these mesoscale constituents can still travel several hundred kilometres, or the distance between major cities, easily. This means that they can accumulate jointly across space, leading to potential cumulative effects. Clark concludes, " For valued atmospheric components affected by mesoscale constituents released from fossil fuel combustion or industrial activity, it would therefore seem reasonable to design an assessment strategy to question the null hypothesis of no cumulative impacts."[143]

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[142]Clark, W. "The Cumulative Impacts of Human Activities on the Atmosphere", in the *Proceeding of the Workshop on Cumulative Environmental Effects: a Binational Perspective*. Canadian Environmental Assessment Research Council and The U.S. National Research Council Board on Basic Biology. 1986.

[143]Clark, W. p. 121

Synoptic Scale Emissions

The next constituents are termed synoptic, and include sulphur and nitrogen oxides, with lifetimes of one to several days. At this scale, constituents are strongly influenced by not only local weather but by large scale weather formations on a regional basis. As Clark suggests, :it is clear that these constituents travel sufficiently far that the emissions from one large city can be expected to reach the next large city...virtually anywhere on earth".[144]

Global Scale Emissions

Clark's third, and last, constituent scale is global. Substances with lifetimes of decades to centuries are grouped here. These elements obviously have the ability to affect the global atmospheric realm. Gases in this category include carbon dioxide, methane, nitrous oxide, and manmade chemicals such as CFCs.

Scale of Emissions - Management Response

Translating these scales to the Alberta example, it can be seen that many compounds come under the synoptic scale. This means that emissions have not only a local impact but a regional one, and that emissions from any given source in Alberta could add to, or create, a cumulative effect. A strategic environmental assessment of these emissions could help in not only planning for sustainable development but in the promotion of the prevention of significant deterioration concept.

Cross-Jurisdictional Emissions

The concept of scale is important in dealing with cross-jurisdictional pollution. As noted, airsheds do not respect political boundaries, even if they are best controlled inside those boundaries. Alberta is a large and efficient exporter of air pollution, due to the predominantly westerly winds. An estimated 77.8% of the

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[144]Clark, W. p. 121

sulphur and 74.9% of the nitrogen generated in Alberta also leaves Alberta.[145] Of this, 67.8% of sulphur and 65.4% of nitrogen enters Saskatchewan; the remainder enters the United States or the Northwest Territories.[146] From Saskatchewan, it is estimated that 31 % of sulphur and 33% of nitrogen imported into the province from Alberta finds its way to Manitoba.[147] These numbers indicate that while control may be achieved in a regional area, the effects will be felt in a much larger area. Conversely, if control is not achieved, inter provincial politics may evolve to include environmental transfer payments to help remediate the economic, environmental, or health effects experienced in the area of ultimate deposition.

Cross Jurisdictional Emissions - A Political Management Response

Transboundary pollution is common when dealing with open systems such as the atmosphere. While control policies may be implemented regionally within political systems, it is necessary that cross jurisdictional policies be developed for long term control. Transboundary pollution has a social significance in that it could affect human health (either directly or through climate modification) and ecological significance in that it could damage valued ecosystems (as in acid rain). Management of the problem is almost exclusively in the hands of governments, although large multinationals have the ability to standardize environmental management systems and programs in all their operations. Large international organizations such as the European Common Market also have this potential.

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[145] Cheng, L. R. Angle, and H. Sandhu. "Mesoscale Effective Acidity Modelling in Acidifying Emissions Management: Western and Northern Canadian Perspective". In *Atmospheric Science* 1, 1996

[146] Cheng, L., R. Angle, and H. Sandhu. p. 9

[147] Cheng, L. and R. Angle. "Model-Calculated Interannual Variability of Concentration, Deposition, and Transboundary Transport of Anthropogenic Sulphur and Nitrogen in Alberta", in *Atmospheric Environment Vol. 30, NO. 23* 1996 p. 4027

Summary

Common pollutants in Alberta include oxides of sulphur, nitrogen, and of carbon. They are classified as pollutants not because of their composition, but because of their concentration in the atmosphere. These compounds are freely circulating and are highly reactive gases. Oxides of sulphur, nitrogen, and carbon are significant emissions as well as being common; volatile organic compounds fall into the significant category, as do secondary pollutants generated by photochemical processes in Alberta. Pollution roses by day as well as by season would benefit environmental management.

The airshed is influenced by the residence times of pollutants. The length of various residence times is a reason a precautionary approach should be taken -- like CFCs, there is no way of predicting what their final effect on the atmosphere may be. Residence times lead to the concept of scale and the meso, synoptic, or global categories. According to this scale, many emissions in Alberta are in the synoptic range, having a regional presence and potential cumulative impacts. A strategic environmental assessment would take into account inputs on a synoptic scale, help plan for sustainable development, and in the prevention of significant deterioration.

CHAPTER 6 - IMPACT ASSESSMENT, CUMULATIVE EFFECTS, AND RECEPTOR RISK

Impact Assessment, Cumulative Effects, and Risk Assessment

Main Points

- Environmental assessment is a longer-term environmental management tool. It is more cost effective to implement this type of assessment early in the planning process to avoid potentially costly mitigation later.
- Tracking of cumulative effects can aid in avoiding undesirable effects to ecologically or socially significant factors at a later time.
- Planning for new industries in the study area should take into account existing sources of emissions, potential secondary reactions, and synergistic effects.
- Use of indicator species to monitor the condition of a component of the ecosystem are an available, inexpensive local tool.
- Monitoring and reporting of releases that currently are not required by regulations should occur.
- Implementation of long term impact studies using projected deposition of pollutants.
- Use of the precautionary principle when possible to avoid long term "mistakes".
- Use of target loading as an effective tool in implementing the process of sustainable development, despite the conflict with the precautionary principle.
- Research of deposition close to emitters is a neglected field and should be researched over the long term.

Strategic Environmental Assessment

A strategic environmental assessment is an environmental management tool that can be used in airshed management as a longer-term planning tool. Beanlands and Duinker suggest the following steps to use as a strategic basis for impact studies:

1. Generally conceptualize the project. This clarifies the relationship between the two critical parts of the assessment, namely, the physical, chemical,

biotic and energetic perturbations and the valued ecosystem components, or receptors.

2. Consideration of the linkages between initial perturbations (physical, chemical, biotic and energetic) and the receptors.

3. Best prediction of changes in the system given time constraints, natural variability, current state of knowledge and the tools available.[148] This suggestion is reflected in the organization of this project.

Strategic environmental assessment (SEA) may be defined as the following:

> SEA is the implementation of environmental assessment at an early stage in the planning process, such that it integrates environmental, economic, and social concerns in the planning, policy, and program stages rather than at the project level. This allows for consideration of alternatives, cumulative impacts, and "sustainable development" issues at a level where choices are proactive rather than reactive.[149]

Atmospheric assessment requires a strategic environmental assessment that attempts to account for cumulative impacts at a regional level rather than the more common environmental impact assessment, which is typically done on an individual project basis. Cumulative effects are implicit in any inputs to a highly volatile airshed as emissions from multiple sources and of various lifetimes can converge on receptors. Volatile is used in the sense that the airshed is continually shifting in response to environmental factors, and inputs to the airshed are shifting in response to economic factors. In this sense, the term strategic environmental assessment is as relevant as the term "cumulative

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[148]Beanlands, G.E. and P.N. Duinker. p. 5

[149]Berg, Karla, Sumitra Dutt, and Elizabeth Henderson. Coursework, EVDS 649.

impact assessment", used by William Clark[150] and defined as follows: "Cumulative impact assessment examines the consequences of multiple sources of environmental disturbance that impinge on the same valued environmental components".

A strategic environmental assessment can be used as a tool to track current inputs and track and prevent future inputs through long term planning. A strategic environmental assessment implies it is a "major longer-term decision(s) about what a major corporation, government, or institution wants to achieve and how it wants to do that."[151] Further, "if those major early decisions are made without due consideration of environmental factors, then they must be brought in late in the process as an expensive and probably less-than-effective afterthought".[152] Government and industry are therefore given a cost effective reason for implementing environmental policies early in developmental planning processes. A strategic assessment gives a longer-term framework to accomplish this.

Driving forces in completing environmental assessments at a strategic and cumulative level include public opinion. "Today's dominant social and economic perspective is that if cumulative effects are either not identified or are ignored at the biophysical level, the next point at which identification will occur is when cumulative social and/or economic effects on the human population are identified."[153] Ontario Hydro noted this trend in 1992: "As with most environmental issues, the public has also been a driving force behind CEE {cumulative environmental effects} research. Many proponents and practitioners have noted that the public is increasingly using the word 'cumulative'. Indeed,

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[150]Clark, W. "The Cumulative Effects of Human Activities on the Atmosphere", in *Proceedings of the Workshop on Cumulative Environmental Effects: a Binational Perspective.*_ CEARC and US National Research Council

[151] Thompson, Dixon. p. 229

[152] Thompson, Dixon. p. 229

the public is likely focusing on CEE to a greater extent than proponents."[154] The public is also the consumer, the worker, and the voter, and thus can wield considerable influence.

The ideal start to an environmental assessment is a baseline, "a description of conditions existing before development against which subsequent changes can be detected through monitoring"[155], against which measured changes take place. In Alberta, The Acid Deposition Research Project provides a baseline from which to measure certain types of changes, such as changes in plant, soil, and water systems from acid deposition.

The Acid Deposition Research Program

In 1987, an expensive and indepth study was completed of the air quality in Alberta. This study covered the effects of acid deposition on soils, agriculture, and forests as well as medical consequences to humans, and provided an emission inventory of sulphur oxides and nitrogen oxides in Alberta. This study was called the Acid Deposition Research Program, or ADRP. The prime research agent was the Kananaskis Centre for Environmental Research at the University of Calgary, although committee members were from industry as well as from many American universities. It was initiated in 1983 and published in 1987.

According to the emissions inventory done as part of the ADRP, the petroleum industry accounts for almost 82% of all sulphur emissions in the province, and about 38% of all nitrogen oxides.[156] Both of these percentages place the

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[153] Shoemaker, Darryl J. p. 8

[154] Shoemaker, Darryl J. p. 2

[155] Beanlands, G.E. and P.N. Duinker. p. 19

[156] Picard, D.J., D.G. Colley and D.H. Boyd. "Overview of the Emission Data: Emission Inventory of Sulphur Oxides and Nitrogen Oxides in Alberta" *in The Acid Deposition Research Program, Biophysical Research* The Kananaskis Centre for Environmental Research, November 1987. pp. 14, 41

petroleum industry as the major contributors of these pollutants. Furthermore, it was discovered that of the top ten sulphur dioxide emitters, five were sour gas plants. The top two sources were oil sands plants.[157]

The ADRP compiled its sulphur dioxide inventory using all sources licensed by Alberta Environment and all sour gas batteries approved by the Alberta Energy Resource Conservation Board (ERCB, currently the Energy and Utilities Board) that emitted a certain amount or more per day.[158] In the inventory, sources are categorized by location, environmental setting, type of source, source characteristics, and type of facility. The nitrogen oxides inventory included all sources licensed under the Clean Air Act and all sources approved by the ERCB with a rated power output of 100 kW or more.[159] They are further categorized into three types of sources, industrial, urban, and highway. The inventory omits smaller sources of nitrogen oxides.

The ADRP divides the province into sectors 1 to 10. The northern part of the province is responsible for only 28.1% of the total sulphur dioxide and nitrogen oxide emissions in the province but contains 58.1% of the area, leaving the remaining 71.9% of emissions to the smaller southern portion. However three areas account for the bulk of all emissions -- 75%.[160] These are the areas of the province with the highest amount of petroleum activity.

Section 9 has the distinction of containing both the highest sulphur dioxide emissions in the province as well as the highest nitrogen oxide emissions. This is the area that contains Calgary, as well as the petroleum rich areas between

[157]Picard, D.J. et al., p. 29
[158]Picard, D.J. et al., p. 3
[159]Picard, D.J. et al., p. 5
[160]Picard, D.J. et al., p.12

Calgary and Rocky Mountain House to the north; the study area is also located here.[161]

The petroleum industry accounts for almost 82% of all sulphur dioxide emission and 38% of nitrogen oxides. In comparison, the electrical utilities are responsible for 22.4% of NO_X, with highways third at 15.9% and urban centres fourth at 15.7%. Electrical utilities are again second in the sulphur dioxide category, but only account for 16.6%.[162]

Emissions by Petroleum Facility Type

As the petroleum industry is the leader in both NO_X and SO_2 emissions, the ADRP provides a breakdown of emissions as a function of facility type. This analysis reveals that sour gas extraction plants are responsible for 55.4% of all petroleum industry related SO_2 emissions. Oil sands plants account for 34.5%, sour gas plants (non extraction) at 4.5%, oil batteries at 2.5%, refineries at 2.2%, and heavy oil plants at 0.9%.[163] The same analysis for NO_X reveals that "other" facilities are responsible for 67.5% of all petroleum related emissions, with "other" being equated to field compressors for produced gas[164]. Other sources include oil sands plants at 9.6%, sour gas plants (8.6%), oil batteries (4%), and refineries (2.4%).[165]

The ADRP gives statistics specifically for the facility type in the petroleum industry, recognizing the significance of this industry to air quality in Alberta. The source types noted are heavy oil, other facilities (compressors), oil sands, refineries, oil batteries, sour gas flares, and sour gas extraction. Sour gas extraction is the largest contributor of SO_2 emissions, contributing slightly less

[161]Picard, D.J. et al., p. 13
[162]Picard, D.J. et al., p. 14
[163]Picard, D.J. et al., p. 18
[164]Picard, D.J. et al., pp. 18, 15.

than 386.5 tonnes per day, with oil sands a close second at 355.8 tonnes per day.[166]

Emissions by Ecoregion

The next step taken by the researchers of the ADRP was to correlate emissions by ecoregions of Alberta. The basis for the ecoregions are areas characterized by a distinctive regional climate expressed by vegetation. The pattern of recurring vegetation, and soil and moisture sequences, was the main basis for the recognition and delineation of the ecoregions. The stated reason for correlating the data is that "ecosystems vary in their sensitivity to air pollution."[167]

The ADRP Section 9, the section with the highest emissions, is also the most diverse in ecoregions. Section 9 contains a representative from the following ecoregions: Mixed Grass, Fescue Grass, Aspen Parkland, Montane, Subalpine, Alpine, and Boreal Foothills. This indicates: first, that airshed management in south central Alberta (in effect, area 9 of the ADRP) will be targeting the area with the most potential for reductions in absolute amounts of emissions, and, second, is the area with the most difficult and diverse terrain to analyze for management purposes, including environmental and cumulative effects assessment.

This second point (Section 9 has the most difficulty and diverse terrain to analyse) reflects the potentially diverse geography and climate contained in this area, which is significant for two reasons. First, ecoregions are defined based upon climate as expressed in rainfall and vegetation type. Second, airsheds are controlled by geography and climate as expressed in local weather. The interaction of these two factors make airshed management in this region challenging. The diversity allows opportunities for study of long term, low impact

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[165]Picard, D.J. et al., p. 18.
[166]Picard, D.J. et al., p. 20

emissions on a variety of ecosystems in an abbreviated area. The diverse physical attributes also emphasize the desirability of putting into effect an airshed management plan that would retain the diversity into the future, even taking into account potential long term, low impact effects.

Cumulative Effects and Risk

A receptor is something that encounters emissions. It can be vegetation, animals, humans, or materials. Risk is "a hazard that threatens a community or population and the probability that a hazardous event will occur".[168] Cumulative effects are "not single stressors creating significant impacts, but multiple causality, interacting processes and populations of both past and present human activities affecting a number of valued resources in a geographic area."[169] The following section will begin with a discussion of the risk of possible multiplying effects of common pollutants.

Air Emission Interactions

Air emissions rarely occur alone, although they are often studied as if in isolation. For example, a sour gas plant may be emitting sulphur dioxide, nitrogen oxides, benzene, and other volatile organics, from various sources simultaneously. This co-occurrence makes interaction and reaction a possibility. The effects of this interaction have been studied on plants:

> "...air is really a mixture of natural and unnatural gases and suspended particulate and aerosol matter. In a polluted atmosphere one contaminant will most likely be predominant, but others may be present in varying lesser amounts. While most studies are directed towards learning about plant responses to a single pollutant, co-occurences

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[167]Picard, D.J. et al., p. 15
[168] Thompson, Dixon. p. 244
[169] Shoemaker, Darryl J. p. 8

> of pollutants do occur, and the combined presence of two or more pollutants may have different effects on vegetation from those of a single pollutant. Theoretically, the combined effects may be the same as when each pollutant is applied alone (additive), greater than the sum of each applied alone (synergistic) or less than if each were applied alone (antagonistic)".[170]

The photodissociation of nitrogen oxides into ozone illustrates the co-occurrence of pollutants. In the typical sequence, nitrogen dioxide is formed from the reaction between NO and reactive hydrocarbons. Nitrogen dioxide reacts with atomic oxygen as the light intensity becomes greater throughout the day to form ozone. However, fine particulate sulphates are often highest at night.[171] The significance of this sequence (high sulphates preceding high ozone levels) is seen in the following:

> Thus, under field conditions, for example, vegetation is first exposed to high concentrations of fine particle sulphate during the early part of the day and subsequently to high concentrations of O_3 during the late afternoon hours. The significance of this has been demonstrated...When plants were exposed to fine particle acid sulphates followed by O_3 under controlled conditions, the injurious effects of O_3 were significantly increased, in comparison with the effects induced by O_3 alone.[172]

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[170] Treshow, M., and F. Anderson. *Plant Stress From Air Pollution.* John Wiley and Sons, 1989. p. 122

[171] Legge, A.H. p. 29

[172] Treshow, F., and M. Anderson. p. 122

This interaction of emissions is of interest in a strategic environmental assessment process, especially given that the scale of influence of the emissions is largely regional. To eliminate socially significant health risks or ecosystem risks, any new industrial planning should take into account the existing sources of emissions and potential secondary reactions as well as the potential synergistic effects.

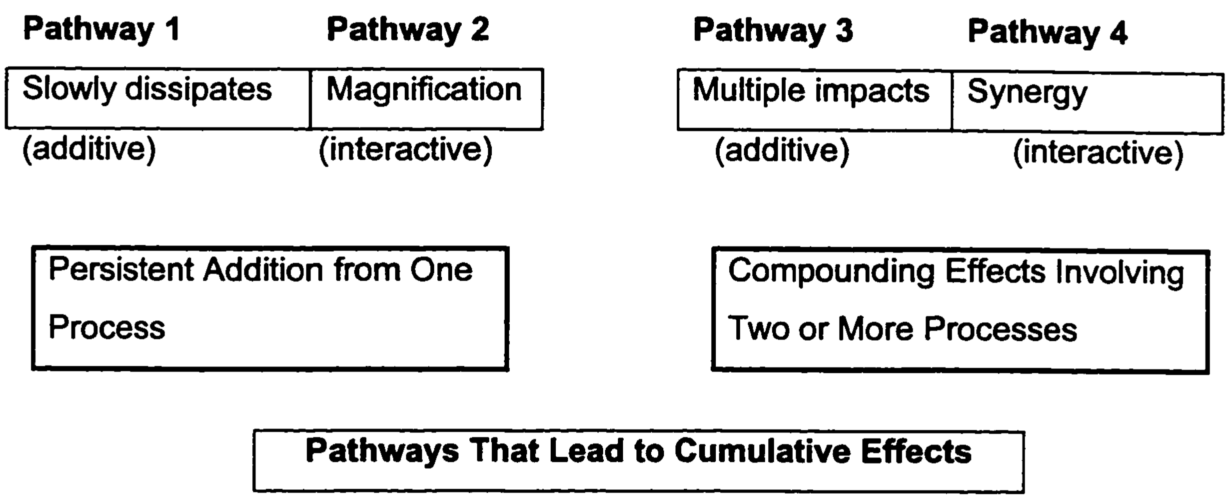

Figure 12 . Pathways of Cumulative Effects. Source: Shoemaker, 1994

Conceptualizing the Environment

Beanlands and Duinker propose two "basic but distinct approaches to conceptualizing the environment"[173]. The first of these suggests that the investigator ask two fundamental questions. These are:

1. At what biological level are the valued ecosystem components in question; and
2. At what biological level is it possible to usefully either predict or detect the expected perturbation?

Unfortunately, receptors of airborne emissions often are affected at a biological or subsystem level where it is unlikely that an observer would notice the effects

[173]Beanlands, G.E. and P.N. and Duinker. p. 5

until the problem rises at the population or system level. For example, it is not likely that anyone would notice cellular damage in an aspen tree, but many people would notice a grove of sickly aspen.

Risk Identification: Potential Effects of Emissions on Plants

The effects of emissions on plants is well documented. In the early part of this century when industrialization viewed pollution as a sign of economic prosperity, the effects of pollutants on plants were obvious to the eye. These effects included vegetation death, curling of the leaves, necrosis, and white spots, among other symptoms.[174] Episodes of high air pollution can cause these effects in areas normally under low ambient intensities of pollution.

Visible injury is accompanied by damage at other levels of plant structure. "Biochemically, injury is expressed as alterations in metabolism, including enzyme activities and metabolic pools. Those cellular disturbances also can be expressed cumulatively as foliar pathologies, altered carbohydrate allocation, reduced growth and yield, and impacts on plant communities and ecosystems."[175] Impacts on plant communities that are non-visible (for example, changes in the ability to compete) as a component of the ecosystem is perhaps the hardest to visualize occurring, especially in the short term, but is probably one of the most common responses to any dose of air pollution.

High Intensity Dosages

Essentially, the effects of air pollution on plants and plant communities is determined by: 1. genetic resistance 2. moderating environmental conditions and 3. pollution intensity.[176] The effects of pollution vary with the intensity and duration. The effects of a high dose of pollution have the visible plant

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[174] Jacobson, J.S. and A. C. Hill, Editors. *Recognition of Pollution Injury to Vegetation: A Pictorial Atlas.* Informative Report NO.1 Tr-7 Air Pollution Control Association, 1970

[175] Guderian, R. Editor. p. 140

morphological responses as described above, but may have other less obvious effects. "A characteristic of the association between high dosage and plant community response is a breakdown of community structure, which is more or less obvious depending on ecosystem complexity".[177]

Moderate Intensity Dosages

Intermediate doses of pollution may have various responses depending upon both intensity and duration. Obvious damage may have been done to the plant, or less obvious structural changes may have taken place that put the plant in danger of becoming less competitive in its ecosystem niche. "Intermediate air pollution dosages are ecologically and economically significant because they are either chronic or subtle, direct or indirect effects on individual species can set the stage for changes in community structure and function".[178]

Low Intensity Dosages

Low doses of air pollution may go undetected, but can affect the individual plant at the structural level. Long term changes in the ecosystem also may be triggered, such as succession, as the plant species are no longer able to compete as effectively as before. Ecosystem structure is damaged. "The impact of low dosages on vegetation lie on the borderline between the normal, i.e., unaffected, and significantly impacted vegetation. Depending on the concentration and exposure duration, effects can range from stimulations to reductions in growth, reproductive capability, or susceptibility to abiotic and biotic stresses. Changes in competitive relationships may also occur, causing alterations in species composition ... Before detectable reductions appear in, e.g., growth, various changes occur in biochemical, physiological, or substructural levels."[179] This essentially means that significant damage may

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[176]Guderian, R. Editor. p. 149
[177]Guderian, R. Editor. p. 146
[178]Guderian, R. Editor, p. 147
[179]Guderian, R. Editor. p. 148

occur before the means to measure this damage become evident. It also puts the emphasis on detection and measurement at the population level, which may show the first measurable change resulting from damage. Beanlands and Duinker consider the population level as "the very level at which our ability to predict or measure change due to human activity is weakest".[180]

Low dosages of air pollution seem to be the most difficult to understand subsequent plant responses. It has been suggested that low levels of acid deposition in Alberta actually encourage plant growth.[181] Another benefit to plant communities of low dosages of air pollutants is the development of resistant species through natural selection, although this process may take many decades.[182] Vegetation may remove pollutants from the air (a sink) without detectable effects in the short term. Possible long term effects may be caused gradually. "The possible long term effect on plants and plant communities is determined by the behaviour of the specific substances in the ecosystem. Pollutants such as ozone and PAN that decompose rapidly cause effects through the summation of individual reactions over one or several years. With other components...they may enter into the nutrient cycles of the ecosystem causing cumulative effects and disturbing the balance of especially sensitive ecosystems".[183] Once again, predictable and measurable changes occur only after the inputs have been in the system for a period of time, and they become visible not necessarily at the individual level but at the population or ecosystem level.

Affected ecosystems may not be in the locality of the source. Due to long range transport capabilities, "synoptic" scale pollutants have the capability of damage on a regional basis. "Studies on conifers located at different distances from

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[180]Beanlands, G.E. and P.N. Duinker
[181]Legge, A.H.. p. 571
[182]Guderian, p. 152

urban and industrial areas (pollution sources) have shown marked reduction in cone dimensions, seed weight and viability, together with reduced pollen viability. Furthermore, these effects may occur at pollution levels lower than that required for foliar injury".[184] Admittedly, different species will have different responses to various levels of pollution, but this example is important in establishing that damage need not be from a local source or of a high intensity to have an effect on vegetation.

The largely unknown long term effects on plants of moderate to low intensity pollution leaves in question possible future problems associated with cumulative pollution. Unknown long term effects may eventually concern health of people and the viability of ecosystems that people may value for food or aesthetic reasons. To be proactive requires the monitoring and reporting of releases, implementation of long term studies on vegetation, and use of the precautionary principle to reduce the absolute amounts of pollutants being emitted until long term effects have been determined.

Environmental Moderation

Moderating environmental conditions also affect the uptake of air pollution. The laminar layer normally contains no turbulence, thus protecting to some extent the surface of the leaf. However, wind speed influences the effectiveness of this barrier, as can be seen in the following example. "...the boundary layer resistance can be appreciable and influence pollutant uptake. For example, ryegrass...exposed to SO_2 at a wind speed of 0.17 m/s was uninjured; when exposed at a wind speed of 0.42 m/s it displayed considerable injury".[185] These environmental conditions (wind speed) can affect different ecosystem

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[183]Guderian,, p. 149

[184]Cox, R.M. "The Response of Plant Reproductive Processes to Acidic Rain and Other Air Pollutants", *in Effects of Atmospheric Pollutants on Forests, Wetlands and Agricultural Ecosystems*, p. 155

[185]Guderian, R. Editor. p. 134

components and thus indirectly affect plant growth. For example, it was found that "forest decline in central Europe is generally characterized by a significant increase in forest damage following warm and dry years."[186] This may be the result of nitrification pulses within the soil, which will be discussed further below.

Indicator Species

The use of indicator species to monitor the condition of a component of the ecosystem may be useful in assessing the effects of pollution. "Indicators will play an important role, especially in determining the state of valued environmental components. An indicator is defined as a monitored component representative of one or more valued environmental components."[187] Some species are more sensitive to pollutants than other species, making them excellent indicator species.

A good species for south central Alberta, particularly those regions in the Aspen Parkland Ecoregion, is aspen itself –*Populus tremuloides*. Studies conducted on a number of species for the effects of pH (an acid deposition indicator, although not the only one) indicate that the threshold inhibition response of aspen (for pollen viability) was between pH 5.6 to 4.6 .[188] The use of indicator species for this purpose should only be undertaken with knowledge of the type and normal pH of the soil in the area to avoid making erroneous conclusions about acidic deposition. Areas naturally acidic might be assessed as having high deposition levels. Conversely, areas that are naturally extremely basic in pH may not be noticed if the pH is not reading as acidic, even though acidity may have increased.

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[186]Matzner, E. and B. Ulrich. "Result of Studies on Forest Decline in Northwest Germany "*in Effects of Atmospheric Pollutants on Forests, Wetlands and Agricultural Ecosystems*. Springer-Verlag, 1985

[187] Shoemaker, Darryl J. p. 15

[188]Cox, R.M. p. 160

There is a danger to using indicator species. Species may vary widely in their response to environmental factors or disturbances other than those being monitored. In this sense, the use of indicator species is "far from an exact science."[189]

An inventory of plants sensitive to sulphur dioxide and ozone was created for the West Central Regional Airshed (a CASA group), which is located immediately north of the study area for this project. Land types in the two areas indicate a significant amount of overlap, allowing the assumption that these species are also found in the study area.[190] Vegetation sensitivity studies should use two species growing in the same place, one tolerant and one sensitive.[191] The table summarizes these species in regard to sulphur dioxide sensitivity.[192]

Table 3. Plant Sensitivity to Acid Deposition in the Study Area

Sensitive	Intermediate	Tolerant
Trembling aspen	Mountain Alder	Buffalo berry
Paper birch	Chokecherry	Kinnikinnick (bearberry)
White birch	Cottonwood	Rocky Mountain Juniper
Lowbush blueberry	Red osier dogwood	
Beaked hazel	Mountain ash	
Saskatoon	Lilac	
Western larch	Balsam polar	
	Big Sagebrush	
	Lodgepole pine	
	White spruce	

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[189] Shoemaker, Darryl J. p. 16

[190] West Central Regional Airshed Monitoring Program. Figure 3.11 Land Use Types in the West Central Zone. p. 27

[191] West Central Regional Airshed Monitoring Program, p. 31

Any of the above sensitive species and a low sensitivity counterpart could be used as an indicator species within the zone, once identified.

Plant reaction to pollution is an area that has been well studied. However, response of vegetation in the field is a necessary component to understand the influence of pollution on plants in a specific area. "The impact of responses...on plants exposed to a variety of stresses in the field needs to be assessed before we can estimate the agricultural and ecological consequences of the dry deposition of SO_2 and NO_2."[193]

Risk Identification: Soils

The Canadian System of Soil Classification describes nine orders of soils, all of which are present in Alberta.[194] Each order has a different susceptibility to acidification, based on factors such as calcium content, pH, or water content. The main precursors to acid deposition in Alberta are SO_X and No_X.[195] Acidification of a soil would have effects upon its fertility -- plants take up bases such as calcium and magnesium and return hydrogen to the soil, increasing its acidity and leading to the necessity for liming in some agricultural systems. Another potential effect is upon water systems adjacent to the land where percolation and run off may leach through the soil, leading to higher acidification of the water. Acidification of natural water systems may lead to "dead" systems, where the base of the food chain is eliminated by the acidic pH and other life depending on this dies, as is happening in eastern Canada with the acid rain phenomenon.

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[192] West Central Regional Airshed Monitoring Program, pp. 31-32

[193] Mansfield, T.A. et al. "Responses of Herbaceous and Woody Plants to the Dry Deposition of SO2 and NO2" in *Effects of Atmospheric Pollutants on Forests, Wetlands and Agricultural Ecosystems.* p. 142

[194] Turchenek, L.W. et al. "Acid Deposition Research Program Biophysical Research: Effects of Acid Deposition on Soils in Alberta" *in Acid Depostion Research Program* 1987. p. iii

[195] Turchenek, L.W. p. 34

Acidification

Essentially, acidification of the soil refers to the availability of free hydrogen ions in solution.[196] "Acidification of soils involves the displacement of basic cations from exchange surfaces, their replacement by H^+ and Al^{3+} ions, and establishment of new exchange/solution equilibria".[197] Soil acidity is balanced by the relationship of hydrogen ions to other cations such as calcium and magnesium in calcareous (basic) soils, and to aluminum in acid soils.[198] Availability of calcium and magnesium tends to "buffer" the effects of acid deposition, while acid deposition in an already acid soil will release aluminum, leading to increased leaching and an increase in potential toxicity.[199]

Some effects of acid deposition are:

1. Soil exchange capacity would be reduced, leading to an increase in acidity (increased aluminum mobility, leaching, availability, and toxicity) and a decrease in base (buffering) saturation;
2. Decreased rate of organic matter mineralization;
3. Plant nutrients:
    a. Nitrogen -- Increased leaching and a decrease in nitrification.
    b. Sulphur -- decreased leaching and reduced plant availability.
    c. Phosphorus -- reduced availability with decrease in pH.
    d. Calcium, Magnesium, Potassium -- increased leaching.[200]

Sensitivity of Soil Orders to Acidification

The nine orders of soils and their potential sensitivity to acid deposition is presented in this section.

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[196]Turchenek, L.W., p. 3
[197]Turchenek, L.W., p. ii
[198]Turchenek, L.W., p. 5
[199]Turchenek, L.W. p. 38
[200]Turchenek, L.W. pp. 38-39

Chernozemic -- generally low sensitivity to areas of high sensitivity. The following types are most sensitive to acidic deposition: "sandy, and some coarse loamy, Orhtic Brown, Rego Brown, Orthic Dark Brown, Rego Dark Brown, Orthic Black, Rego Black, and Eluviated Black. A small area of Dark Brown soils in the Cypress Hills was indicated as being moderately sensitive."[201]

Luvisolic -- moderately sensitive to occasionally highly sensitive; under 5% are considered highly sensitive. "The highly sensitive group consists predominantly of Orthic Gray and Brunisolic Gray Luvisols developed on sandy and coarse-loamy parent material of glaciofluvial and eolian (sic) origin. They often occur in association with sandy Brunisolic soils".[202]

Solonetzic -- moderately sensitive to occasionally low sensitivity. About one third of the extent of Solonetzic soils are considered to be moderately sensitive. including those of the Solonetz great group occurring on coarse parent materials or shallow glacial deposits. The Grey Solonetz subgroup is also moderately sensitive due to the lack of a Chernozemic-type A horizon, leaving it more leached and with less availability of bases. [203]

Brunisolic -- highly sensitive to very occasionally low sensitivity. Approximately 40 - 45% of this group is considered sensitive to acidic deposition. Sensitive groups in this order include Eluviated Eutric Brunisols and Eluviated Dystric Brunisols on sandy glaciofluvial or aeolian deposits.[204] The soils of this order, if occurring in the study area, are unlikely to be sensitive, as: "Brunisols developed on finer textured materials such as Cordilleran and Continental tills in the foothills region have a low sensitivity rating."[205]

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[201]Turchenek, L.W. p. 130
[202]Turchenek, L.W. p. 145
[203]Turchenek, L.W., p. 141
[204]Turchenek, L.W. p. 150
[205] Turchenek, L.W. p. 150

Organic -- highly sensitive to very occasionally low sensitivity. "Practically all" Organic soils in Alberta are considered sensitive to acid deposition because the bases available are already low; further base depletion due to acidic inputs would reduce an already low pH and base saturation levels.[206]

Podzolic -- very low sensitivity. Podzols are not common in Alberta but are found mainly in foothills and Alpine regions.[207] As with Brunisols, this may indicate that Podzols that have developed on Cordilleran and Continental tills in the Foothills are not sensitive. In comparison, Podzols developed on coarse materials are considered highly sensitive to acidic deposition.[208]

Gleysolic -- low sensitivity. This is because gleysols are saturated with water, either from runoff or from the subsurface. This water flows from other soils and introduces base cations from these sources. There is one small area (northeast of Grande Cache) that has a high sensitivity rating. A concern that needs further research is the possible introduction of acids and mobilized toxic metals into streams and lakes that Gleysolic soils may drain into.[209]

Regosolic -- highly sensitive except where calcareous. The largest area in Alberta is found on the Peace-Athabasca delta and is considered insensitive because of the continuous replacement of calcareous sediment. Smaller areas of regosols are considered highly sensitive due to the lack of calcareous parent material: one is in northeast Alberta on the small area of PreCambrian shield, another in Cordilleran areas.[210]

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[206]Turchenek, L.W. p. 155
[207]Turchenek, L.W., p. 161
[208] Turchenek, L.W. p. 150
[209]Turchenek, L.W., p. 156
[210]Turchenek, L.W., p. 157

Information on total areas covered by each order of soils and their sensitivity ratings is presented in Table 4 - Soil Sensitivity to Acid Deposition In Alberta.

Table 4. Soil Sensitivity to Acid Deposition in Alberta

Order	**Area km² [211]**	**% of Total[212]**	**% Moderate to Highly Sensitive*[213]**	
			% of Order	**% of Total**
Chernozemic	141,500	22.9	12.30%	2.80%
Luvisolic	203,000	32.9	95.00%	31.20%
Brunisolic & Podzolic	53,000	8.6	45.00%	3.90%
Solonetzic	42,960	7.0	33.00%	2.30%
Gleysolic	21,500	3.4	3.90%	1.60%
Cryosolic	43,800	7.1	None	
Regosolic	7,400	1.2	indeterminate	
Organic	104,500	16.9	95.00%	16.00%
Total	**617,660**	**100.00**		**57.80%**

*The first number indicates percent of the area of the individual soil order. The second number indicates percent of total soil (soil orders combined) area.

From the information contained in Table 4 above, it is seen that 57.8% of Alberta's total land area is considered sensitive in some way to the effects of acid deposition.

[211] Turchenek, L.W., pp. 130 - 157
[212] Derived from the areas given above.
[213] Derived from Turchenek, pp. 130 - 157

Influence of Parent Material on Soil Sensitivity

The factors that influence the genesis of a soil are parent material, climate, vegetation, and time. These factors may also be seen as influencing the rate of acidification of a soil. Parent material is particularly important. Rocks may be low in bases, such as granite, quartzite, or sandstone; the absence of bases mean the rock and the soil developing on these materials have a low buffering capacity to acidic inputs. In Alberta, the Gog quartzite is a common component of Cordilleran tills[214], and has no buffering capability. These are possibly components of sensitive Regosols in the Cordilleran region, as presented above. Rocks such as limestone or dolostone contain large amounts of calcium or magnesium. These bases act as buffers to acidic inputs. In Alberta, rocks coming from the Cordilleran icesheet (found in the foothills) contain large amounts of limestone and dolostone. The soils that have developed on these parent materials are therefore more likely to resist, or be buffered, from acidic inputs than those soils developing on other parent materials.

Influence of Time on Soil Sensitivity

Time, a factor in the development of soils, also influences acidic deposition. Soils in Alberta may be considered as fairly young, having developed within the last 10-14,000 years since the last ice sheet receded. This means that bases in Alberta soils, developing on calcareous-rich Cordilleran tills, are much more likely to be present than in older soils. Time is also an unknown factor - there is no consensus on how long it may take to acidify base-rich soils given present and possible future rates of anthropogenic acidic deposition.

Risk Analysis: Long Term Implications

The soils in Alberta are probably not in immediate danger of acidification, at least not in the short term. Studies that produced the numbers given in the table above used very conservative parameters in which a worst case scenario was

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[214] Henderson, C.M. Associate professor, Geology and Geophysics, University of Calgary, personal communication.

used. However, this does not mean that acid deposition on soils is not worthy of concern or further research, especially on a very localized level near to emitters or in an area that is likely to be influenced by deposition of acid precursors. The Acid Deposition Research Program states, "...there is insufficient evidence to either substantiate or refute the possibility of harmful impacts by long-term, low level deposition of acid forming substances. The impact of deposition on soils near emitters or point sources may be greater than on soils under ambient depositional conditions but there is also little knowledge of these"[215]. The precautionary principle would imply that lack of knowledge about the long term impacts is no excuse to ignore them.

Soils: Risk Management

Further research into long term impacts using projected deposition is needed to ensure unknown effects do not become significant enough to take away future benefits of the resource, whether it is currently being exploited or not. A necessary first step is the monitoring and reporting of emissions not currently required by regulations. This may be effected with the administration of an environmental auditing program.

Acidification Pulses

A long term, recurring effect or possibility of being an effect is the phenomenon of the acidification pulse. This is a seasonal pulse triggered by increased soil temperature. Nitrification in the soil is promoted by increased mineralization that occurs as soil temperatures rise. If nitrate uptake by plants is slower than the rate of nitrification, then an acid pulse is produced in the soil.[216] This pulse is also promoted by exceptionally warm years.

The ability of the soil to buffer these pulses depends on its composition and the rate of alternate sources of acid inputs. "At this point the interrelationship among

[215]Turchenek, L.W.. p. 1
[216]Matzner, E. and B. Ulrich, p. 31.

acidification pulses, deposition of acidity, and other processes leading to soil acidification (e.g. harvesting) becomes clear, since acid deposition continuously stresses and slowly exhausts the buffering capacity of the soil."[217] This slow exhaustion of the soil leads to a concern for long term effects of acid deposition on the soils of Alberta, particularly the 57.8% that are regarded as moderately to highly sensitive.

Long Term Effects

The unknown effects of long-term, low-impact deposition of soils is again reason to monitor and reduce emissions, following the rationale of the precautionary principle. Soils are essential to agriculture, ranching, and the viability of ecosystems. There is a potentially large social cost to losing productivity in the soil, and a large economic cost associated with remediating any decrease in viability. More research is needed in this area on the cumulative impacts of deposition and the effects on the sustainability of Alberta ranching and agriculture in the long term until long term effects and a timeline have been established.

Water Systems

The study area contains many water systems. This includes river systems such as the Red Deer River and wetlands such as the Charlton Muskeg. The response of water systems in Alberta to acid deposition can be very low to highly sensitive, but the areas of high sensitivity are few due to the high buffering capacity of much of the bedrock. The study area has been classified in an area of very low sensitivity.[218]

Long term effects of acid loading in water systems are well known: it is in this area that pioneering studies on acid rain took place. The buffering capacity of

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[217] Matzner, E and B. Ulrich. p. 31

[218] West Central Regional Airshed Monitoring Program. Figure 3.13 lake Sensitivity to Acidic Inputs. p. 30

bedrock will not last forever and at this point pH drops sharply[219]. Unfortunately, it cannot be predicted when this point will be reached.[220]

Acid Pulses

As in soil systems, acid pulses from storm runoff and snowmelt can affect aquatic ecosystems.[221] This can be devastating to amphibians, which breed in runoff pools. Areas with large amounts of snow are most vulnerable to this process. A literature search has turned up no studies on this phenomenon in Alberta; this may be a necessary step if there are endangered amphibians in Alberta that warrant further research.

The Charlton Muskeg may play another role in acid pulses. Storage of acidic inputs into the system may add to the chronic (low impact, long term) effects over time.

> While several effects of acidic deposition on wetland ecosystems are known, the most important response is storage of atmospherically deposited S and N for time periods of years to decades. This storage delays acidification of exported waters beyond that associated with the normal export of natural organic acids; however, most of the S and approximately half of the N stored in the surface layers of the peat are exported eventually, accompanying oxidation of organic matter. Hence, protracted release of stored S and N also delays recovery after deposition levels decline.[222]

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[219] Sanderson, K. *Acid Forming Emissions - Transportation and Effects.* Environment Council of Alberta, March 1984. p. 17

[220] Sanderson, K. p. 17

[221] Sanderson, K. p. 17

[222] Jeffries, D. *Watershed Responses and Aquatic Effects Caused by Atmospheric Deposition of Acidifying Pollutants.* April 1996

This storage function may result in an acidification pulse in dry years, much like the one experienced in soils, as the muskeg gets drier.[223]

Long Term Effects

Long term effects, as in vegetation, can produce changes to the ecosystem composition. If pH drops, the number of species tends to decline.[224] Reproductive systems may be affected.[225] Lower pH tends to mobilize aluminum; aluminum in turn can increase fish mortality.[226] The base of the food chain in aquatic ecosytems, phytoplankton, is also sensitive to acidic inputs. Reduced numbers of these organisms control numbers and diversity of species all the way up the foodchain.[227]

Critical Load

Critical load is the concept of how much pollution the environment can take and deal with using natural sinks. Associated with critical load is the concept of target loading, a concept used by some stakeholder groups to determine appropriate amounts of pollution emissions by industry in a defined area, taking into account socio-economic factors as well as scientific assumptions. A common definition of critical loading is: "a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge".[228] As evident from the above definition, the concept of critical load, that is widely used, does not conform to the concept of prevention of significant deterioration or the precautionary principle. However, target loading may be an effective tool in trying to achieve sustainable development and thus is a very useful concept in managing the airshed. "The target load may be greater than

[223] Jeffries, D.. April, 1996
[224] Sanderson, K. p. 16
[225] Sanderson, K. p. 17
[226] Sanderson, K. p. 17
[227] Sanderson, K. p. 17

the critical load because of uncertainty or cost-benefit, or the target load may be less than the critical load if the goal of the management system is to prevent the occurrence of ecosystem damage and achieve sustainable development".[229] A target load provides a quantifiable measurement that is more easily identified than small changes in the ecosystem due to the "inherent variability of biological systems".[230]

Summary

A receptor is something that encounters emissions. The interaction of emissions makes possible additive or synergistic effects possible on receptors. Receptors are often affected at a biological level; effects would only be noticed in the longer term at the population or system level. While high dosages on plants cause visible damage, low and intermediate doses are not obvious. The plant may be structurally damaged and thus affect ecosystems in the long term, such as a change in succession to due changes in competitive ability. Emissions may also enter the nutrient cycle and cause cumulative effects.

Due to long range transport, the source of emissions does not need to be local to affect receptors. The use of indicator species known to be more susceptible to the effects of certain pollutants may be a valuable part of a long term monitoring program.

Acidification of the soil refers to the availability of free hydrogen ions in solution and the displacement of base cations by hydrogen and aluminum ions. The concept of buffering refers to the natural availability of base cations in soil or the surrounding bedrock. Nearly 58% of Alberta soils are in some way sensitive to acidification. The long term impact of low level deposition is unknown.

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[228]Nillson, L and T. Johansson. p. 65

[229] Angle, R. and H. Sandhu. "Application of Acid Deposition Critical or Target Loads to Limit Source Emissions in Sensitive Areas", in *Atmospheric Chemistry*. 1992

[230] Angle, R. and H. Sandhu.

The concept of critical load weighs how much pollution the environment is thought to be able to cycle through its natural sinks without any noticeable damage. This concept is widely used but does not conform with the principle of prevention of significant deterioration. However, it may be the best available tool.

Part Three - Predictors (Tools)

CHAPTER 7 -- ENVIRONMENTAL AUDITING AND REPORTING STANDARDS

Environmental Auditing and Reporting Standards

Main Points

- Environmental auditing is an effective management tool to identify sources of emissions, detect sources of problems, give cost estimates for current and future remedial or preventative action, and remain in compliance.
- Lifecycle assessment is a complementary policy to environmental assessment and environmental auditing and can be used to assess operational efficiencies and evaluate investments in environmental technology.
- Better knowledge of the roles that eddies, topography, and stability parameters play in deposition are needed for more effective placement of monitors.
- Placement of monitors in topographically appropriate areas will aid in obtaining specific data for potential "hot spots" but is not foolproof.
- Placement of monitors should be done with regard to valued ecosystem and economic components.
- Stricter reporting protocols are necessary on more emissions than currently required.
- Reporting protocols should include standards on placement of monitors within and outside the facility.
- Reduction or prevention of emissions is necessary to repel any civil charges of release of dangerous substances (strict liability).

Environmental Auditing

Environmental auditing is a useful tool within the environmental management portfolio. It is defined as: "A systematic, documented, periodic and objective review of environmental operations, management systems, performance or practice carried out in a rigorous process of obtaining and evaluating evidence regarding a verifiable objective or assertion about an environmental matter, to ascertain the degree of conformity within established criteria, and then communicating written findings to the client".[231] Environmental audits have many benefits, including:

- Information for the formulation of long range environmental management strategies;
- Compliance with current and future regulations;
- Resolution of technical or legal uncertainties;
- Development of image enhancing environmental programs;
- Environmental research and development;
- Financial planning for long term capital or operating expenditures related to environmental concerns;
- Positive public relations if there are no problems;
- Buying and selling of assets related to environmental processes;
- Evaluating the impact of new laws and regulations.[232]

The current state of emissions monitoring and reporting indicates that environmental audits, administered to industry, regulated by government, and done by an accountable third party[233], would be an effective tool to create standards for emissions reporting. The following sections detail this need by looking at an informal comparison of emission reporting by several agencies.

Accuracy of Emission Monitoring

Very little up-to-date information on actual releases by company in the petroleum industry is available, due to lack of reporting necessity and company reluctance to share this information. However, a representative of one company made available a summary analysis of emissions, on the understanding that this information would not be traceable back to the company. This company has been given the pseudonym "X". This information is retained in a file and may be

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[231] Young, Steven Scott. Environmental Auditing. Cahners Publishing Company, 1994. p. 95

[232] Young, Steven Scott. pp. 22, 55 - 57

[233] Young, Steven Scott. p. 2

viewed upon request. The information provided is for the year 1994 as known on March 4, 1996, and is for this company's operations in Alberta.

Company X breaks its emission summary down by process unit for the following releases: carbon dioxide, sulphur dioxide, nitrogen oxides, sulphuric acid, carbon monoxide, nitrous oxide, volatile organics, benzene, ethylbenzene, toleune, and xylene. For the purposes of comparison, only nitrogen oxides and sulphur dioxide will be referred to, as these are consistently in the reports from each agency. The process units in the analysis are compressors, gas dehydrators, flares, gas treaters, gas wellheads, heaters and boilers, incinerators, pipeline headers, pumps, storage tanks, and oil treaters.

According to this information, Company X releases a total of 4, 590.4 tonnes a year of nitrogen oxides from its process units. The sources of these emissions are accounted to the following process units:

Table 5. Company X Releases of No_x by Processor Type

Processor Type	**Nox Emissions in Tonnes/Year**
Compressor	3,392.40
Gas Dehydrator	27.11
Flaring	83.31
Heater/Boiler	644.30
Incinerator	396.70
Oil Treater	46.50
Total Emissions	**4,590.40**

The majority of NO_X is released from compressors; in 1994, there were 49 compressors in the company's system. This gives an average release per compressor of 69.23 tonnes per year. Combustion (flaring, heater/boiler, incineration) accounts for only 1124.3 tonnes per year in totality. Yet, when these figures are compared with Environment Canada statistics for 1985[234] (the last year for which statistics are available), fuel combustion is the only source of NO_X in gas plants. I do not intend to make a close comparison of numbers because of the nine year disparity; however, most of these plants can be assumed to have been in operation in 1985. This does suggest that emission estimation and measurement can err significantly, and that the process of estimation and measurement can change over time with new procedures.

The same information is given for sulphur dioxide. The breakdown of emissions by processor unit is as follows:

Table 6. Company X Releases of So_x by Process Unit

Process Unit	**SO2 Emissions in Tonnes/Year**
Compressor	6.74
Gas Dehydrator	1.10
Flaring	274.49
Heater/Boiler	13.77
Incinerator	13,436.00
Oil Treater	1.89
Total Emissions	**14,734.00**

The majority of SO_2 as reported by Company X comes from incinerators at gas plants -- 97.9%. In 1994, Company X had 6 gas plants in operation in Alberta. Comparing these numbers to the Canadian Emissions Inventory, we find that gas plants are responsible for 240,280 tonnes per year of SO_2 in Alberta. In

[234]Environment Canada. *Canadian Emissions Inventory of Common Air Contaminants (1985).* Report EPS 5/ap/3 March, 1990..

1995, there were 710 gas plants in Alberta.[235] This number is probably similar to those in operation in 1994 and not very dissimilar to those in operation in 1985. However, the number of sour gas plants compared to sweet gas plants is less than this; in 1994 the ERCB gives the total of sulphur recovery plants in Alberta as 60, and the total of Acid Gas flaring plants at 198.[236] This leaves us with about 258 gas plants that can emit SO_2. The assumption is made that levels of emissions over nine years would be improving with better available technologies.

If we compare these numbers, we find the following. If Company X is responsible for 14,734 tonnes per year of SO_2 from six gas plants, this is approximately 6.13% of the total emission of SO_2 from gas plants reported by the Canada Emissions Inventory for 1985. If, as we are assuming, there were 258 "sour" gas plants in Alberta in 1985, and each (on average) emits 2,450 tonnes per year of SO_2 (14,700/6), then Alberta would be emitting around 632,100 tonnes per year of SO_2 from gas plant sources. This differs significantly from the reported 240,280 tonnes per year in the Canada Emission Inventory. In fact, this number would differ from the above if any more than around 100 gas plants in Alberta were in fact sour. Emission control technology from 1985 to 1994 would have presumably improved.

The Acid Deposition Research Program was discussed in Chapter 6. The ADRP reports that sour gas is responsible for approximately 386.5 tonnes per day of SO_2. Extrapolating this to tonnes per year, we find that the ADRP researchers hold that sour gas is responsible for only 141,072.5 tonnes per year in Alberta. This number differs from both of the above numbers, the Canada Emissions Inventory and the data given by Company X. Keep in mind that the ADRP study is closer in time to the Canada Emissions Inventory, as it was completed in 1988.

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[235]Alberta Gas Plant Directory, 1996.

ADRP study is closer in time to the Canada Emissions Inventory, as it was completed in 1988.

A fourth source gives us yet different emission estimates. The ERCB, in a presentation to the Clean Air Strategic Alliance in September 1994, presents a chart that claims that SO_2 from sour gas production has remained relatively constant in Alberta from 1985 to 1993 at around 300,000 tonnes a year. This differs again from the 240,280 tonnes/year claimed by the Canada Emissions Inventory, the 141, 072 tonnes a year claimed by the Acid Deposition Research Program, and the 632,100 that was extrapolated from the emissions from Company X.

This comparison, based as it is on data from different years, still serves to illustrate that measurement and estimation of emissions is less than an exact science. Part of the problem is lack of monitoring devices located at the various points in the process where fugitive emissions may be located, such as valves.

Acid Deposition Research Program - Emission by Source Type

The ADRP also breaks down industry by source types within the different facilities. These source types are boiler units, heater units, nitric acid plants, reciprocating engines, turbine engines, flares, incinerator units, electric motors, and kilns. Major sources of SO_2 include boiler units, flares, and incinerators. Major sources of NO_x include boiler units and reciprocating engines.

The breakdown by source type, above, allows for the recognition of smaller point sources within the plant as sources of significant emissions. While most attention is paid to visible icons such as the gas plant stack, significant reductions in emissions apparently may be accomplished by monitoring equipment for leaks and keeping this equipment in good repair. This could be achieved through environmental auditing practices.

Environmental Management Structure

For environmental auditing to be effective within industry, the environmental management system within the organization should have well defined reporting relationships as well as a policy statement affirming support of environmentally friendly policies[237]. The structure can place those responsible for environmental management where they are needed (decentralized) or in one unit (centralized), or a mix of the two without compromising effectiveness[238]. Facilities within the corporation or environmental management area can then be organized by:

- Geography;
- Function;
- Operating status (current, past, future);
- Age of facility;
- Pollution history;
- Type of material processed;
- Proximity to environmentally sensitive areas; and
- Sensitive local or community factors.[239]

These categories will be discussed in Chapter 10 – Framework for the Study Area.

Regional controi of airshed emissions is advocated in this paper because of the potential political problems related to management of an open system between these political boundaries. "Authority is also hindered by the multitude of administrative boundaries. Even within the administrative units, several jurisdictions usually exist over diiferent aspects of resource and environmental use, both within and among governments, which has largely frustrated truly integrated planning ... this is especially true for cumulative environmental effects that often transcend institutional and jurisdictional boundaries, making

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[237] Young, Steven Scott. p. 6-7
[238] Thompson, Dixon. p. 230
[239] Young, Steven Scott. pp. 6-7

assessment difficult".[240] Regional control is not to the exclusion of management tools that make the cross jurisdictional process easier. Environmental auditing may be aided by international organizations such as the Global Environment Management Initiative, The European Unions' Eco-Management and Auditing Scheme, or the International Organization for Standardization.[241]

Lifecycle or "Cradle to Grave Approach"

The regional model may be useful for implementing what may be described as a "zonal audit", or "class assessment".[242] A zonal audit would meld the environmental management tools of environmental auditng within a corporate entity and strategic environmental assessment, to help achieve a type of Lifecycle or "cradle to grave" approach. "Cradle to grave is a management approach in which chemicals are controlled from their initial development to their ultimate disposal. This approach would allow all the stakeholders to track a chemical throughour its lifecycle, helping to predict where and when people, or the environment, may be exposed to toxic chemicals."[243] The precedent for a "cradle to grave" approach has been set in Canada: "the recent inclusion of waste management under *the Environmental Assessment Act* in Ontario provides an example of a process that does consider some aspects of the lifecycle of an activity."[244] For industry, lifecycle assessments can determine the cost effectiveness of investment in prevention technology and resulting resource efficiencies.[245]

This type of zonal approach would require governmental backing, a strong diffusion model (see Chapter 9), and a standardization of audits within each corporate entity, the results that would then need to be shared within the zone.

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[240] Shoemaker, Darryl J.
[241] Thompson, Dixon p. 227
[242] Shoemaker, Darryl J. p. 67
[243] Shoemaker, Darryl J. p. 23
[244] Shoemaker, Darryl J. p. 23
[245] Thompson, Dixon. p. 240

Lifecycle assessment therefore needs strong predicitve abilities, which has been questioned by other researchers: "However, attempting to account for the lifecycle impacts of an activity raises the question of our limited predicitve abilities. Sadler (1992) has wryly commented that there is a 90 precent chance of being wrong, with the other 10 percent only understood after post-project monitoring."[246] With continuing use of this management tool, predicitve abilities should increase through agreement on methodologies and development of data bases.[247]

Placement of monitoring devices outside of the facility seems to be less than an exact science. For example, members of the Parkland Air Management Zone, as a working group of CASA, have decided that they need to monitor the airshed in this zone. They will place two monitoring stations here, "One average and one high"[248]. This should illustrate that the placement of monitoring devices is largely uncharted territory in industry. Better knowledge of the roles that wind eddies, topography, and stability parameters play in deposition is needed for proper placement of monitoring devices.

The above information also serves to illustrate that, along with environmental audits, stricter reporting protocols than are currently required are necessary. Currently, the Alberta government requires only reporting on sulphur (sulphur dioxide and hydrogen sulphide) emissions. Reporting protocols should include standards on where monitoring devices are placed within the facility as well as a process to designate where monitoring devices should be placed outside of the facility. This process should be formulated using what we know of airshed mechanics and could follow, at least initially, the steps stated in the introduction to this project.

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[246] Shoemaker, Darryl J. p. 23
[247] Thompson, Dixon. p. 241

1. Definition of the region's physical attributes:

- Topography;
- Local wind and weather patterns;
- Vegetative cover;
- Soils;
- Human habitation.

Placement of monitors near human dwellings, by environmentally valuable systems, or by elements of economic productions such as cattle will aid in defining long term effects due to individual specific pollution intensities. A pilot project instituted in the fall of 1996 put Personal Exposure Monitors (PEMs) on people in the Fort McMurray area designed to capture sulphur dioxide, nitrogen dioxide, VOCs, ozone and particulates.[249] Accomplishing the checklist, above, will identify potential areas of deposition by season, stability patterns, and topography as well as receptors that may be negatively affected.

2. Define valued ecosystem and economic components. This may include rangeland, rare or sensitive vegetation, people, cattle, vegetation, houses, or even clean smelling air.
3. Identify common emissions, including:
    a) sources (point, line and area);
    b) residence times;
    c) risk (effects on valued receptors).

Accomplishing Step 3 will identify emissions, the scale of their impact, and the magnitude of the risk on receptors. Unfortunately, placing monitors with regard to these factors may not be precise, due to the complexity of factors controlling depostion. As previously suggested in this project, the use of monitors at the

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[248] Parkland Airshed Management Zone minutes of meeting June 21, 1996 (Olds Legion)

source of emissions may help in the accuracy of measurement, if not with the accuracy of deposition. However, any greater accuracy that can be achieved may aid in pinpointing the source of the release. This could identify the emitter and introduce some legal concerns. The concept of strict liability in law may apply.

Legal Liability

The concept of strict liability is defined by the case Rylands vs. Fletcher (1868). The principle adopted by this case is that: "if something inherently dangerous is brought onto property, and it escapes, the occupier is responsible for any consequence whether or not there is any negligence".[250] The actual rule is as follows: "We think that the true rule of law is, that the person for his own purposes brings on his land and collects and keeps there anything likely to do mischief if it escapes, must keep it there at his peril, and if he does not do so, is prima facie answerable for all of the damage that is the natural consequence of its escape."[251]

The concept of strict liability differs in law from the tort of nuisance, which is "the act of wrongfully allowing or causing the escape of harmful or obnoxious things onto another person's land — for example, water, smoke, smell, fumes, gas, noise, heat, vibrations and electricity that are capable of destroying a person's health or property."[252] To prove nuisance, one must prove that the neighbour must be using the property in an unusual manner[253] -- for example, if the adjoining area is industrial, a homeowner cannot complain about usual amounts of noise. The concept of strict liability allows that the duty of care is so high, only

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[249]Clean Air Strategic Alliance. *Clean Air Views*, Volume 5 Issue 3. September 1996.

[250]Yates, R. *Business Law in Canada, Second Edition.* Prentice Hall Canada 1989. p. 53

[251]Bates, J.. *Business Law in Alberta, Second Edition.* Copey Publishing Group, 1991. p. 31

[252]Bates, J. p. 50

the release of the potentially damaging thing, regardless of negligence, is needed to be proved. Under the concept of nuisance, it is most often the case that the escaping substance enters adjacent land. However, under strict liability, even a passerby could sue if injured by the escaping substance. It should be noted that the defense of due diligence is not acceptable under the charge of strict liability: The standard of care is so high that if damage occurs, the defendent is liable no matter how responsibly he behaved."[254] Inherently dangerous things have included water, electricity, gas, oil, fire, poisonous plants, and parts of buildings.[255] It is not a big stretch to include harmful air in this list. It is also easy to speculate (as this statement does) that actors responsible for air pollution may one day be facing class action suits similar to those being faced by the tobacco companies in the United States at this time.

The Alberta Environmental Protection and Enhancement Act (1992) allows that the Act itself cannot interfere with remedies in civil law. "Subject to sections 208 and 236, no civil remedy for an act or omission is suspended or affected by reason only that the act or omission is an offense under this Act or gives rise to a civil remedy under this Act, and nothing in this Act shall be construed as to repeal, remove, or reduce any remedy available to any person at common law or under any Act of Parliament or of a provincial legislature".[256] This means that the civil case of strict liability is an option under law in Alberta for a remedy to air pollution. The solution to such a charge is prevention and the use of the precautionary principle.

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[253]Yates, R. p. 52
[254] Bates, J. p. 30
[255] Bates, J. p. 31
[256]Province of Alberta. *Environmental Protection and Enhancement Act (1992)*. Section 206.

Summary

Environmental auditing is an important environmental management tool. Audits can help in the formulation of long-range strategies, compliance, research and development, financial planning, and public image enhancement. Audits would help standardize the reporting of emissions, which currently varies among agencies. Very little information on company releases is available, due to lack of reporting necessity and reluctance of companies to share this information. Company "X" has provided some information on its releases provided it is not traceable back to the company. The comparison of this information with other statistical sources indicates that monitoring and reporting of emissions is less than an exact science. It is recommended that better reporting protocols are established for an increased number of emissions, as well as for placement of monitors within the facility. Placement of monitors outside the facility should take into account airshed mechanics as discussed in this project as well as valued ecosystem components. Zonal or class audits and the lifecycle approach can aid in creating methodologies to accomplish the goal of tracking cumulative effects.

Monitoring and reduction of releases should be essential to avoid any recourse under civil law such as under the principle of strict liability. Under this principle of law, no negligence needs to be proved, only that a damaging substance has escaped. The Alberta Environmental Protection and Enhancement Act does not interfere in the procuring of civil remedies such as strict liability. Strict liability cannot be avoided through a due diligence defense.

CHAPTER 8 -- REGULATORY AND ECONOMIC INSTRUMENTS

Regulatory and Economic Instruments

Main Points

- A mix of regulatory and economic tools is optimal in order to retain predictability and maximize flexibility, responsiveness, and cost effectiveness.
- The use of emission reduction credits and emissions trading can aid in tracking and reducing cumulative effects and in the implementation of a strategic environmental assessment.
- The use of emission taxes likely will result in an outcry from industry, similar to the response to the National Energy Program. However, some of the negative aspects of such a tax may be eliminated by directing the tax to a third party research vehicle.

Background

There are essentially two common approaches to the control of pollution -- regulatory and economic. Regulatory approaches also are known as command-and-control strategies. In this chapter these two approaches will be explored and recommendations made for their use in Alberta.

Regulatory Tools

Regulatory or the command-and-control strategy is the most common strategy among governments to control pollution. As the term suggests, it uses legislation, standards, enforcement, and penalties to control the amount and type of pollution that is emitted into the environment by various users.[257] Generally, these instruments designate schedules and the setting of ecology or health based ambient objectives.[258] The command and control approach gives regulators (the government) the ability to predict pollution levels and reductions,

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[257]Bernstein, J.D. *Alternative Approaches to Pollution Control and Waste Management: Regulatory and Economic Instruments*. The World Bank, 1993. p. 1

[258]Bernstein, J.D., p. 1.

and the authority to control the resources used to achieve environmental objectives.[259] The three most common command-and-control instruments are standards, permits, and zoning.

Standards

Standards are perhaps the most frequently used command-and-control tool in the regulatory arsenal. Standards may be put on ambient air quality, amounts or concentrations of substances, the level of technology, performance, products, or the process used.[260] The use of standards implies monitoring and enforcement, which is the role of the regulatory agency. Several types of standards are:

Ambient standards: The highest allowable concentration of a substance in the air or water.

Emission standard: The highest allowable amount of concentration to be emitted from a specific source.

Technology standard: The type of technology to be used in a specific industry.

Performance standard: Allows the industry or source the choice of technology as long as certain emission standards are met.

Product standard: Sets the maximum allowable output per unit of product.[261]

Standards are in common use. The Alberta Environmental Protection and Enhancement Act (1992) refers to these standards by stating that: "No person shall knowingly release or permit the release of a substance into the environment in an amount, concentration, or level or at a rate of release that is in excess of that expressly prescribed by an approval or the regulations."[262]

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[259]Bernstein, J.D., p. 1
[260]Bernstein, J.D., p. 5
[261]Bernstein, J.D., pp. 6 - 8
[262]Environmental Protection and Enhancement Act (1992), Part 4, Division 1, 97 (1)

Permits

Permits are another regulatory tool used to control pollution. The Alberta Environmental Protection and Enhancement Act (1992) refers to "approvals", that are used in the same manner as permits, to control designated activities. "No person shall commence or continue any activity designated by the regulations as requiring an approval unless that person holds the appropriate approval."[263] An advantage of the permit or approval process is that all standards and pollution control obligations may be contained in one document.[264] A permit also gives the issuer of that permit the right to renew or not to renew that permit, based upon environmental or economic factors. In Alberta, an approval may be issued for a specified period[265], and that period may be extended for periods of not more than one year each.[266] In addition, these approvals may be amended or cancelled if deemed appropriate.[267]

Permits or approvals in Alberta regulate emissions levels for stationary sources, but all emissions must also meet ambient air quality standards. The ambient dose is equal to concentration of a substance multiplied by its duration. Ambient levels are set according to known health risks or known toxic levels. As such, ambient levels do not conform to the concept of prevention of significant deterioration. Ambient levels have another problem -- they are usually averages over time, which can mask any short, but intense emissions that would have the potential to cause more damage than otherwise moderate ambient levels would indicate. An ancillary problem is the difficulty in monitoring effectively enough to get a significant reading.[268] A product standard that sets the maximum allowable output per unit of product could be more effective.

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[263] Environmental Protection and Enhancement Act, Part 2, Division 2, 59.
[264] Bernstein, J.D. p. 8
[265] Environmental Protection and Enhancement Act, Part 2, Division 2, 65 (5)
[266] Environmental Protection and Enhancement Act, Part 2, Division 2, 66 (3)
[267] Environmental Protection and Enhancement Act, Part 2, Division 2, 67 (1)
[268] Strosher, M. p. 113

Zoning

Zoning is a regulatory tool that is used most often in an urban setting. The purpose of zoning is "to determine the location and intensity of various ... activities; it is used to separate types of land use that are likely to have an adverse effect on each other if located in proximity.[269] Zoning is a tool that is used extensively by the Alberta government, however, not with the stated purpose of air pollution control.

The Integrated Resource Management (IRM) process, instituted in the 1970's, is essentially a zoning policy. The Eastern Slopes Policy is one example of an IRM. IRMs are viewed as "an effective tool for resolving land use conflicts, allocating land and resources for different uses, and communicating the government's policy on current and future management of public land and resources".[270] This is to achieve the stated goals of "balance among resource protection, conservation and development and the maintenance of public land and resources for the future".[271] Airshed management has an intrinsic link to the land, and yet due to airborne pollution's ability to be transported, has not found a place within the IRM process.

Evaluation of Regulatory Tools

In general, regulatory tools have not only the benefit of predictability, but the disadvantages of: 1) being unresponsive to economic or environmental change; 2) being expensive to collect information on and have the expertise to evaluate various industries ; 3) little opportunity to use economies of scale on abatement technologies; and 4) lack of flexibility for those industries that may want to

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[269]Guldman, J-M. and D. Shefer. Industrial Location and Air Quality Control: A Planning Approach. John Wiley & Sons, 1980 p. 104

[270] Alberta Energy. Environmental Regulation of Natural Gas Development in Alberta, Canada. p. 10

[271] Alberta Energy, p. 10

innovate. Regulatory tools also are unresponsive to cumulative, non-point, and global problems stemming from air pollution.[272]

In Alberta, regulatory tools are governed by the Environmental Protection and Enhancement Act (1992), as referred to previously. The Act governs the environmental assessment process, approvals, appeals, release of substances, civil remedies, penalties, and enforcement. However, the Act is only as strong as the political will to enforce it.

Economic Instruments

Economic instruments are relatively new tools used to control emissions. They may take the form of emissions permit trading, pollution charges (polluter pays principle), or subsidies. They are not currently in use in Alberta, although some of their advantages are a greater amount of flexibility, cost effectiveness, the elimination of governmental expertise, and the opportunity to innovate within the private sector in finding new control and abatement technologies or procedures.[273] A mix of regulatory and economic instruments is probably the most effective mix of tools in order to retain predictability and maximize flexibility, responsiveness, and cost effectiveness.

Polluter Pays Principle - Emission Taxes

The polluter pays principle governs the implementation of effluent or emissions charges and are based on the amount of pollutants discharged by a facility. Generally, this charge is on a per unit or quantity basis and is used in conjunction with standards or permits; any amount over the permitted level has an associated charge payable to the governing institution. The current system of permits is, in a sense, a polluter pays system, because the industry pays for the permit. However, there do not seem to be any associated charges for exceeding the permit. This instrument will only be effective if the charges for amounts over

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[272]Bernstein, J.D., p. 3

the permitted level are greater than any profits associated from producing the pollution. Otherwise, it is in the economic interest of the polluting facility to continue to pollute. Of course, any fee or levy on pollution raises the questions of intrinsic worth of valued economic or environmental components; these fees can only be viewed as generally helping to remediate the social costs of pollution.[274] Fees may be simple charges based on permits or may become more sophisticated as they are based on ecological, diurnal, or seasonal cycles. The greater the sophistication of an emission charge system, the greater the cost of enforcement and monitoring.

As recently as the 1960s, the market economy was looked upon as an adversary to any environmental program. More recently, the realization that the power of the market economy can be harnessed and channelled toward the achievement of environmental goals has led to the use of economic instruments and particularly the creation of a market in which to trade emission rights.

Emissions Trading

Emissions trading as a form of economic instrument was introduced in the United States in 1975; this has developed into a program now known as the Emissions Trading Program, run by the Environmental Protection Agency (EPA).[275] This program does not rely solely on economic instruments, but is instead a mix along with more traditional regulatory approaches. Emission reduction credits are earned by reducing emissions by more than what the traditional permit allows. "The program attempts to facilitate compliance by allowing sources a much wider range of choice in how they satisfy their legal pollution control responsibilities

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[273]Bernstein, J.D., p. 3

[274]Bernstein, J.D., pp. 10 - 11

[275]Tietenberg, T. "Market-Based Mechanisms for Controlling Pollution: Lessons from the U.S." in *Economic Policies for Sustainable Development*, Kluwer Academic Publishers, 1994. p. 21

than possible in the command-and- control approach".[276] This program not only allows firms the flexibility to choose, but allows greater possibilities of cost reduction. "By making these credits transferable, the EPA has allowed sources to find the cheapest means of satisfying their requirements, even if the cheapest means are under the control of another firm."[277]

Emission reduction credits can be viewed as currency; other policies govern how this currency can be spent or banked. The offset policy requires that any expansion of facilities or new facilities in certain areas (typically, those that have poor attainment of ambient standards) must acquire sufficient emission reduction credits to ensure that the air will be cleaner after their entry than before.[278] The bubble policy controls multiple emission points as if they were a single point source, with total emissions of each pollutant being regulated. Emission credits may be traded within the bubble.[279] This policy has an important contribution to make to the idea of cumulative impacts and strategic environmental assessment that can potentially be applied to Alberta.

Other economic instruments that have been used throughout the world include product taxes and administrative charges in Sweden, Norway, Denmark, and Finland; effluent charges in Sweden and Norway; and subsidies, non-compliance fees, and marketable permits in Poland.[280] Many of these economic instruments are based on the idea of the polluter pays principle. According to this principle, "the polluter pays a financial penalty for higher levels of pollution and pays a smaller penalty or receives a financial reward for lower levels of pollution".[281]

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[276]Tietenberg, T., p. 22
[277]Tietenberg, T., p. 22
[278]Tietenberg, T., p. 22
[279]Tietenberg, p. 22
[280]Zylicz, T. "Environmental Policy Reform in Poland" in*Economic Policies for Sustainable Development*. p. 91
[281]Bernstein, J.D. p. 2

External Offset

Another potential economic instrument is the use of the external offset. "The idea of external offsets is that a given actor (which could be a firm, industry, region, or country) has an initial target, but is allowed to "offset" this by investing in measures to reduce emissions by an equivalent amount elsewhere".[282] The use of the external offset has potential for use in Alberta. For example, if a given "actor" was mandated to reduce emissions of NO_X, this entity could buy up old cars off the roads to help reduce the emissions from another type of source. The disadvantage to the external offset is that it does not necessarily reduce effects on valued components that occur in the specific geographic area affected by industry related deposition. Compounds with a strictly mesoscale, or local, range could not be part of this type of program.

Alberta potentially could apply some of the economic instruments discussed above, used jointly with the current regulatory or command and control type of approach. Emissions trading and emissions taxes are two economic instruments that are appropriate for use in the study area, based on a physical analysis of the study area (Chapter 10) and a need for funding to foster long term research on deposition issues. However, in order for emissions trading to be most effective, it should be tempered with increased control of reporting and monitoring standards through auditing, technology standards, and product standards. This flies in the face of the current move towards "self regulation" in the petroleum industry by the Klein government in Alberta, as seen in Bill 41, now law in the form of the Government Organization Act. This Act allows ministers to appoint non-governmental agencies to take over government services.[283]

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[282]Grubb, M. "Global Policies for Global Problems: the Case of Climate Change" in *Economic Policies for Sustainable Development*, 1994. p. 297

[283] Lowey, M. "The Brutal Bottom Line", in *Environment Views*, Volume 17 Number 3 Spring 1995.

Summary

The two most common approaches to pollution control are regulatory (command and control) and economic instruments. Command and control is the most common method and includes legislation, standards, penalties, permits, and zoning. Standards and permits (approvals) are controlled in Alberta by the Environmental Protection and Enhancement Act. Alberta uses ambient air objectives as standards. The problem with ambient air quality is that measurements are taken as averages over time and this may mask short but intense episodes of pollution. Command and control tools are predictable and familiar but are generally unresponsive to economic and environmental fluctuations.

Economic instruments are not in use in Alberta at this time. They include permit trading, emissions charges, or subsidies among others. Economic instruments are currently in use in the US, Sweden, Finland, Norway, Denmark, and Poland. The intent behind economic instruments is to harness the power of the market economy for the benefit of the environment. Emission permit trading may also be useful in tracking and reducing cumulative effects. In the study area, a mix of economic and command-and-control measures is appropriate based on an assessment of the physical features of the study area and of current regulatory systems, to be analyzed in Chapter 10.

CHAPTER 9 -- MODELLING AS A TOOL FOR ASSESSMENT

Diffusion Models as a Tool for Assessment

Main Points

- The use of diffusion models as a tool to gather accurate information for analysis can be done on local or long term regional bases.
- Models must be flexible to account for atmospheric mechanics, topography, and valued economic and ecosystem components.
- Classical Gaussian models are useful for single sources and the effects of their plume on selected receptors.
- The well mixed cells model is suited for overall analysis of the airshed for use in policy, tracking of cumulative impacts and sustainability efforts due to its flexibility in accounting for airshed mechanics, topography, and valued economic and ecosystem components.
- The RELAD (Regional Lagrangian Acid Deposition Model) model is immediately available for use in Alberta and combines many of the attributes of the Classical Gaussian and the well mixed cells model. However, it or any other long term regional model is not able to account for local effects on valued receptors.

Background

In order to effectively analyze the present condition of the airshed and the effects on valued ecosystem and economic components for use in practical policy applications, it is necessary to develop a tool that will give accurate information regionally, locally, and for different receptors. Diffusion models traditionally have been used for this purpose.

There are several theoretical models available for use in analyzing pollution plumes. The model used should be able to be flexible enough to take into consideration the factors discussed in this project -- atmospheric mechanics, which transport, transform, and deposit pollutants; and valued ecosystem and economic components, which can include human habitation, animals, vegetation, or economic ventures. VECs may carry different "weights" depending on sensitivity of the receptor to immediate or long term effects. The most common of these diffusion models is known as the Gaussian model. There are two derivatives of this model, the "puff kernel" model and the classical Gaussian model.[284]

The Puff Kernel Model

The puff kernel model is used for point sources. It assumes that the source is located at the origin of a three dimensional coordinate plane (with x, y, and z axes). Each puff is seen as moving independently, and therefore in a continuously emitting plume, the model can predict the trajectories and diffusion of individual cross sections of that plume.[285] This model is extremely effective in dealing with a single point source. In order to deal with multiple sources, the classical Gaussian model is more adaptable.

Classical Gaussian Model

The classical Gaussian model assumes the superposition of puffs in time and space over time. It assumes the following factors: constant source strength, constant wind speed and direction, constant diffusion rate, and non reacting pollutants. It also assumes that the plume is reflected from the ground and not adsorbed, and that the ground is flat terrain. The usual method of using a classical Gaussian model is to superimpose plumes from many sources to find the concentration at a specific point. Therefore, it is useful for a single point source to evaluate the effect of its plume on selected receptors, or for clusters of point sources to assess the combined impact of emissions on selected points.[286]

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[284]Guldmann, J.M. and D. Shefer. p. 40
[285]Guldmann, J.M. and D.Shefer
[286]Guldmann and Shefer, pp. 42-43

Gaussian Modelling in the Alberta Oilsands

In 1981, a modified Gaussian model was used in an attempt to analyze the airshed surrounding the Alberta oil sands. This is essentially "prehistoric" in terms of current models. At that time, Suncor was the only operator in the area. The consultants developing the model took into account the needs of the users. The two main concerns were that the resulting model must take into account the susceptibility of the ecosystem to ground level concentrations (that depends on meteorological conditions) and the time between successive episodes of high concentrations of emissions.

Previous models used an average ground level concentration for different wind speeds, directions, and meteorological conditions; the elimination of these factors was felt to be inappropriate. Instead, a "time series" approach was developed. This approach gave a weight to the ground level concentration depending on biologically important parameters for various individual receptors. Also, statistics could be kept of return periods of episodes of high emission concentrations on receptors.[287]

The accuracy of the Gausian model was reported to be good by those who used it if the input was accurate, which was judged to be not always the case. There were also some concerns felt at the time (1981) that the computer used was not powerful enough. However, the use of the Gaussian distribution model in the Alberta oil sands illustrates the practical application of the theoretical model. Another simple model exists that has the potential to be modified to suit the situation. This is called the "well-mixed cells" model.

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[287]Alberta Environment. *Airshed Management System for the Alberta Oil Sands. Volume I: A Gaussian Frequency Distribution Model*, 1981. p. 7

The Well- Mixed Cells Model

The well-mixed cells model is based on the diffusion of emissions in a "cell" of fixed volume. In this approach, the airshed is divided into cells by superimposing a grid on the area to be analyzed. Each cell is considered a discreet entity, but "with permeable walls and a movable lid".[288] For each cell, the following variables are defined: concentration of pollutant i in cell k; rate of emission of pollutant i in cell k; volumetric rate of airflow from cell j to cell k; rate of creation of pollutant i in cell k by chemical reaction; and the rate of decay of pollutant i in cell k.[289]

All variables are a function of time. The total inflow of pollutants from all other cells into a specified cell is taken into account, as is the total outflow of pollutants from a specified cell into any other cell. Net accumulation is the sum of emissions, decay, and chemical reactions.[290]

Because each cell is considered to have a movable lid, the mixing volume of the cell can depend on current meteorological conditions. Volume is the base of the cell multiplied by the effective mixing height (as explained previously in this project). In this way, it becomes easy to account for not only inversions but also topography.[291] Because of the versatility of this model to account for changes in topography and mixing height and the importance of chemical reactions, the well mixed cells model has been used in practice to model the Los Angeles airshed.[292] The Los Angeles airshed is controlled not only by local wind systems but by topography.

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[288]Guldmann, J.M. and D.Shefer, p. 38
[289] Guldmann J.M. and D. Shefer, p. 38
[290]Guldmann J.M. and D.Shefer. p. 38
[291]Guldmann J.M. and D.Shefer, p. 39
[292]Guldmann J.M. and D.Shefer, p. 40

The RELAD Model

The model currently in use in Alberta for analytical purposes is RELAD (the Regional Lagrangian Acid Deposition model).[293] RELAD uses a latitude-longitude grid with a default of one degree by one degree.[294] This model divides the atmosphere into three layers depending upon mixing height; during unstable daytime conditions mixing is assumed to occur through all three layers, and during the evening emissions are allocated into the three layers depending upon stack height.[295] The model works by tracking emission puffs from each grid cell that contains sources at user specified periods.[296] The RELAD model is adapted from an United States Environmental Protection Model called RELMAP and was chosen because of its low cost, its ability to work with a small volume of data, and short computation times.[297] A small adjustment was made to include the effective acidity calculations for sulphur and nitrogen.[298]

RELAD is probably an effective tool in the management of the Alberta airshed; it is certainly light years ahead of the original Gaussian models used in the oilsands a decade earlier. However, it does not allow for monitoring of specific trouble areas; "for long term regional scale models such as RELAD, turbulence-generated dispersion is not as significant as transport and removal processes".[299] Instead, ambient levels are measured and rated in terms of the target load for the area. Trouble areas within the study area that have an effect on valued

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[293] Cheng, L., R. Angle, E. Peake, and H. Sandhu. "Effective Acidity Modelling to Establish Acidic Deposition Objectives and Manage Emissions" *in Atmospheric Environment* Vol. 29, No. 3 1995 p. 387

[294] Cheng, L., R. Angle, E. Peake, and H. Sandhu

[295] Cheng, L., R. Angle, E. Peake, and H. Sandhu

[296] Cheng, L., R. Angle, E. Peake, and H. Sandhu, p. 387

[297] Cheng, L., R. Angle, and H. Sandhu. "Mesoscale Effective Acidity Modelling in Acidifying Emissions Management: Western and Northern Canada Perspective" in *Atmospheric Science* 1996

[298] Cheng, L., R. Angle, and H. Sandhu, p. 5

[299] Cheng, L., R. Angle, E. Peake, and H. Sandhu, p. 387

environmental or economic components cannot be evaluated effectively by RELAD, or by any long term regional model.

Using Models for Analysis

RELAD, the classical Gaussian, and the well-mixed cells model all have a place in the management of the Alberta airshed. The well-mixed cells model seems to be well suited for an overall analysis of the airshed for policy, control, cumulative impacts, and sustainable development considerations. Adapting the model would fit with the following general recommendation for the elements of any model: "It is necessary to design a model that will simulate both the effect of the strategy on pollution generation, in all its spatial and temporal dimensions, and the impact of such generation on airborne concentrations through atmospheric diffusion. The design of the emission model will first require a complete inventory of all the pollution sources, according to type, size, location, and all the required technical characteristics".[300] The importance of atmospheric processes in pollution transport, transformation, and deposition has been well documented elsewhere in this project. There is also a need for an inventory of sources. The well mixed cells model allows for consideration of these factors. This model would provide the needed variables and the flexibility to be used in policy decisions.

However, for tracking potential deposition on selected receptors, a Gaussian model may be appropriate. There is a need to define valued receptors on a community level before modelling and monitoring begins. The responsibility for modelling should belong to the emitters whose plume could affect these receptors, taking responsibility off of the taxpayers and putting it in the hands of industry, which profits most from the products that cause emissions.

[300]Guldmann J.M. and D.Shefer, p. 88

Mapping of Valued Components

To use this model in the study area with maximum effectiveness on locally valued receptors the following steps are necessary. First, the study area would be divided into cells by superimposing a gridlock on the map -- for example, RELAD has a default of 1 degree by 1 degree. The township and range system is another option. I used map units of the study area at a scale of 1:50,000 (a total of six) for these divisions. Each division would then conduct an inventory of sources. The inventory could be started by grouping industry specific emissions and then by common and significant emissions. There may be cells in some divisions with few or no sources. Analysis of these cells should still be undertaken as far as inputs from neighbouring cells are an issue.

The gridlock and divisions are then superimposed on a series of other maps, such as wildlife, vegetation, or topography, following the preplanning process advocated by R. Revel.[301] Valued economic or ecosystem components should be identified. Overlaying each map on the next provides a quick analysis of areas considered most valued, and therefore, most at risk for any negative consequences of air pollution. Alternatively, components can be transferred to a base map. This process can be done easily with programs such as CorelDraw, with the use of a scanner. The best information could be obtained if the overlay process is done at a cell level for which detailed maps of at least 1:50 000 are available.

Chapter 1 provided a checklist of factors to consider while attempting to manage a regions' air quality. The tools discussed above (modelling, inventory of sources, identification of valued economic and ecosystem components through maps) cover the first three points on this checklist. These points are:

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[301]Revel, R. *Preplanning Resource Developments: Science, Economics, and Planning*. presented at the International Association for Impact Assessment Conference, September, 1985.

1. Definition of the region's physical attributes:
- Topography;
- Local climatological patterns;
- Vegetative cover;
- Soils;
- Human habitation;
- Livestock and wildlife.
2. Define valued ecosystem and economic components.
3. Identify common emissions, including:
- emission sources;
- emission residence times;
- emissions risk (effects on valued receptors).

Summary

Diffusion models are used as a tool to track deposition regionally, locally, or for various receptors. The puff kernel model tracks single sources. The Gaussian Model tracks single or multiple sources and deposition on selected receptors. The Gaussian model may aid tracking deposition on selected valued receptors. The well mixed cells model is able to consider complex factors like stability, secondary reactions, chemical decay, and topography. RELAD, currently in use in Alberta, is a type of well mixed cells model. As a long term model, it cannot track deposition on specific receptors but is useful for regional analysis and cumulative impact assessment.

CHAPTER 10 -- FRAMEWORK FOR THE STUDY AREA

Framework for the Study Area

In this chapter an environmental management framework will be created for the study area using the tools available (not including modelling) discussed in previous chapters. The application of these tools will reflect the physical factors that control the airshed and the subsequent chemical-biotic responses on valued receptors. The chapter is divided into three parts; general conclusions of the project, analysis of additional data from the study area, and recommendations for the study area.

Part One: General Conclusions

The main conclusions of this project are:

1. The airshed is controlled by:

A. Meteorological conditions, including:

- Wind strength and direction;
- Temperature gradients (stability factors)
- Rainout and snowout;
- Solar radiation.

B. Topography;

C. Emission lifetimes;

D. Emission interactions (secondary reactions).

2. The airshed interacts with the environment in its roughness layer and laminar layer, including with:

- Soils;
- Vegetation;
- Water;
- Humans and animals;
- Materials.

3. The airshed does not have specific boundaries as does a watershed. Control then can be implemented most effectively at a political level in the short to mid term, and may be divided arbitrarily therein. Long term effectiveness necessarily implies interjurisdictional cooperation.

4. Any component of the environment may have a natural, aesthetic, economic or other human value, and be considered a valued ecosystem or economic component.

5. The interaction of the polluted airshed with the environment may produce:

- Damage to plant physiology at a high to low intensity;
- An alteration in the composition of the plant community and therefore the ecosystem due to changes in competitive ability at the species level (a change at the system level).
- An alteration in the pH of soils, resulting in a change of species composition able to grow in that soil.
- An alteration in the pH of muskegs, resulting in possible acid pulses during dry years.

6. 57.8% of soils in Alberta are rated as moderately to highly sensitive to acid deposition.

7. Long term effects of low intensity emissions to the airshed on vegetation, soils, and water are unknown.

8. Effective monitoring and reporting of most emissions into the airshed are not required by regulation.

9. Reporting of emissions into the airshed are not accurate.

10. Placement of monitors is an inexact science but can be aided by wind direction, topography and plume modelling. Monitors at the source identify emissions but not areas of deposition.

11. Turbulence and cross winds are two uncontrollable, environmental factors that influence the number of emissions into the airshed from flaring operations.

12. Tools exist to manage the airshed including:

- Environmental assessment;
- Environmental auditing;
- Risk Assessment;
- Lifecycle assessment;
- Economic instruments;
- Legislation;
- Modelling.

13. Petroleum industries in Alberta account for the majority of sulphur dioxide and nitrogen oxide emissions in the province.

14. The following emissions were found to be potentially significant in the study area:

- Sulphur oxides;
- Nitrogen oxides;
- Volatile organic compounds; and
- Other hazardous air pollutants.

15. The precautionary principle as advocated by the Rio Declaration should be used when there is a lack of scientific certainty about short, mid, or long term effects.

Part Two: Analysis of Additional Data

The study area has the following characteristics:[302]

Number of Gas Plants: 29

Oil & Gas Activity Sites: Approximately 2500

Urban Centres: Caroline, Olds, Bowden, Sundre, Carstairs, Didsbury, Cremona

Hamlets: Dickson, Westward Ho, Spruceview, Water Valley

Localities: Crammond, Stauffer, Ricinus, Chedderville, Dovercourt, Evergreen, Congressbury, Bearberry, James River Bridge, Westcott, Harmattan, Eagle Hill, Elkton, Bergen

Natural Areas: Markerville, Chedderville, Clearwater, Bearberry, Snake's Head, Sundre

Provincial Parks: Red Lodge Provincial Park

Recreation Areas: Red Deer River Valley, Rocky Mountain Forest Reserve, Clearwater River Valley

Other Riparian Environments: Rosebud River, Carstairs Creek, Dogpound Creek, Medicine River, Little Red Deer River, Prairie Creek, Raven River, North Raven River, James River

Muskeg: Charlton Muskeg

Topography: Rolling

Soils: Chernozemic and Luvisolic

Ecoregions: Boreal Uplands, Boreal Foothills, Aspen Parkland, Fescue Grasslands

Other Economic Components: Ranching

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[302] Information from a series of six Provincial Resource Base maps, dated 1986 - 1995 produced by Alberta Forestry, Lands, and Wildlife and Alberta Environmental Protection. Map sheets are 82-O-9, 82-O10, 82-O-15, 82-O-16, 83-B-01, and 83-B-02

Wind Rose for the Rocky Mountain House Area

Two wind roses for the Rocky Mountain House district were obtained from Environment Canada, one for the years 1961 to 1978, the second from the years 1978 to 1990.[303] They show a stable profile with no major shifts between the two. They show that winds come primarily from the following directions: west-north-west; northwest; north-north-west; south-southeast; southeast; and east-southeast. This is not surprising, because the foothills trend in the same general direction, from northwest to southeast. Winds channel down the valleys. Wind roses of the Edmonton area show a similar northwest - southeast dominant pattern.[304] It can then be assumed that this pattern holds true for most of south central Alberta, including the study area, which is located 14 kilometres south of Rocky Mountain House.

A table of percentage frequency by direction per month for the years 1955 to1980 for Rocky Mountain House confirms the primary directions remain the same.[305] The information in the table also allows the observation that the winds are primarily from a north westerly direction for the months May through January, and primarily from a south easterly direction for the months February, March, and April.

Mapping

Base maps of both infrastructure and topography were used to map:

- Gas plants;
- Gas activity sites;
- Topographical relief;

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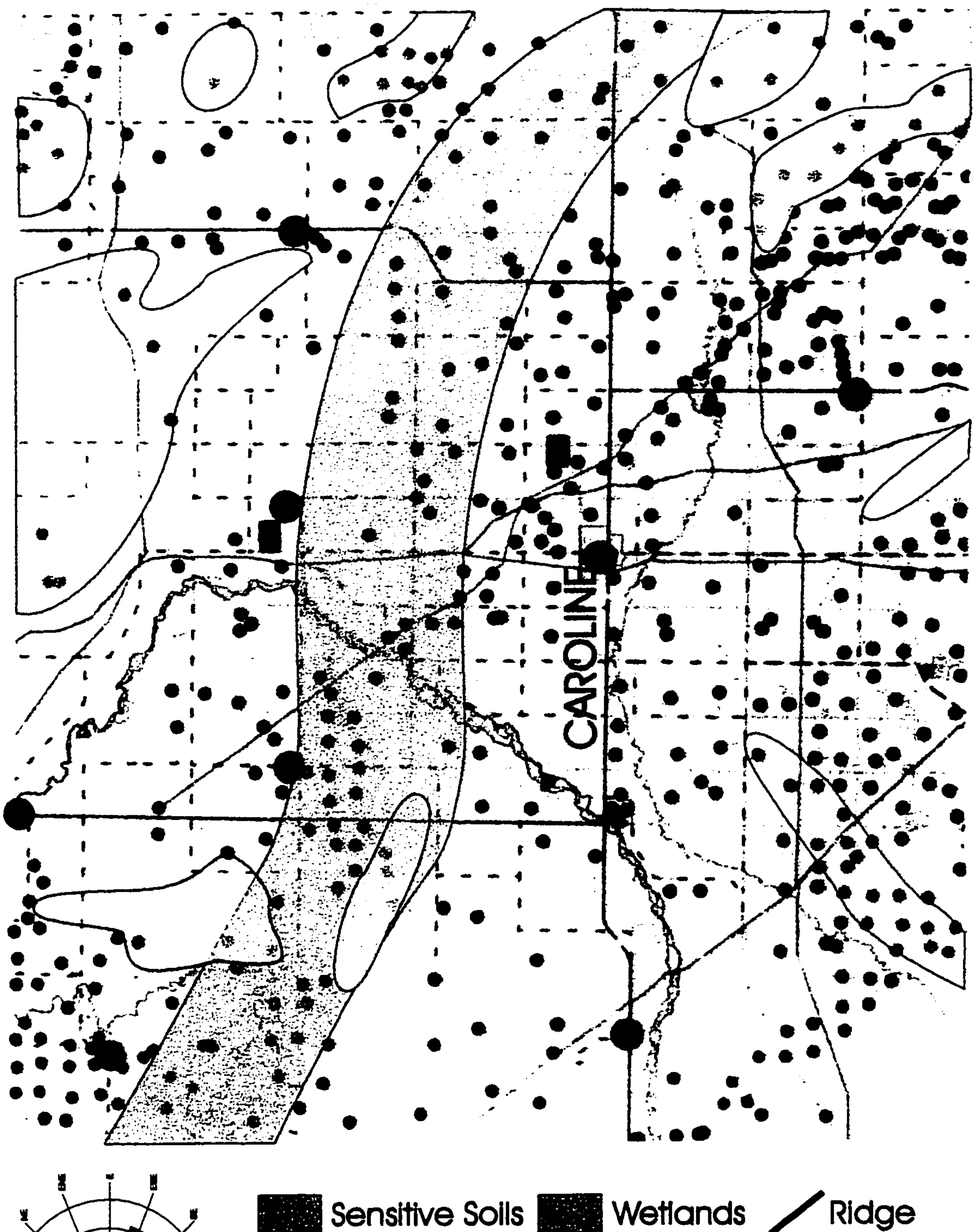
[303] Environment Canada, Prairie and Northern Region, Southern Alberta Environmental Service Centre

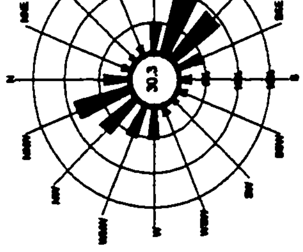
[304] Leahey, D.M. *Estimated Ground Level Concentrations of Products of Incomplete Combustion (PIC) Associated With Flaring at Two Sites in Alberta*. Prepared as part of the study Investigations of Flare Gas Emissions in Alberta, 1996. p. 15

[305] Environment Canada, Prairie and Northern Region, Southern Alberta Service Centre.

- Human habitation;
- Natural areas.

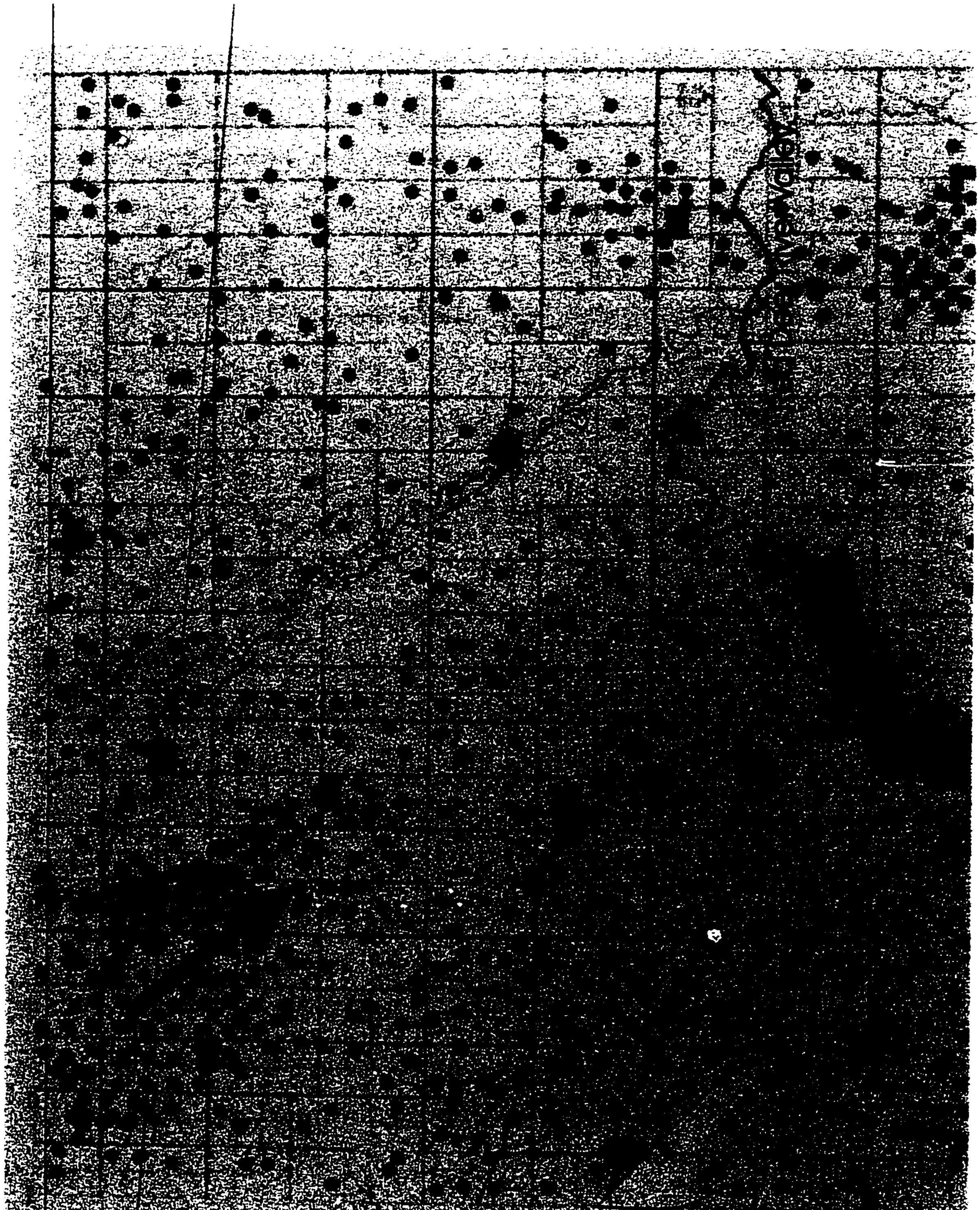
This shows that gas activity sites (wells, batteries) trend north west to south east, generally following the fault lines of the foothills. This clusters the gas plants in the northwest - southeast trending valleys, creating a natural cluster, or bubble.





Sensitive Soils Wetlands Ridge
Localities or towns • Wells Hydrocarbon field trends

Figure 13. Valued environmental components at risk for long-term negative effects within the study area. Map unit 83-B-02; northwest unit (section 1) of study area.



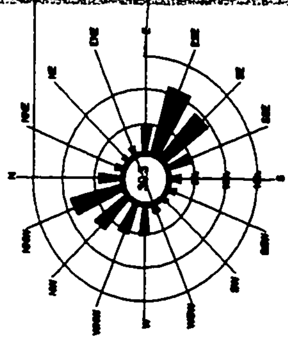
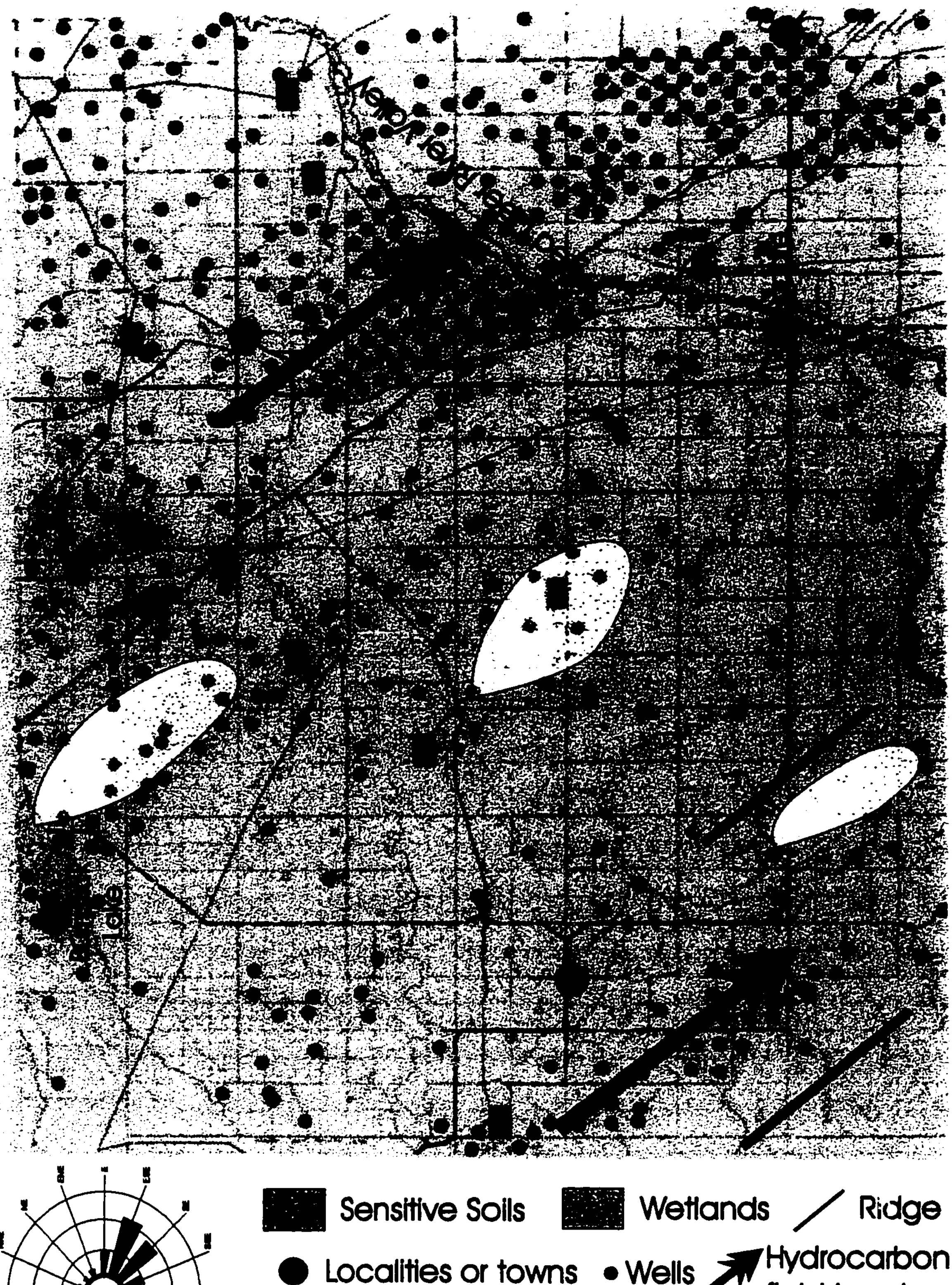


Figure 14. Valued environmental components at risk for long-term negative effects within the study area. Map unit 83-B-01; northeast unit (section 2) of study area.



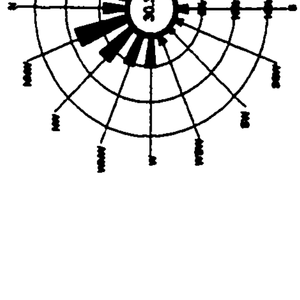


Figure 15. Valued environmental components at risk for long-term negative effects within the study area. Map unit 82-O-15; west central unit (section 3) of study area.

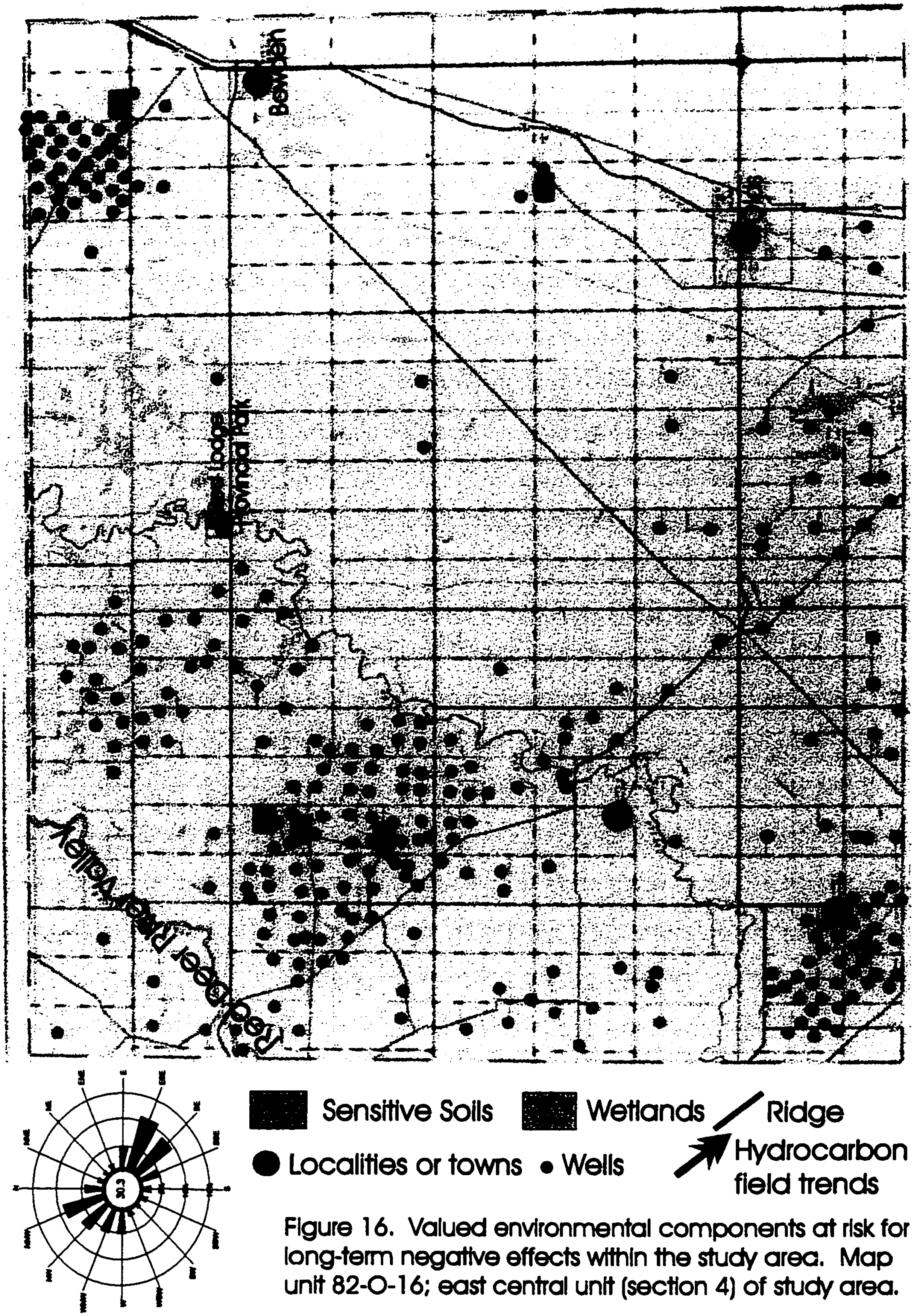
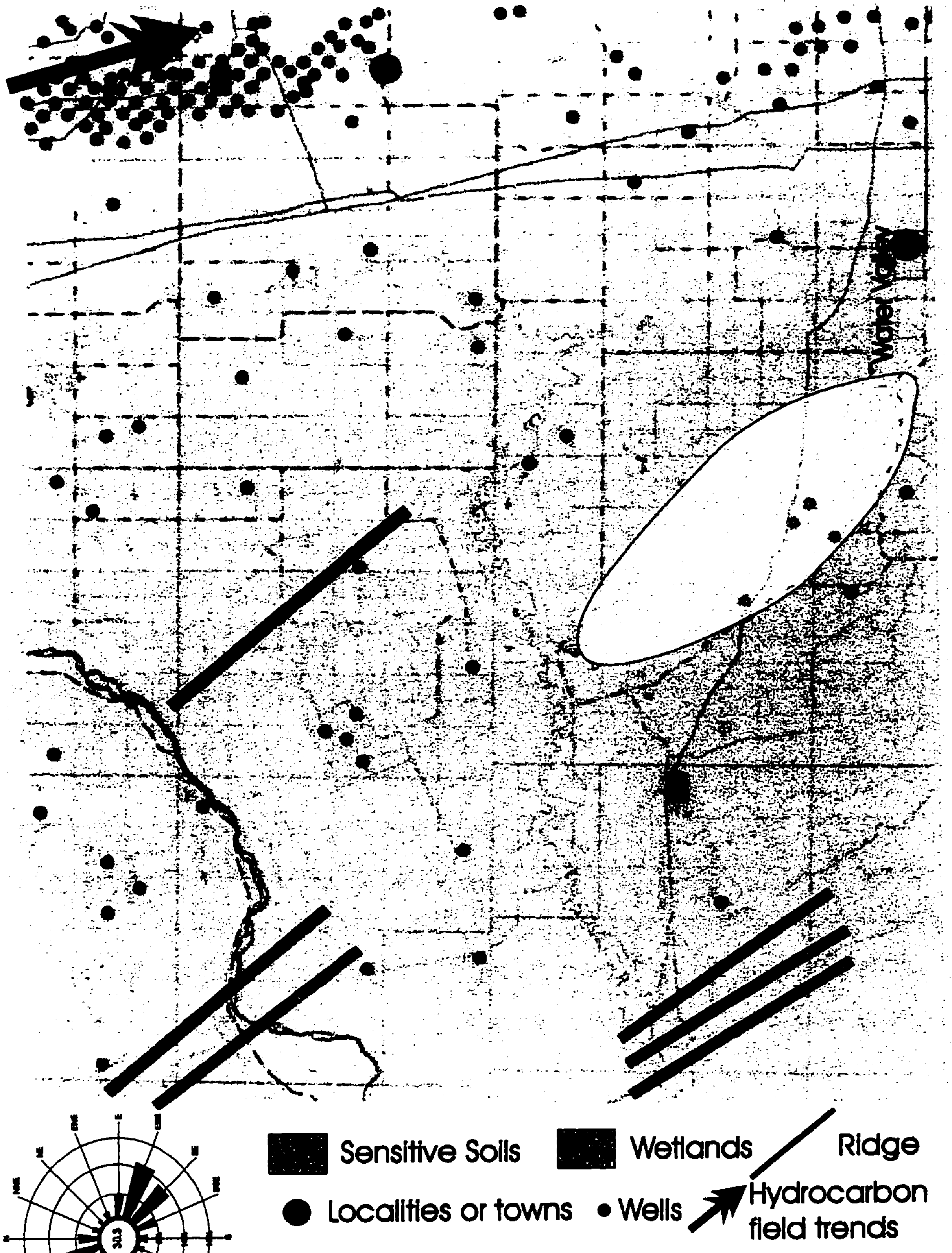


Figure 16. Valued environmental components at risk for long-term negative effects within the study area. Map unit 82-O-16; east central unit (section 4) of study area.



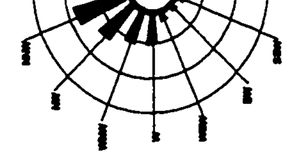


Figure 17. Valued environmental components at risk for long-term negative effects within the study area. Map unit 82-O-10; southwest unit (section 5) of study area.

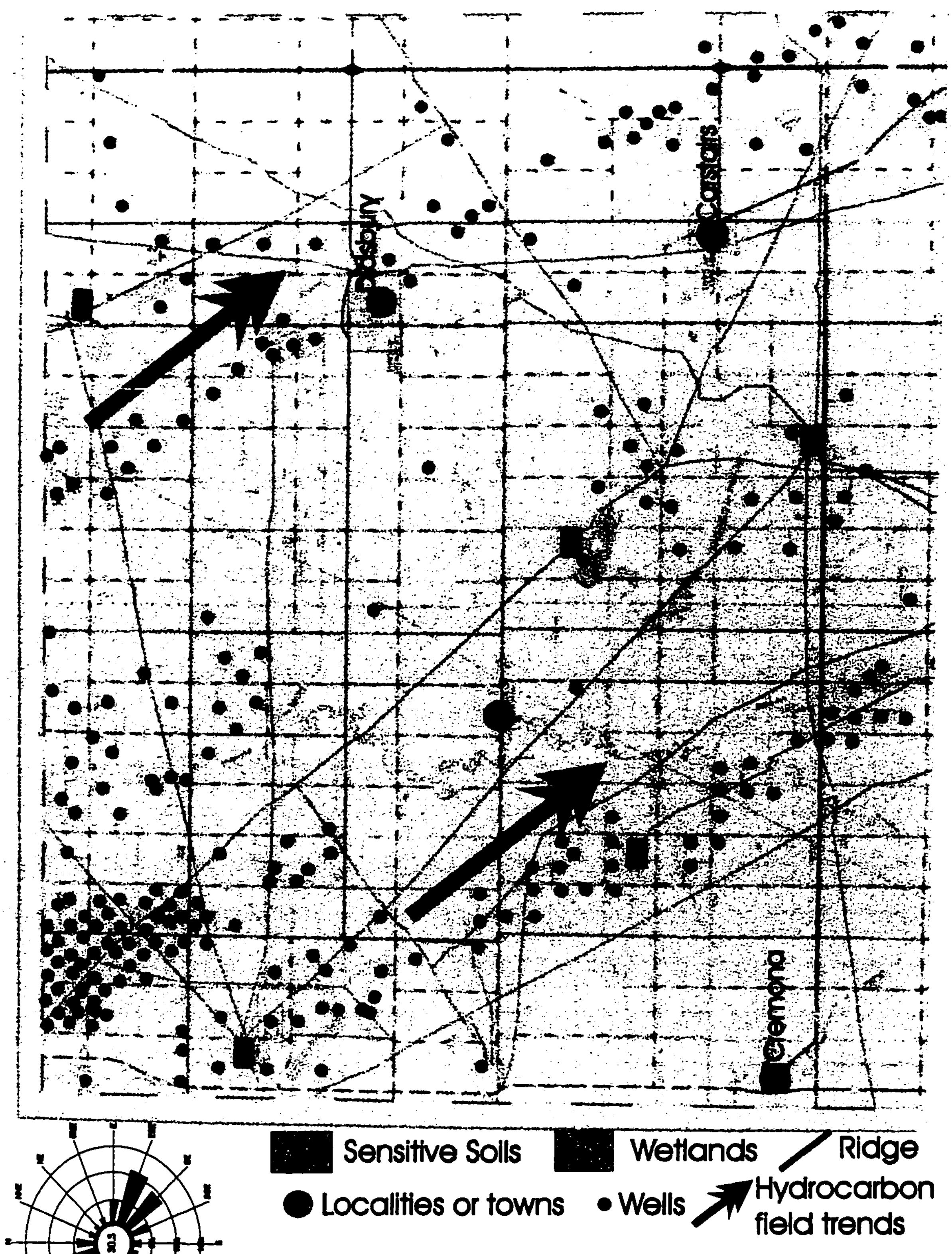


Figure 18. Valued environmental components at risk for long-term negative effects within the study area. Map unit 82-O-9; southeast unit (section 6) of study area.

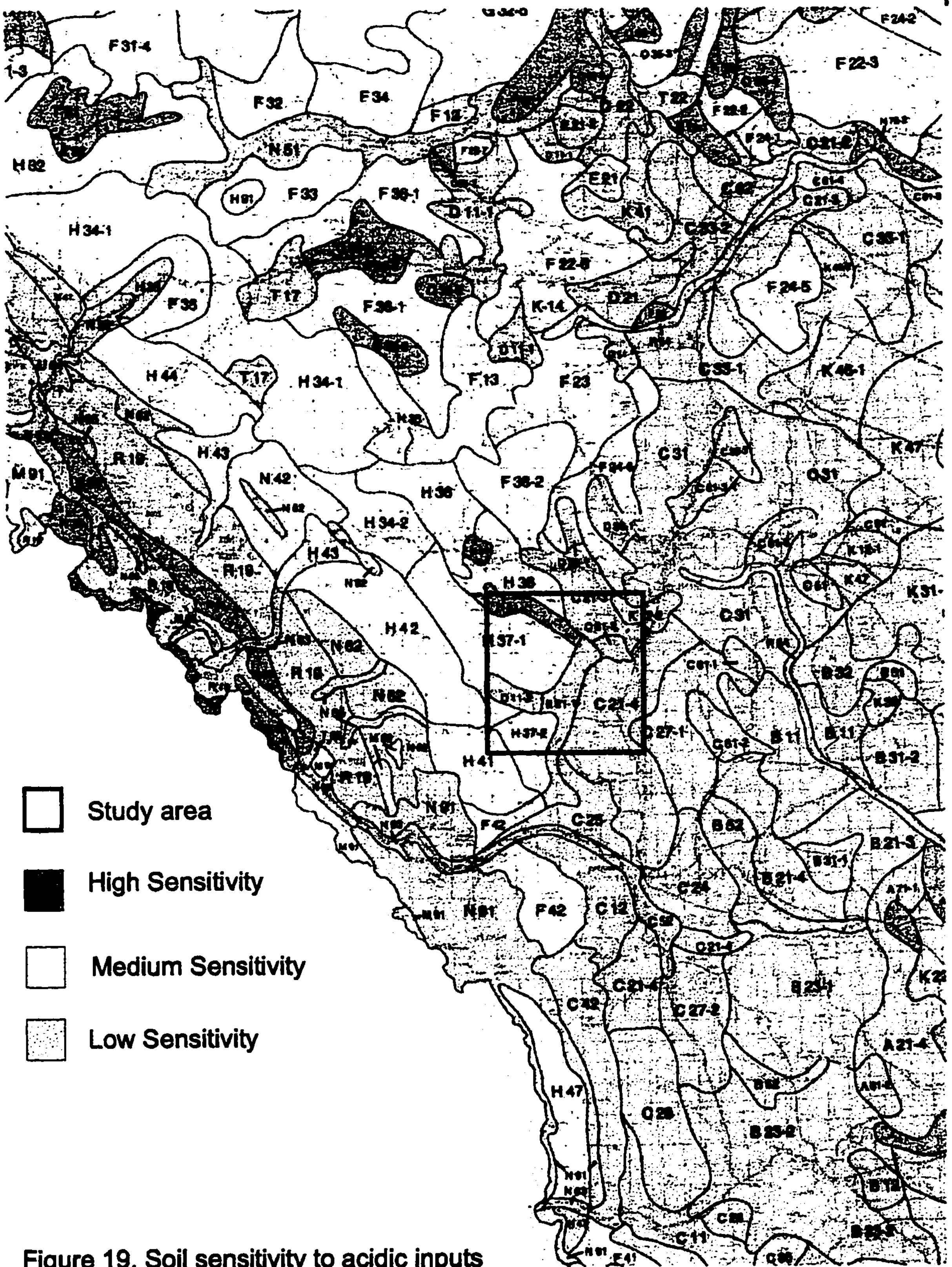


Figure 19. Soil sensitivity to acidic inputs in the study area. Adapted from Holowaychuk, N. and R.J. Fessenden. Soil Sensitivity to Acidic Inputs, Alberta. Alberta Research Council, 1986.

Mapping - Soils

The soils in the study area range from low to high sensitivity, with much of the area considered of medium sensitivity.[306] There are two pockets of highly sensitive soils, one located in a strip running from northeast to southwest through the Caroline area, the other just west of Rocky Mountain House and thus just outside of the study area[307]. These soils have a sandy or loamy sand texture, a medium to strongly acidic pH, a low cation exchange capacity, a high amount of base loss (mobilization through leaching), and a high level of aluminum solubility.[308] The parent material is calcareous with a high buffering capacity.[309] The high buffering capacity of the bedrock gives no clue as to why this area is classed as sensitive -- it must be assumed that it is because of the low pH of the soil, which is perhaps caused by the native vegetation.

Modelling

The current modelling done through RELAD focusses on long term depositional effects. This is necessary for long term research and tracking of cumulative effects, but leaves a gap when dealing with specific emission sources and specific receptors in the short term. Additional (Gaussian) modelling could be done on a source-specific basis for a variety of meteorological conditions. This could help pinpoint potential areas of high deposition, enabling monitoring and research efforts to be focussed there. Valued receptors should be identified by the community.

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[306] West Central Regional Airshed Monitoring Program. Figure 3.12 Soil Sensitivity to Acidic Inputs. July 1994. p. 29

[307] West Central Regional Monitoring Program, Figure 3.12

[308] Holowaychuk, N. and R. Fessenden. Soil Sensitivity to Acidic Inputs, Alberta. Map prepared for Alberta Environment by the Terrain Science Department, Natural Resources Division, Alberta Research Council. 1986

[309] Holowaychuk, N. and R. Fessenden. Potential of Soil and Geology to reduce Acidity of Incoming Acidic Deposition, Alberta. Map prepared for Alberta Environment by Terrain Sciences Department, Natural Resources Division, Alberta Research Council. 1986

Part Three: Recommendations

Economic Instruments - Emissions Trading Program

The physical clustering of gas activity sites and processing plants along the transects of the foothills corresponding with dominant wind direction lends itself to an emissions trading program (see Figures 13 – 18). This would allow industry to trade credits within a long bubble defined by the clusters, emission lifetimes (as defined through pollution roses), and wind direction. A trading program defined in this manner is attempting to keep pollution reductions in the area that pollution is generated. A trading area outside the boundaries where most pollution is generated and deposited can function as a pollution transfer mechanism from one area to another. Although overall pollution may go down, the area that buys the credits for use will have an increase in pollution.

Trading programs would need to classify what emissions could be traded in what areas, given the lifetimes of the emissions. For example, sulphur dioxide has a lifetime of one to four days, while nitrogen oxides have lifetimes of two to ten days. These lifetimes control the potential trading area. In an area the size of the study area, most pollutants would be able to be traded based on lifetimes, as they would be able to be easily dispersed through the area during their lifetimes.

A necessary part of a trading program is the initial set of emission permits, or standards per unit of product. If these are set equal to the current permits, there is little incentive to bring in new technology, as the status quo would be maintained. Setting them at less than the current permits would stimulate new technology, as it would be economically advantageous for companies to bring in newer technology faster, in order to gain from others with the sale of their allocation of permits. This is the same idea as the American system of offsets, where any new industries must acquire enough offset credits to ensure that air quality in the area will be higher than before their entry.

Reporting Standards

A necessary complementary policy is the mandatory reporting and accurate measurement of a number of emissions not currently mandated under existing regulations. This was identified earlier in the project as an omission from the current regulations. Measurement and reporting will allow for trading, and additionally will aid in the tracking of secondary reactions, cumulative emissions, and thus in the development of sustainable policies.

Environmental Auditing

The lack of reporting protocols and the seeming discrepancy between various agencies that report emissions indicate the need for environmental auditing, to be initiated by industry, regulated by government, and administered by a third party. Audits that identify sources of fugitive emissions within the processes have the ability to reduce emissions. Audits can also be cost effective in determining future capital costs and operating expenditures, and creating a positive public image.

Audits within a trading zone could be administered on a zonal basis. This could involve the use of plume modelling to "audit" valued receptors for contributions to cumulative impacts. An "audit zone" within the trading "bubble" is categorized by geography (See Figures 13 – 18). Consideration while categorizing areas into audit zones should be given to facility function, age, type of material processed, technology, proximity to environmentally sensitive areas, and local or community factors.[310] Operating status is also important. Future facilities should be a part of the zonal "audit" to help in assessing cumulative effects. A lifecycle

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[310] Young, Steve Scott. pp. 6-7

or cradle to grave approach within the audit structure would aid in tracking cumulative impacts.

Lifecycle Assessment

As a complementary policy to environmental auditing and cumulative environmental assessment, lifecycle assessment of the products of petroleum processing would aid in: 1. cost-benefit analysis of environmental technology; 2. greater accountability for the byproducts of production; 3. enhanced public image; and 4. anticipating future legislation.

Reduction

Reduction in atmospheric inputs is ultimately the only way to reduce effects on receptors. Reduction in production is unlikely; therefore, to reduce emissions, technology will have to be improved. Use of the best available reduction technology either could be regulated or prompted through the use of emissions trading, where (theoretically, at least) companies would seek to maximize profits through the sale of permits unused because of better technology. Reduction in emissions would encourage a move away from ambient standards, because measurements at the source would be necessary.

Monitoring

Current practice averages the measurements taken from monitors to reach an ambient quality. This practice is not consistent with the episodic nature of high intensity deposition. As discussed, deposition depends on atmospheric conditions and topographical features. Moderate or extreme deposition events can be hidden when averaged into an ambient measurement. It is not necessarily relevant to argue that emissions are negligible because nine times out of ten they are measured close to zero if the tenth time emissions are strong enough to cause receptor stress or damage. Instead of ambient standards, emphasis should be placed on emission control. This can be accomplished through use of best available control technology or product standards that control units of emissions by units of product. Either solution probably would incur increased cost to the producer and thus to the consumer.

Monitoring should include many more compounds than currently are required. Because many physical components of the area influence deposition, care should be taken to place monitors in areas that tend to collect emissions, such as river terraces, the base of hills on both the windward and leeward sides. Monitoring at the source will help in tracking actual compounds but not areas of deposition. The use of "personal" monitors should be considered for mobile receptors, such as cattle or people. Monitoring is an inexact science, and will remain so because of the many variables controlling deposition; using physical features as a guideline could increase the accuracy somewhat. The answer to this inaccuracy is specifically monitoring valued receptors regardless of location.

Monitoring of emissions should also take place directly in the emissions stream, and immediately above it. This does not target areas of deposition, but does allow knowledge of what is being emitted. The vast number of hydrocarbons identified in flares that currently are unreported and unmonitored could cause health concerns.

Monitors should be placed with regard to valued ecosystem and economic components, and in areas of higher risk of long term effects. For example, urban centres should be monitored. Communities could become involved and may find that their concerns are not as great if monitoring results were displayed in the community. Communities not large enough to warrant a permanent monitoring station could share a mobile monitor for several weeks a year. Areas of high soil sensitivity to acid inputs should be monitored on a long term basis, as should the Charlton Muskeg. Indicator species for the area should be monitored on a yearly basis; in the long term, these records can be used to assess the level of change in the ecosystem at a system level (competition, change of dominant species, etc.).

Mapping

In order that monitoring efforts have maximum effect, community involvement should be sought in the mapping of valued ecosystem and economic components. One of the assumptions of this project is that these VECs are valued most highly at a local level. They could include:

- houses or communities;
- pastures;
- natural areas;
- water sources for drinking or for recreation;
- valuable wildlife areas;
- unique vegetation.

Monitoring systems could be set up with maximum effect on a permanent basis in these areas.

Emissions Tax

It is likely that the petroleum industry will disagree. However, it is necessary that long term research of the effects of low intensity pollution be conducted, and the funding should come from industry itself. The tobacco industry in the United States is an example of an industry currently being held responsible for research into long term effects and for current health problems. A research tax cannot be viewed as a money grab by government, especially if the fund is administered by a third party. The tax could be based on amount of certain emissions (for example, sulphur and nitrogen oxides) and the presence of others (volatile and non-volatile organics, heavy metals).

Strategic Environmental Assessment

A strategic Environmental Assessment (SEA) previously was defined as "the implementation of environmental assessment at an early stage in the planning process, such that it integrates environmental, economic, and social concerns in the planning, policy, and program stages rather than at the project level. This allows for consideration of alternatives, cumulative impacts, and 'sustainable development' issues at a level where choices are proactive rather than reactive". With the level of petroleum industry activity in the province and the study area at this time, an SEA may seem like an absurd recommendation. However, new plants, activity sites, and programs can be assessed on a cumulative effects basis.

An emissions trading program like the one suggested above would be ideal to reduce cumulative impacts. Each new plant could be required to purchase enough credits to reduce the total amount of emissions in the area (the American offset policy).

Research

This project concluded that there has been little research on long term effects on receptors from pollution. This needs to be rectified. Issues worthy of further research are:

- Effects of flaring emissions on cattle, humans, and vegetation. Ranching and the petroleum industry co-exist through much of the study area. Since the volatile and non volatile hydrocarbons emitted by flaring under various meteorological conditions are deposited locally, research needs to be done and published on resulting health effects.
- Long term ecosystem changes in the climax vegetation (aspen parkland). Aspen have been identified as a good indicator species for

the area for emissions with acidic properties. A monitoring and reporting system should be created on aspen health in the area.

- Long term research into the effect on soils of acidic deposition. Since the study area contains one area of highly sensitive soils, monitoring and reporting could be based in this area.
- Research on the role of wetlands. The study area contains many wetlands, including the Charlton Muskeg.
- Research on the limits of buffering capacities on bedrock in the study area.
- Research on the variability of ecosystems to cycle pollution (critical load).

Using Environmental Factors To Regulate Production

Environmental factors control the deposition and some of the creation of atmospheric pollutants. Taking them into consideration in an airshed management program requires some complex adjustments to current methods of production. These may entail:

- Control of rate of production by stability and wind type;
- Seasonality of rate of production, which may not reflect demand;
- Diurnal cycles to production.

None of these seem immediately practical, and all would probably mean an increase in costs to the producer and therefore the consumer. The answer may be mandatory use of the best available control technology, product standards, and mandatory emissions monitoring. This, too, would imply a greater cost to the producer and consumer, but would eliminate the uncertainty that would emanate from using environmental factors as control. Long term patterns of stability (seasonality) would be the most appropriate use of environmental parameters, but these are not reliable.

Cross Jursidictional Cooperation

This project has emphasized the need for control of emissions to come on a regional basis within one political jursidiction. This is the most effective strategy for short to mid term control. Longer term objectives must be considered for the future, and this must include cross-jurisdictional cooperation on air emissions due to the open nature of the system. Cross-jursidictional includes other provinces and other nations. Cooperation with existing organizations that have the potential to structure this cooperation among their members should be emphasized.

Towards Sustainability

The recommendations in this project have tried to take into consideration the philosophy known as sustainable development, a marriage between economic and environmental concerns. Limits on production have not been emphasized singularly. Rather, accountability for the byproducts of production is suggested, recognizing that certain economic and environmental components have value. Accountability includes tracking of cumulative effects, use of available tools, further research, and use of guiding principles such as sustainable development and the prevention of significant deterioration to accomplish long term goals.

References

Alberta Energy. *Environmental Regulation of Natural Gas Development in Alberta, Canada*. Undated

Alberta Environment. *An Analysis of Techniques for Measuring the Dry Deposition Rate of SO2*. 1981

Alberta Environment. *Airshed Management System for the Alberta Oil Sands. Volume 1: A Gaussian Frequency Distribution Model*, 1981.

Alberta Gas Plant Directory, 1996.

Angle, R. and H. Sandhu. "Application of Acid Deposition Critical or Target Loads to Limit Source Emissions in Sensitive Areas", in *Atmospheric Chemistry*, 1992.

Bates, J. *Business Law in Alberta, Second Edition*. Copey Publishing Group, 1991.

Beanlands, G.E and P.N. Duinker. *An Ecological Framework for Environmental Impact Assessment in Canada*. Federal Environmental Assessment Review Office, 1983

Bernstein, J.D. *Alternative Approaches to Pollution Contol and Waste Management: Regulatory and Economic Instruments*. The World Bank, 1993.

Campbell, Monica. "Our Cities, Our Health: Perspectives on Urban Air Quality and Human Health", *in The Environment and Canadian Society*. Thomas Fleming, Editor. ITP Nelson Publishing Company, 1997.

Cartright, Hugh and Stephen Harris. " Analysis of the Distribution of Airborne Pollution Using Generic Algorithms" in *Atmospheric Environment* Vol. 27 No. 12 August, 1993

Cheng, Lawrence. *Concentration and Deposition of Anthropogenic Air Pollutants in Alberta (Summary Report)* April 1994.

Cheng, L., R. Angle, and H. Sandhu. "Mesoscale Effective Acidity Modelling in Acidifying Emissions Management: Western and Northern Canadian Perspective". In *Atmospheric Science* 1, 1996.

Cheng, L. and R. Angle. "Model Calculated Interannual Variability of Concentration, Deposition, and Transboundary Transport of Anthropgenic Sulphur and Nitrogen in Alberta", in *Atmospheric Environment* Vol. 30, No. 23, 1996.

Cheng, L., R. Angle, E. Peake, and H. Sandhu. "Effective Acidity Modelling to Establish Acidic Deposition Objectives and Manage Emissions", in *Atmospheric Environment* Vol. 29, No. 3, 1995.

Clark, W. "The Cumulative Effects of Human Activities on the Atmosphere", in *Proceedings of the Workshop on Cumulative Environmental Effects: A Binational Perspective*. CEARC and the US National Research Council. 1986

Clean Air Strategic Alliance. *A Better Way* (pamphlet) July 1996.

Clean Air Strategic Alliance. *Clean Air Views*, Volume 5 Issue 3, September 1996.

Colitti, M. "Economic Stagnation and Sustainable Development" *in Sustainable Development and the Energy Industries*. Nicola Steen, Editor. Royal Institute of International Affairs, 1994.

Columbo, Umberto. "Development and the Global Environment", *in The Energy - Environment Connection*. Jack Hollander, Editor. Island Press, 1992.

Cox, R.M. "The Response of Plant Reproductive Processes to Acidic Rain and Other Air Pollutants", in *Effects of Atmospheric Pollutants on Forests, Wetlands, and Agricultural Ecosystems*. T.C. Hutchison and K.M. Meema, Editors. Springer - Verlag in cooperation with NATO Scientific Affairs Division. 1985.

Environment Canada. *Canadian Emissions Inventory of Common Air Contaminants, 1985*. Report EPS 5/ap/3 March, 1990.

Erbrink, Hans J. "Plume Rise in Different Atmospheres: A Practical Scheme and Some Comparisons With Lidar Measurements" *in Atmospheric Environment*, Vol. 28 No. 22 December 1994

Energy Resources Conference Board. *Management of SO2 Emissions in Alberta*. ERCB Presentation to Clean Air Strategic Alliance, September 30, 1994.

Foot, David. *Boom, Bust, and Echo*. McFarlane,Walter & Ross, 1996

Greyson, Jerome. *Carbon, Nitrogen, and Sulphur Pollutants and their Determination in Air and Water*. Marcel Dekker, Inc. 1990

Grubb, M. "Global Policies for Global Problems: The Case of Climate Change", in *Economic Policies for Sustainable Development.* Thomas Sterner, Editor. Kluwer Academic Press, 1994.

Guderian, R. Editor. *Air Pollution by Photochemical Oxidants.* Springer - Verlag Berlin Heidelberg, 1985.

Guldmann, J.M. and D. Shefer. *Industrial Location and Air Quality Control: A Planning Approach.* John Wiley and Sons, 1980.

Guidotti, Dr. T. "Air Quality Studies in Alberta: Past and Future". From the *Acidifying Emissions Symposium* in Red Deer, Alberta, April, 1996

Hare, Kenneth F. "Global Warming", in *The Environment and Canadian Society.* Thomas Fleming, Editor. ITP Nelson Publishing Company, 1997.

Hollander, J. and Duncan Brown. "Air Pollution", in *The Energy - Environment Connection.* Jack Hollander, Editor. Islander Press, 1994.

Jacobson, J.S. and A.C. Hill, Editors. *Recognition of Pollution Injury to Vegetation: A Pictorial Atlas. Informative Report NO. 1 Tr - 7* Air Pollution Control Association, 1970.

Jeffries, D. *Watershed Responses and Aquatic Effects Caused by Atmospheric Deposition of Acidifying Pollutants.* April, 1986.

Leahey, D.M. *Estimated Ground Level Concentrations of Products of Incomplete Combustion (PIC) Associated With Flaring at Two Sites in Alberta.* Prepared as part of the study, Investigations of Flare Gas Emissions in Alberta, 1996.

Legge, A.H. *The Present and Potential Effects of Acid and Acidifying Air Pollutants on Alberta's Environment Critical Point 1 Final Report.* The Acid Deposition Research Program, 1988

Leithe, W. *The Analysis of Air Pollutants.* Ann Arbour Science Publishers Inc. 1970

Mansfield, T.A. et al. "Responses of Herbaceous and Woody Plants in the Dry Deposition of SO2 and NO2", in *Effects of Atmospheric Pollutants on Forests, Wetlands, and Agricultural Ecosystems.* T.C. Hutchison and K.M. Memma, Editors. Sprnger - Verlag, 1985.

Matzner, E. and B. Ulrich. "Result of Studies on Forest Decline in Northwest Germany" in *Effects of Atmospheric Pollutants on Forest, Wetlands, and Agricultural Ecosystems.* T.C. Hutchison and K.M. Meema, Editors. Springer - Verlag, 1985.

McMenamin, M. and D. Mcmenamin. *Hypersea.* Columbia University Press, 1994.

Meszaros, E. *Atmospheric Chemistry Fundamental Aspects.* Elsevier Scientific Publishing Company, 1981.

Munn, R.E. *Proceedings of the Workshop in Cumulative Environmental Effects: A Binational Perspective.* CEARC.

Nilsson, Lars and Thomas Johansson. "Environmental Challenges to the Energy Industries", in *Sustainable Development and the Energy Industries.* Nicola Steen, Editor. Royal Institute of International Affairs, 1994.

OECD. *Hazardous Air Pollutants*, The London Workshop. OECD 1995.

Oke, T.R. *Boundary Layer Climates, Second Edition*. Routledge, 1987

Parkland Airshed Management Zone. Minutes of meeting June 21 1996, Olds Legion.

Picard, D.J. et al. *Overview of the Emission Data: Emission Inventory of Sulphur Oxides and Nitrogen Oxides in Alberta*. Acid Deposition Research Program. November, 1987.

Province of Alberta. *Environmental Protection and Enhancement Act, 1992*. Queens Printer for Alberta.

Sanderson, K. *Acid Forming Emissions: Transportation and Effects*. Environment Council of Alberta Staff Report. 1984.

Revel, R. *Preplanning Resource Developments: Science, Economics, and Planning*. Presented at the International Association for Impact Assessment Conference, September, 1985.

Roan, S. *Ozone Crisis: The 15 Year Evolution of a Sudden Global Emergency*. Wiley Science Editors, 1989.

Shoemaker, Darryl J. *Cumulative Environmental Assessment*. Department of Geography Publication Series Number 42, University of Waterloo, 1994.

State of Canada's Environment Report, 1991

Stern, A.C. et al. *Fundamentals of Air Pollution, Second Edition*. 1984

Sterner, T. and M. Lowgren. "Environmental Taxes: A Cautious Start in Sweden", in *Economic Policies for Sustainable Development*. Thomas Sterner, Editor. Kluwer Academic Publishers, 1994.

Strosher, M. *Investigations of Flare Gas Emissions in Alberta*. Alberta Research Council, 1996

Thompson, Dixon. "Environmental Management", *in The Environment and Canadian Society*. Thomas Fleming, Editor. ITP Nelson Publishing Company, 1997.

Tietenberg, T. "Market Based Mechanisms for Controlling Pollution: Lessons from the US", in *Economic Policies for Sustainable Development*. Thomas Sterner, Editor. Kluwer Academic Publishers, 1994.

Treshow, M. ad F. Anderson. *Plant Stress From Air Pollution*. John Wiley and Sons, 1989.

Turchenek, L.W. et al. *Biophysical Research: Effects of Acid Deposition on Soils in Alberta*. Acid Deposition Research Program, 1987.

Vanderzwagg, David. *CEPA and the Precautionary Principle/Approach. Reviewing CEPA, The Issues, #18*, 1994

West Central Regional Monitoring Program. July 1994

West Central Regional Airshed Monitoring Program Technical Design. July 1, 1994.

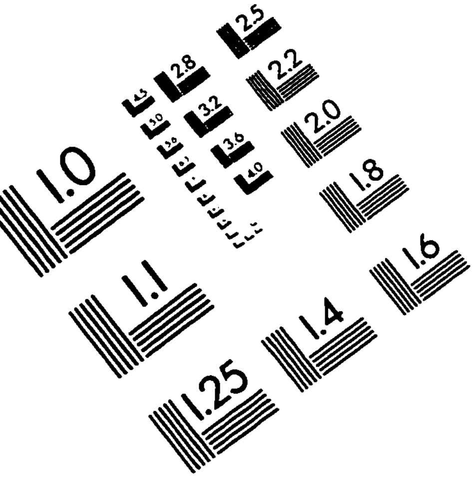
Yates, R. *Business Law in Canada, Second Edition*. Prentice Hall Canada, 1989.

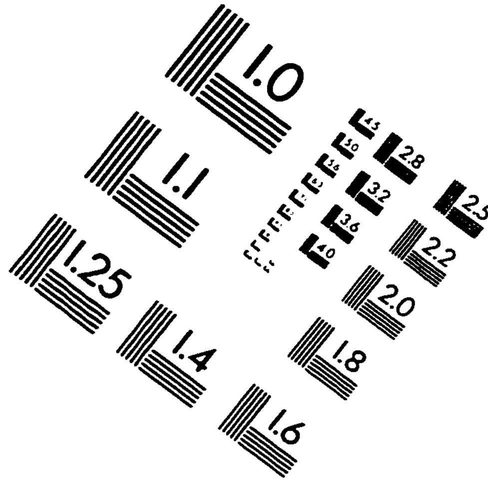
Young, Steven Scott. *Environmental Auditing*. Cahners Publishing Company, 1994

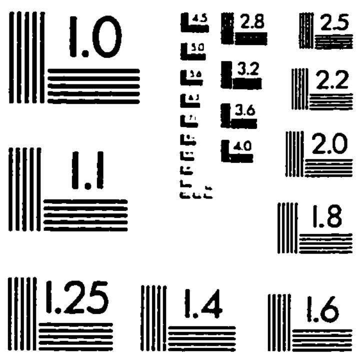
Zhang, Xiaoming and Ahmed F. Ghoniem. "A Computational Model for the Rise and Dispersion of Wind-Blown, Bouyancy - Driven Plumes - III. Penetration of Atmospheric Inversion", in *Atmospheric Environment* Vol. 28 No. 18 October, 1994.

Zylicz, T. "Environmental Reform In Poland", in *Economic Policies for Sustainable Development*. Thomas Sterner, Editor. Kluwer Academic Press, 1994.

IMAGE EVALUATION TEST TARGET (QA-3)







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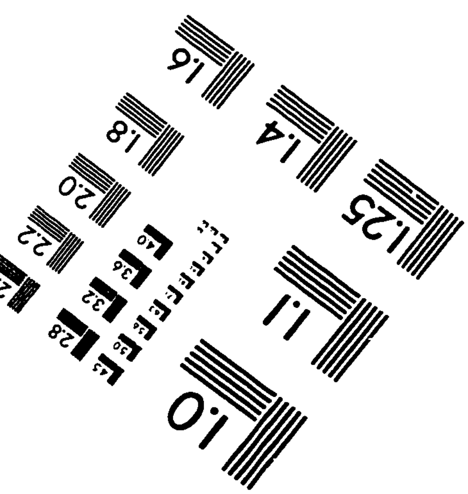

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