

# 02

## Understanding and Anticipating Environmental Change in North America

Building Blocks for Better Public Policy

Commission for Environmental Cooperation

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## Preface

Thirty years of experience in environmental policy shows that it is important to focus both on prevention as well as remediation, that is, it makes more sense to anticipate and prevent environmental problems before they occur than to react to them after they have arrived. To do this, it is necessary to define and understand a wide range of trends within the environment and their drivers. There is a need for data-intensive analyses to provide a more detailed understanding of past and present environmental trends. Finally, we should attempt to identify potential problems before they become serious and widespread.

Such research and policy goals are central to the role of the Commission for Environmental Cooperation (CEC),<sup>1</sup> an international organization created by Canada, Mexico and the United States under the North American Agreement on Environmental Cooperation (NAAEC), a parallel accord to the North American Free Trade Agreement (NAFTA). More specifically, the CEC was established to address regional environmental concerns, help prevent potential trade and environment conflicts and promote the effective enforcement of environmental law. The Commission's over-arching objectives include advancing our understanding of the relationship between the environment, the economy and trade, and pursuing policies that make environment and trade mutually supportive. Meeting this objective has been a major responsibility of the Environment, Economy and Trade program area of the CEC Secretariat.

To this end, a key project has been to identify and analyze existing and upcoming environmental issues over the next 10 to 20 years (2010 to 2020) within the three countries. A Critical and Emerging Environmental Trends Group, composed of experts from a variety of fields, was created to help identify:

- drivers of environmental changes,
- environmental trends, and
- methodologies to allow policy-makers to better understand and anticipate environmental conditions in North America.

The approach taken in the trends project has been somewhat unique in that its focus covers the three nations linked geographically, culturally and economically through NAFTA. This coverage lends itself better to dealing with trade and environment, transnational and cross-border issues.

<sup>1</sup> The Commission for Environmental Cooperation is made up of a Council of Ministers, a Secretariat and a Joint Public Advisory Committee representing the public.

This report summarizes much of the work done under the guidance of the trends project, including:

- four background trends reports produced by the Secretariat, and
- five analyses commissioned to assess methods of foreseeing future North American environmental problems.

The report does not champion any of the different methods, but rather recognizes the complexity of the issues involved and serves to demonstrate in what ways the different methods can be used, as well as the strengths and weaknesses of each of them. In this way they are intended to contribute by helping to provide useful information to individuals or organizations when considering how best to evaluate emerging environmental trends.

The report itself was prepared by Chantal Line Carpentier and Zachary Patterson of the Environment, Economy and Trade program area. The background papers were produced by Scott Vaughan, Jane Barr, and Chantal Line Carpentier, also of the Environment, Economy and Trade program area.

The sections of the report dealing with the different methods of assessing method of foreseeing future environmental problems were drawn directly from the original analyses. The authors of those underlying analyses as indicated at the beginning of each section are as follows: for material flows analysis, Emily Mathews and Christian Ottke of World Resources Institute; for the Ecological Footprint Analysis, Mathis Wackernagel; for IMPACT-WSM, Mark Rosegrant and Ximing Cai of the International Food Policy Research Institute and Ford Runge of the University of Minnesota.

The Secretariat would also like to acknowledge the contribution of the members of the trinational trends working group who oversaw the work undertaken by the Secretariat. Although membership of the group changed over the course of the project, and a large number of people participated in the group, the Secretariat would like to express particular thanks to Michael Brody of the EPA for chairing the working group since its beginning.

## Executive Summary

Is the environment we have now better than it was in the past, or have things gotten worse? Are we better off than our parents? Why have things changed? Do we really know? Can we know? What will the future look like? Will present trends continue? What will be the quality of air, water, sea, land and the biosphere as a whole for our children and grandchildren? Will the biodiversity of this continent be richer or poorer? Will our climate be the same or will it change?

This report offers insights and approaches that should help illuminate some of the answers to these questions. Yet its most important message is that, when examining the effects on the environment of trade, and the North American Free Trade Agreement (NAFTA) in particular, it is not sufficient to look just at our past experiences. We must also think imaginatively and systematically about future impacts on the environment. The future is, of course, unpredictable, involving less a linear extension of past trends than a terrain of unforeseen departures and unconsidered possibilities. This report calls for analysis of both the past and future effects of trade, utilizing the tools discussed here—analyses of environmental trends and drivers, material flow analysis, scenarios in areas of great uncertainty and various kinds of modeling—either alone or in combination. Such an approach, melding rigorous looks at the past with insights into the future, is crucial for building the information base needed to support the proactive environmental policies that will address environmental problems before they become serious and pervasive.

The report draws on four background trends reports produced by the Secretariat of the Commission for Environmental Cooperation (CEC) and five analyses commissioned to assess methods for foreseeing North American environmental problems.<sup>2</sup> This work was carried out as part of the CEC's Critical and Emerging Environmental Trends project and with the support of its advisory group.

The focus of this report, and the background papers and analyses on which it draws, is how best to examine the environmental effects of trade on Canada, Mexico and the United States, the three signatories to the North American Free Trade Agreement (NAFTA). Two broad categories of approaches are examined:

- data-intensive methods for gaining a more detailed and easier-to-communicate understanding of past and present environmental trends and the factors underlying them, and
- techniques for diagnosing and anticipating future environmental problems.

<sup>2</sup> The section on the state of the environment from these background papers is not summarized here and was incorporated into *The North American Mosaic: A State of the Environment Report*, published by the CEC Secretariat in January 2002.

## **Drivers of Environmental Change and Environmental Trends**

The starting point for this examination is the conceptual framework, developed by the CEC Secretariat with the advice of its Critical and Emerging Environmental Trends Group, with respect to drivers of environmental change and the environmental trends resulting from them.

The Trends Group identified four main drivers of environmental change:

- population growth and urbanization,
- economic growth,
- factors that link or decouple economic growth from environmental damage, and
- choices of technologies in areas such as transport, energy, informatics, and so on.

Clearly, none of these drivers acts alone and their interaction can be exceedingly complex. Yet certain blunt realities stand out. The economies of the United States, Canada and Mexico produce \$11 trillion worth of goods and services each year, and trade among them has already more than doubled to reach \$700 billion since NAFTA was signed. Despite some success in decoupling economic growth from environmental degradation, growing production and trade have serious implications for resource use, water and other natural resources, air quality, biodiversity and other aspects of the environment.

The CEC Trends Group identified three broad categories of critical environmental trends in North America—land-use change, depleted marine ecosystems and air pollution—in addition to those already on the environmental agenda, such as climate change, shrinking fish stocks and others. All these were extensively treated in the state of the environment report issued by the CEC in January 2002. In this report, the emphasis will largely be on those trends associated with land-use, though there will be some discussion of air pollution as well.

## **Perspectives on the Past and Present**

Though drivers of environmental change can be readily defined and identified, it is an exceedingly complex task to sort out in any particular situation just what drivers are in play, what effect they are having, how they are interacting, how their impact should be weighted in relation to other drivers, what environmental variables magnify or diminish their influence, and so on. Indeed, given that environmental change can affect the economy and human society as a whole, it may make sense to speak of “environmental drivers” too.



The CEC Trends Group decided to look at two approaches for examining past and present environmental trends and their drivers. The first was material flow analysis, a promising data-intensive technique that was applied to the forestry and agricultural sectors in Canada, Mexico and the United States. The second was the ecological footprint, which purports to provide a readily understandable picture of the impact of human groups upon the environment.

### **Material Flow Analysis**

Material flow analysis is a methodological tool that documents, characterizes and quantifies (in tons of material) the physical flows of materials through the economy as inputs to various industrial sectors and subsectors. The technique allows for the tracking of resource efficiency and exploration of the potential effects on the environment and human health of the uses to which materials are put. Two kinds of material flows are tracked:

- The “visible” flows of commodities and finished products traded in the marketplace and thus amenable to tracking through monetary accounts to some extent.
- The “hidden” flows of materials that are associated with making commodities available for economic use but do not themselves enter the economy (such as, for example, forestry slash, crop residues or soil eroded from cultivated fields).

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Needless to say, hidden flows can be very difficult to document. They are usually ignored in (or specifically excluded from) monetary accounts, though their impacts on the environment may be significant. One of the strengths of material flow analysis is that it attempts to track these hidden flows.

Most of the flaws in material flow analysis derive from its newness as an approach. It is very data-intensive, and compiling a material flow database can be arduous. As well, every material flow is converted to the same units: one ton of toxic waste has the same weight as one ton of eroded soil, although their environmental impact of different materials is obviously very different. There is also no formula for developing an estimate of the predicted environmental impact from the flow or use of a ton of material. Its sectoral focus can miss the flow of materials between sectors. Also, it does not address water issues.

On the positive side, the technique is one of the few that allows tracking of materials of particular interest for environmental reasons—such as toxic substances. Once it has been further tested and refined, it could prove quite useful, in combination with scenario-building, modeling and other approaches, for

exploring the environmental impact of using different technologies in the production of goods and services.

On balance, material flow analysis has considerable promise, though at present the advisory group was cautious in using it as a guide for policy because of the quality of the data now available to support it and conceptual problems associated with it. Even with these limitations, the initial results presented here of material flows in forestry and agriculture within North America reveal patterns of material use not always apparent from monetary data, thereby demonstrating the potential usefulness of the technique.

### **Material Flows in Forestry**

The preliminary analysis of material flows in the forestry sector within the three NAFTA countries clearly demonstrates that there have been substantial gains in the efficiency with which the sector utilizes both materials and resources. These gains represent at least a partial decoupling between economic growth and environmental damage within this sector. Yet because of the soaring demand for lumber, wood products and paper, the amount of fiber required by the sector continues to grow, as therefore do environmental impacts. This situation creates growing pressure on forests and wildlife habitat and indicates an urgent need to develop and diffuse at a faster rate technologies that support efficiency gains and limit or reduce the environmental impacts of the forestry sector.

The environmental implications of the increasing demand for fiber differ in each NAFTA country and region within that country. Broadly speaking, in Mexico and Canada, there continues to be growing pressure on natural forests. In the US, the trend continues towards a more managed forest which is ever more uniform with respect to age, size, species and over-all structure. In all three countries, there remains the potential for losses in biodiversity, though these manifest themselves in different ways.

### **Material Flows in Agriculture**

While representing only a small fraction of GDP in Mexico, Canada and the United States, the agricultural sector in the NAFTA region can be characterized as growing at an impressive rate in terms of both value and volume terms. It is also a land-intensive natural resource sector that, along with forestry, dominates land use and largely governs the amount of habitat available for wildlife. Many analysts also consider agriculture as a greater source of water pollution than any other economic sector. Particular problems stem from the fact that farming has traditionally been a nonpoint pollution source and is thus difficult to monitor and regulate. Despite industry consolidation and industrialization, the sector remains by and large lightly controlled.

The preliminary analysis of material flows in agriculture suggests that the scale of these environmental challenges varies enormously both within and between the NAFTA countries. Though large-scale intensive agricultural operations are emerging in all three nations, the environmental problems they create will vary enormously, depending on the size of the operation, terrain, hydrological characteristics, crop or livestock in question, areas under cultivation, the degree of crop specialization and livestock concentration and a host of other variables. For this reason, environmental assessment and policies in all three countries should be more specifically targeted to the areas and issues where the adverse environmental impacts of the sector are most likely or already evident.

Policies which respond to adverse environmental impacts will also have to take into account the fact that production efficiency in agriculture has improved dramatically over the past 25 years, with fewer inputs required to produce a constant amount of outputs for many kinds of crops and livestock products. Yet there is no denying that constant growth in demand for agricultural products has meant that the requirements for material inputs have continued to grow in absolute terms. Similarly, with constant increases in the volume of intermediary and final outputs, the amounts of wastes and unwanted byproducts have also continued to expand. For this reason, it is becoming a matter of ever more urgent priority to speed up the development and diffusion of efficient technologies to contain or reduce the environmental effects of the agricultural sector.

This pattern is typical of material throughput in industrial economies as a whole. Improvements in efficiency, such as those observed in the farm sector, brought about by advances in technology, labor productivity and economic restructuring away from energy and materials-intensive industries, are offset in part by the pace of economic growth. A recent analysis of the United States economy revealed that, while the economy grew by 74 percent between 1975 and 1996, waste outputs grew by only 30 percent. This situation represents an impressive degree of “decoupling,” but it is not sufficient to achieve any absolute decrease in waste volumes. For this study, our documentation of material throughputs was not comprehensive and thus it was not possible to construct a macro indicator showing total material flows in either the agriculture or forestry sector and their relation to sectoral economic performance. But analysis of individual flows or categories of flow—such as, for example, the poultry subsector—indicate that the same trends are present.

Material flow analyses indicate that higher priority should be placed on innovation to hasten the rate of development and adoption of technologies that increase the efficiency of resource use and reduce environmental impacts by the agriculture and forestry sector, given that gains in materials and/or resource efficiency have thus far not been able to keep up with increases in the scale of production. For this reason, futures methods should be used to target areas most likely to be affected by increased scale of activities.

## Ecological Footprint

The Trends Group also examined the notion of an ecological footprint, because it purports to provide a readily understandable picture of the impact of human groups upon the environment. This accounting tool “aggregates human impact on the biosphere into one number: the bio-productive space occupied exclusively by a given human activity.”<sup>3</sup> More specifically, measuring an ecological footprint involves estimating a population’s consumption of food, materials and energy in terms of the area of biologically productive land or sea required to produce those natural resources (or, in the case of energy, to absorb the corresponding CO<sub>2</sub> emissions). The unit of measurement employed is generally a hectare of land (or sea) whose productivity is average in global terms. Thus, biologically productive land serves as a proxy for natural capital and the many resource flows and services rendered by nature.<sup>4</sup> As an environmental and natural resource indicator, the ecological footprint method has the advantage of rolling all possible factors up into a single number—a goal that continues to elude just about everyone else working on aggregated environmental indicators.

x While the ecological footprint has many attractive features, its policy utility remains unclear. The transformation of energy use into land is more a rhetorical than a scientific concept, and it penalizes energy-intensive, industrialized economies because of the forest area required to sequester the CO<sub>2</sub> created by energy use. It is also unclear whether a country’s footprint should be compared to its own capacity or to global capacity. As well, because the method involves so much aggregation, it is necessary, though perhaps not entirely possible at this stage in our understanding, to be scrupulous about what indicators are being mixed, why such mixtures are appropriate and how different indicators are compared, weighed and averaged. In addition, this method requires the adding up of each category of consumption; but since reliable data for indirect consumption (such as embodied energy in goods) is scarce, the approach is prone to error. The level of aggregation is, in fact, so high that many experts doubt the approach constitutes an adequate guide for national policies.<sup>5</sup> In the same vein, many economists doubt whether the approach tells us much that is useful about carrying capacities, assumed rates of technological innovation or progress towards future sustainability objectives.

Thus, while provocative and occasionally useful to explore certain kinds of environmental impacts, the Advisory Group decided that, as an analytical concept, ecological footprint had fundamental weaknesses and would not be pursued by this group.

3 Wackernagel 1999.

4 Wackernagel 1999.

5 Ayres 2000.

## Perspectives on the Future

Exploring and communicating past and present environmental trends can be an important adjunct to the development of environmental policy. At the same time, it is important to take preventive action before environmental problems become severe and pervasive. Though knowledge of past and present trends should inform and even provide a foundation for efforts to understand the future, they are insufficient in themselves to illuminate that future—unless one accepts the improbable proposition that past and present trends will continue uninterrupted and unchanged into the indefinite future. In fact, an array of methods, techniques and approaches has been developed to throw light on a future where new factors may come into play and trends may disappear or evolve into startling new configurations. The last part of this report looks at some of the promising techniques for looking into our environmental futures, applies one of them to future competition for freshwater resources and draws some lessons to guide futures work in coming years.

## Techniques for Exploring Environmental Futures

Researchers have developed literally dozens of methods for looking into our environmental future, ranging from those assuming a continuation of present trends into the future to those allowing more imaginative and unexpected constructions of the future. The prestigious Battelle Seattle Research Center has grouped these into six useful categories<sup>6</sup> that we will adapt for our purposes here. The categories, grouped in pairs, are:

- environmental scanning/monitoring and trend exploration,
- canvassing opinion and scenario-building, and
- modeling and morphological analysis.

It is important to understand that none of these categories is airtight, and most people grappling with predicting future environmental conditions use different combinations of methods from a number of these categories. The reason is that none of the techniques are sufficient to the task themselves, though all may have a role to play.

Environmental scanning and monitoring are essentially data-gathering activities that provide much of the basic empirical data required to understand the environment and provide a basis for the identification and analysis of environmental trends. Trend extrapolation involves the extension of past and present trends into the future and is often used in environmental outlook and state of the

6 Skumanich and Silbernagel 1997.

environment reports. Data on trends could emerge, for example, from the application of techniques such as material flow analysis or the ecological footprint.

Both canvassing opinion and scenario-building can involve reaching beyond the traditional circles of environmental policy-makers in government and engaging a variety of experts, members of nongovernmental organizations, the private sector and concerned citizens. The discipline of qualitative scenario-building is exceptionally well-suited to prepare for the surprise events that often shape our future and cannot be captured with more quantitative forecasts. The approach involves the development of different scenarios to explore a range of possible future outcomes. However, though leaps of imagination may be important in scenario-building, it is also necessary to maintain a connection to scientific knowledge and quantitative tools, and to methods that can bring speculation “down to earth” and reveal less obvious patterns and relationships between variables and patterns.

Such tools include modeling and morphological analysis the latter being modeling without as much reliance on quantitative data. Both place more weight on computer models and other technical analytical tools. Both can be indispensable for providing internal consistency to data that go into and emerge from scenarios. Both can take into account the myriads of relationships between economic sectors and the environment and can establish causal relationships among them. As a consequence, models are often employed to understand interactions between the economy and the environment and how these may affect the future. Though gaps remain in the data and theory needed to support the economic and bioeconomic models used to explore this interaction, these techniques remain among the few quantitative, replicable methods available and are vital tools for researchers and policy-makers to anticipate and take action on environmental problems before they become pervasive and severe.

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### **Modeling Future Competition for Water**

Many observers consider the availability of water as one of the most critical factors in food security for many regions of the world. In dry areas of North America, it seems likely that urban sprawl will collide head on with irrigated agriculture in a competition for ever scarcer freshwater resources. In some areas, meeting the rapidly growing demand for water by cities and industry will increasingly mean less water available for irrigation in agriculture—a critical input that could not be included in the analysis of material flows in agriculture described above. In order to understand this play of forces, the CEC decided to utilize one of the comprehensive global models for illuminating these issues and how they may evolve over the next 10 to 20 years: the IMPACT-WSM<sup>7</sup> model, which integrates a water simulation model with the already functional and well-

used IMPACT trade economics model. This model was applied to 14 river basins in the United States.

The results suggested that significant additional transfers of water to meet increased water demand could be achieved without a devastating impact on overall US food production and trade. Although local effects on agricultural employment and related sectors can occur under a scenario of rapidly increasing competition for scarce water resources, the most important effects would be concentrated in specific basins where production shortfalls occur. It would be here that interventions might be necessary to compensate farmers negatively affected by environmental diversions. However, investments in the development of improved irrigation systems can mitigate many of these negative impacts, even when water is reallocated for environmental purposes. Investment in such improvements could be encouraged by policy reforms—such as, for example, more aggressive water pricing—to encourage conservation and constrain the municipal and industrial uses assumed under our scenarios to be the first claimant for water.

Such action becomes more important when one considers that, even if no change occurs, deficits in the amount of water available for irrigation will occur in some dry basins in the western United States, as well as in the Midwest, where intensive use of water for irrigation purposes takes place. Clearly, efficient use of water is becoming crucial for all regions because of environmental constraints and rapid increases in the demand for water by municipalities and industry. Sound management of US water resources will be necessary, not only to serve growing cities, environmental purposes, agricultural and other users, but also to make cereals/grains available to developing countries at affordable prices in increasingly integrated regional and global food markets.

For all these reasons, given the growing pressure on water resources, mechanisms for pricing water should be put in place to provide clear incentives for the conservation of water and for investment in the development and adoption of more efficient technologies for water use.

### **Lessons for Futures Work**

Though no method for exploring future environmental conditions provides a perfect vision through the window to tomorrow, each has its special strengths and there have been some notable successes—and failures. Lessons can be learned from both.

The sequence of steps followed in the progression from a scientific hypothesis on depletion of the ozone layer to a broad international accord on anticipatory action was so successful that it deserves emulation in other high-priority areas

7 IMPACT is the International Model for Policy Analysis of Agricultural Commodities and Trade developed by the International Food Policy Research Institute. WSM is a Water Simulation Model that simulates the availability of water for crops.

of environmental concern. The approach involved skillful scenario-building backed by solid scientific modeling and evidence, a realistic mix of policies taking into account the transition costs in meeting the objectives, the availability of cost-effective alternatives to chlorofluorocarbons (CFCs), and effective communications to engage the scientific community, industry (producers of CFCs), government regulators, end users, other experts and the general public. Similar approaches might be used in both the forestry and agricultural sectors where, as shown here in the preliminary analysis of material flows, production increases in both sectors due to rising demand far outweigh efficiency gains because of new technologies and productivity improvements, with the result that adverse environmental impacts may grow progressively more severe. Thus, scenario-building, supported by science-based modeling, investment incentives to make available "cleaner" substitutes, regulatory intervention that is predictable with long lead-times for implementation, and effective communications, seems a winning approach that could be applied to other areas of high-priority environmental concern such as forestry and agriculture.

When information technologies were being introduced in the 1970s and 1980s, many pundits, and not a few economists and environmentalists, predicted structural changes that would result in a new, more environmentally benign information economy, where offices would be paperless, less mail would be sent and electronic communications would replace energy-intensive transportation. The new economy has clearly arrived, but the demand for paper continues to grow rapidly, mail volumes keep rising, a whole new courier and parcel delivery industry with vast fleets of trucks and planes has emerged and up until 11 September 2001, ever more people were on the move. Why did so many experts get it so wrong? Perhaps we can learn something from their mistakes. The case of information and communication technology should be further studied to discover whether its failure to reduce pressure on the environment was predictable, as well as to reveal lessons that might be applicable to technologies now emerging.

In early 2002, the CEC's work on emerging environmental trends was combined with ongoing work on NAFTA's effects on the environment and trade in general. The goal was to improve environmental assessments of market integration of the North American economy, with emphasis on the environmental effects of trade liberalization, past and future. The approach taken to assess the relationship between trade and the environment will involve integrating futures or forecasting work carried out over the course of the CEC's Critical and Emerging Environmental Trends project, with analytical work on the effects of NAFTA since its inception. An important focus will be sector-specific analyses building on the insights described here with respect to trends in agriculture, forestry and energy.



This new program will help clarify the extent to which market integration—driven by trade and trade-related investment among the NAFTA partners—directly or indirectly affects environmental quality and environmental policies. Robust environmental assessments provide a sound basis for identifying proactive policies, both in the environmental and economic policy arenas, intended to mitigate negative environmental effects of market integration and maximize positive environmental outcomes.

# 1 Introduction

Is the environment we have now better than it was in the past, or have things gotten worse? Are we in a better or worse environmental situation than our parents? Whatever the answer to these questions, why have things changed? Can we know why? Will present trends continue into the future? What will be the quality of air, water, sea, land and the biosphere as a whole for our children and grandchildren? Will the biodiversity of this continent be richer or poorer? Will our climate be the same or will it change?

This report offers insights and approaches that should help illuminate some of the answers to these questions. If the goal is modest, its importance cannot be denied. NAFTA ministers face an avalanche of environmental and economic data and analyses of the future on which they are expected to base environmental policies. The challenge is not an absence of data, but arranging the available data to be informative and encouraging proactive policies that reflect the non-linearity of some aspects of environmental change.

To this end, the report looks at a variety of methods for answering such questions and applies several of these techniques to Canada, Mexico and the United States, the three signatories to the North American Free Trade Agreement (NAFTA). Two broad categories of approaches are examined:

- data-intensive methods for gaining a more detailed or easier-to-communicate understanding of past and present environmental trends and the factors underlying them, and
- techniques for diagnosing and anticipating future environmental problems.

The starting point for this examination is the conceptual framework and findings, developed by the CEC with respect to drivers of environmental change and the environmental trends resulting from them.

## **1.1 Drivers of Environmental Change**

The Trends Group identified four main drivers of environmental change:

- population growth and urbanization,
- economic growth,
- factors that connect or decouple economic growth from environmental damage, and
- choices of technologies in areas such as transport, energy, informatics, and so on.

Clearly, none of these drivers acts alone and the interaction among them can be complex and intimate, as will be seen below. One test of the utility of the various techniques described below for examining past, present and future trends will be their capacity to illuminate the effects of these drivers.

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### **1.1.1 Population Growth and Urbanization**

It is clear that population growth and urbanization intensify pressure on the environment. Clearly, neither demographics pressure nor urban expansion act in isolation and their relationship is far from linear or one-dimensional. Much needs to be understood about the many different ways they can bring about change in to a wide range of environmental variables.

The combined population of North America is approximately 405 million people—roughly seven percent of the world’s population—and is expected to increase by roughly 30 percent to 515 million by 2025, especially in coastal urban areas. In the same period, the proportion of North Americans living in urban areas will likely grow from 75 to 85 percent. Virtually every chapter of this report addresses direct or indirect environmental impacts of population growth and urbanization. Chapter 8 focuses in depth on one particular impact of urbanization—the potential for and possible costs of increased competition between urban and rural areas for water, as well as ways of reducing the negative impact of this competition.

### 1.1.2 Economic Growth

Between 1994 and 2000, total trade among Canada, Mexico and the United States increased from US\$347 billion to more than US\$700 billion. In 2000, these three economies produced over US\$11 trillion worth of goods and services. Economic and population growth mean more production and consumption, which in turn (all else being equal) imply more pollution, more intensive use of land and more pressure on environmental resources. Although many market and pricing failures—failures trade liberalization and structural adjustment programs are intended to address—are now widely regarded as important underlying causes of environmental degradation, most economic policies do not incorporate environmental considerations.

However, as will be seen in the next section, environmental degradation does not increase at the same rate as economic or population growth because of the mediation of a large number of intervening variables, as well as a wide variety of structural and technical changes that can intensify or reduce the damage. Virtually every chapter of this report, but particularly Chapters 2, 3, 4, 6, 7 and 8 illuminate various considerations relevant to understanding some aspect of the environmental impact, direct and indirect, from past, present, and future.

### 1.1.3 Decoupling Factors

Decoupling factors are those that can reduce or eliminate the negative impact of economic growth on the environment. They can include the effects of:

- economic changes and measures that mitigate negative environmental effects of economic growth—such as environmental regulations or incentives to encourage the use of pollution abatement equipment, increased profitability that allows expenditures on such equipment, or productivity improvements that increase outputs without increasing inputs;
- shifts in the underlying structure of the economy away from high-impact activities such as resource extraction and primary manufacturing, to lower-impact services or information-based products; and
- technological improvements that may improve the efficiency of resource use.

Strong evidence now exists of some decoupling between economic growth and environmental degradation. However, the North American economy and trade flows between NAFTA partners have been growing so rapidly that the increases in scale have tended to overwhelm the efficiency gains resulting from decoupling factors. This question is examined in Chapters 3 and 4 (in the context of an analysis of environmental implications of the flows of materials in the

forestry and agricultural sectors), Chapter 6 (in an examination of ways to anticipate future environment conditions) and Chapter 7 (insofar as it affects competition over water between urban and rural areas).

#### **1.1.4 Choice of Technologies**

“Green” technologies, defined as technologies that maintain or reduce resource use and pollution emissions, can contribute to the decoupling of economic growth and environmental degradation. Other technologies can intensify negative effects on the environment. Sometimes, it is not entirely clear whether, on balance, a technology contributes to more efficient resource use or fewer emissions. In Chapters 2, 6 and 8, there are further discussions of decoupling and the expectations that information and communications technology might constitute a decoupling factor. By way of contrast, when modeling competition for water between urban and rural uses, Chapter 7 looks at the potential environmental benefits flowing from greater efficiency in irrigation systems. Chapters 3 and 4, in their overview of material flows in forestry and agriculture, look at the impact of more efficient resource use within these sectors.

### **4 1.2 Environmental Trends in Land Use and Air Quality**

A trend can be defined as “a verbal or numerical representation of a series of characteristics that can be estimated over time, providing an indication of the general direction of change. A trend may be a subjective assessment of a situation or an objective/numerical measure. A trend may be increasing, decreasing, or static.”<sup>8</sup> Trend analysis can be very helpful to policy-makers and others needing to understand what has happened in the past and what is happening now. It is often less successful as a basis for predicting what will happen in the future—an important consideration if one objective of environmental policy is to take preventive action to limit environmental challenges before they become severe and widespread.

The CEC Trends Group identified three broad categories of critical environmental trends in North America—land-use changes, depleted marine ecosystems and air pollution—in addition to those already on the environmental agenda, such as climate change, shrinking fish stocks and others. All these were extensively treated in the state of the environment report issued by CEC in January 2002. In this report, the emphasis will largely be on those trends associated with land use, though there will be some discussion of air pollution as well.

### 1.2.1 Changes in Land Use

Virtually all the drivers of environmental change have an impact on land use in ways that vary in degree and complexity depending on the geographic area under consideration, the environmental concern, and so on. These complex and tangled chains of causality are not always very well understood.

Whatever the mix of causes, it is well recognized that the effects of land-use changes can reverberate throughout the environment on a planetary scale. For example, worldwide trends in land use can affect the generation of greenhouse gases, whose accumulation in the atmosphere may bring about global climate change. It has been estimated, though perhaps not reliably, that changes in land use, principally deforestation, have increased the level of CO<sub>2</sub> in the atmosphere by as much as 35 percent during the last 100 years, as well as leading to significant loss in natural habitat and biodiversity. Chapter 3 looks at a number of these concerns in relation to material flows within the rapidly North American forest industry.

Agriculture is another sector that makes extensive use of land and can have a profound impact on the environment. The continuing increase in agricultural production may have outstripped many of the efficiency gains in resource use and is putting increased pressure on the environment in a variety of ways—as a source of greenhouse gases, a generator of pollutants, a depleter of freshwater resources, and so on. Chapter 4 examines material flows in agriculture within the NAFTA region with a view to clarifying the factors influencing the impact of the sector upon the environment. Chapter 7 looks at the water issue by modeling the implications of future competition for water between rural and urban users.

### 1.2.2 Air Pollution

Population growth, urbanization, economic growth, decoupling factors and choices of technologies can all affect levels of air pollution. This report leaves an extensive discussion of air quality in North America to the CEC's *The North American Mosaic*, released in 2002. Instead, this report focuses in Chapter 8 on examining how futures work can predict the emergence of an environmental problem—in this case, depletion of the ozone layer—and mobilize international opinion around preventive action.

## 1.3 Key to Report

At least two conclusions can be drawn from this discussion of environmental trends and drivers of environmental change.

The first is that causation in this realm of drivers and trends is multi-dimensional. Though drivers of environmental change can be identified, it can be a

complex task to sort out just what drivers are in play, what effect they are having, how they are interacting, how their impact should be weighed in relation to other drivers, what environmental variables magnify or diminish their influence, and so on. As well, given that environmental change can affect the economy, it may make sense to speak of “environmental drivers.” The CEC Trends Group examined two approaches to looking at communicating past and present environmental trends and conditions—material flow analysis and ecological footprint analysis. These techniques are described and applied to the North American setting in the next four chapters:

- **Chapter 2** examines material flow analysis, a method for exploring the flows of materials within the economy and its implications for the environment.
- **Chapter 3** undertakes a preliminary analysis of material flows in the forestry sector within the three NAFTA countries.
- **Chapter 4** describes a preliminary analysis of material flows in agriculture in the United States, Canada and Mexico.
- **Chapter 5** examines the ecological footprint approach to quantifying environmental impacts.

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The second conclusion is that environmental trends, while useful in establishing what has happened and is happening in the environment, are less capable of helping policy-makers, researchers and others understand what will happen. Knowledge of past and present trends should inform, and even provide a foundation for, efforts to understand the future, but it is insufficient in itself to illuminate that future—unless one accepts the improbable proposition that past and present trends will continue uninterrupted and unchanged into the indefinite future. In fact, an array of methods, techniques and approaches have been developed to throw light on a future where new factors may come into play and trends may disappear or evolve into new configurations. The last part of this report examines some of the promising techniques for looking into our environmental futures:

- **Chapter 6** briefly surveys a range of methods for anticipating future environmental conditions.
- **Chapter 7** combines sophisticated trade economics and water simulation models to build scenarios portraying future competition for water between urban and rural areas.
- **Chapter 8** draws lessons from the successful effort to anticipate and control the effect of ozone-depleting substances, and the failure to anticipate some of the major environmental effects of information and communications technology.

## 2 Material Flow Analysis

Material flow analysis<sup>9</sup> is a data-intensive tool for tracking the physical flows of materials through the economy. It is especially useful in documenting the efficiency of resource use and linking the use of materials to potential impacts on the environment and human health. This chapter delineates some of the main strengths and weaknesses of material flow analysis and explains why its application to forestry and agriculture can illuminate major features of the interaction between the economy and the environment.

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### 2.1 Strengths and Weaknesses

Material flow analysis is a methodological tool that documents, characterizes and quantifies (in tons of materials) the physical flows of materials through the economy as inputs to various industrial sectors and subsectors. The purpose of this kind of analysis is to keep track of resource efficiency and explore the potential effects on the environment and human health of the uses to which materials are put.

This kind of analysis is intended to track two kinds of material flows:

- The “visible” flows of commodities and finished products traded in the marketplace and thus amenable to tracking through monetary accounts to some extent; and

<sup>9</sup> This chapter and the next two are derived from Matthews and Ottke, 2001.



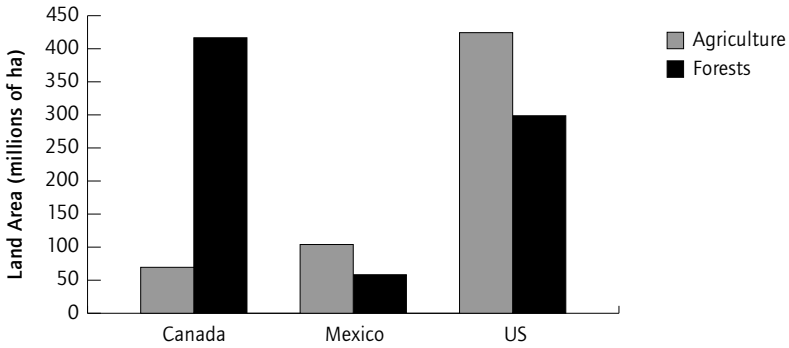
- The “hidden” flows of materials that are associated with making commodities available for economic use which do not themselves enter the economy (such as, for example, forestry slash, crop residues or soil eroded from cultivated fields).

Needless to say, hidden flows can be very difficult to document. Usually, they are ignored in (or specifically excluded from) monetary accounts, though their impacts on the environment may be significant. Clearly, it would be desirable to have a systematic accounting of this physical dimension of economic activity, and this is what material flow analysis attempts to do.

The method does, however, have flaws, but these are mainly due to our lack of experience in collecting and analyzing data—problems that in all likelihood will be rectified over time. For example, the technique is very data-intensive and compiling a material flow database can be arduous. Another difficulty is that every material flow is converted to the same units; one ton of toxic waste has the same significance as one ton of eroded soil. There is also no formula for developing an estimate of the predicted environmental impact from the flow or use of a ton of material. This kind of analysis also tends to ignore the important interaction between related economic sectors—such as, for example, agriculture and forestry. As well, the method does not address water issues. Finally, important information can be lost when the data are aggregated.

It is expected that many of these weaknesses will disappear once we have had more experience with it and are able to refine it. Material flow analysis promises to provide a useful way of exploring in a quantitative way the intersection between the economy and the environment. Already, it can be helpful in tracking substances that have acquired environmental significance, perhaps because of their toxicity or some other attribute. The technique can also be used to help organize complex environmental and economic indicators, as well as a wide range of other data in ways that are accessible to the public and experts alike. On the basis of trends in material flows, it may also be possible to develop future scenarios for material flows, emissions and efficiency for the next 10 or 20 years in line with macroeconomic and sectoral projections. For example, the method could allow examination of flows in wood fiber under different assumptions about economic growth rates, technologies employed and/or rates of recycling. Such an approach could also permit comparisons of the contributions of different chemicals to greater input efficiency (lower resource use per unit of economic output), greater output efficiency (lower emissions to environment per unit of economic output), or reduced toxicity per unit of economic output. Conceivably, material flow analysis could also be used, in conjunction with modeling, scenario-building and some of the other techniques discussed in Chapters 6, 7 and 8 to explore future environmental conditions.

**Figure 1. Forests and Agricultural Land (Crops and Pasture) in Each Country**



Sources: Total land and forest area: NRCan 1998;  
 Cropland and Pasture: OECD 1995b, INEGI, Semarnap 1998;  
 forest area: SARH 1994; cropland: INEGI 1995a; Pasture: FAO

## 2.2 Agriculture, Forestry and the Environment

A material flows database already exists for forestry and agriculture in the United States. This database was developed by the World Resources Institute covers about 95 percent of material flows in the sectors between 1975 and 1996. It was partly because of the availability of this rich data source that the CEC prepared in cooperation with Canada and Mexico, a preliminary analysis of selected flows for this period in the forestry and agricultural sectors within Canada and Mexico. But this was not the only reason for undertaking this analysis. Forestry and agriculture are important sectors of the economy in all three countries and their environmental impact is highly visible because they are so land-intensive.

In fact, agriculture and forestry together account for 67 percent of the three countries' landmass. Forest or woodland covers about 37 percent; pasture or grazing land, 17 percent; and crops, 13 percent. According to the United Nations Food and Agriculture Organization (FAO), the forest covering one-quarter of the land in the US, Canada and Mexico represents about 16 percent of the world's forests.<sup>10</sup>

Forests are far from evenly distributed among these countries. They feature enormous variation in land cover: Canada has 54 percent (418 million hectares) of the regions' forests and woodland, while the US has 39 percent (298 million hectares) and Mexico, seven percent (57 million hectares).

They also differ in the amount of land devoted to agriculture. In Mexico, 12.7 percent of land is used for growing crops while 14.2 percent is set aside for pasture.<sup>11</sup> About one-fifth of the United States is set aside for crops.<sup>12</sup> By way of

<sup>10</sup> FAOSTAT 1998.  
<sup>11</sup> INEGI-SEMARNAP 1998.  
<sup>12</sup> USDA 1992.

contrast, only seven percent of Canada's large land base is classified as agricultural, though this represents about three-quarters of the nation's potentially arable land.<sup>13</sup> In fact, 88 percent of North America's agricultural land lies south of the Canada/US border.

As will be seen below, the amounts of land devoted to forestry and agriculture in the three countries have profound implications for the size and direction of material flows within these sectors in the three countries.

### **2.3 Summary**

As the next two chapters will show, material flow analysis can provide a unique insight into the uses of materials within the forestry and agricultural sectors and their environmental implications during the last 25 years. However, because of the quality of the data now available and conceptual problems associated with material flow analysis at its present early stage of development, it is important to be cautious about its implications for policy. For example, while many aspects of both sectors were explored, it proved impossible at this point to bring in information on energy and pesticide use, both of which have significant environmental impacts. Despite these limitations, the preliminary results presented in the next two chapters reveal patterns of material use not always apparent from monetary data, thereby demonstrating the promise of the methodology.

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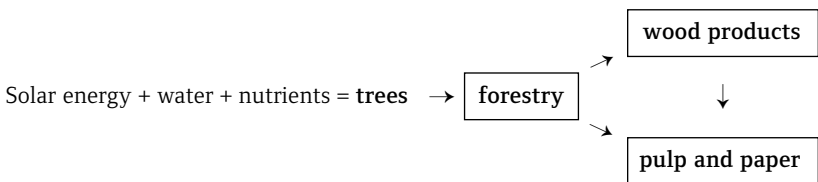
### 3 Material Flows in Forestry

Application of material flow analysis to the forestry sector can illuminate both the efficiency of the sector and the degree to which it is sustainable. But first it will be necessary to define what was covered by our material flow analysis of forestry and what we mean by materials and the various forestry subsectors into which the materials flow. Only then will it be possible to discuss in a meaningful way the size and nature of these flows and their environmental implications. Finally, we will look at these flows and their implications in the context of NAFTA and present trends in trade for forestry commodities and products.

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#### 3.1 Defining Material Flows and Industries in the Forestry Sector

At the most general level, material flows in the forestry sector can be characterized as follows:



In other words, the natural or material cycle begins with solar energy, water and nutrients that are metabolized by trees into woody tissue. Only the three elements—carbon, nitrogen and phosphorus—present in wood in reasonably constant ratios were presented as materials in the CEC’s preliminary analysis of material flows, and even these will not be discussed here.

All of these materials, however, represent inputs to the forest industry that harvests the trees. Unfortunately, data are lacking at the national level that would allow analysis of man-created inputs such as fossil fuel energy, nutrients and pesticides. Basic outputs from the forest industry take the form of fuelwood and charcoal, as well as industrial roundwood (hardwood and softwood). Waste outflows from the forest industry include wood residues (slash), and their constituent elements, though slash is increasingly finding a market as mulch.

Industrial roundwood outputs from the forest industry become inputs for the wood products industry. This industry processes the roundwood into a variety of products, including lumber, plywood, veneers and panel products. The industry also utilizes as inputs:

- recovered fiber from processing residues and waste wood, such as waste from demolitions;
- chemical inputs such as preservatives and adhesives; and
- fossil fuel energy which is not documented in this analysis.

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Waste outflows from the industry include emissions to air and water from processing and fuel combustion, as well as the wood disposed after it has been used. In the time available, it was possible to document only a few of these outflows.

To the pulp and paper industry, roundwood from the forestry subsector, residues from the wood products industry and recycled waste paper all represent fiber inputs, as do a few fibers from non-woody material. Other inputs include fossil fuels, biomass fuels (derived from wood and paper industry byproducts) and the chemicals used to break solid wood down to wood fiber and stabilize and bleach paper. Outputs from the industry include wood pulp, pulp from other fibers, paper and paperboard. Waste outflows include emissions from processing and fuel combustion, as well as the paper and paperboard products disposed after use.

It is important to understand that the sector has a strong international dimension and imports from other countries may supplement material inputs at all stages. Forestry operations may use imported fertilizers and pesticides. The wood products industries in all three countries import logs, lumber, and board, as well as finished products. The pulp and paper industries import pulp and recycled paper, as well as paper and paperboard products. Similarly, some fraction of product outputs from all three subsectors is exported to other countries.

Waste outflows in the form of airborne or waterborne emissions may also be “exported” when transported by natural processes across national borders. This category of flow represents one of the more interesting aspects of material flow analysis, but requires original research that was beyond the scope of this study.

### **3.2 Analyzing Material Flows in the Forestry Sector**

The analysis of material flows in the forest industry focuses on its three major subsectors: the forest industry, the wood products industry, and the pulp and paper industry. Highlights of the material flows within each of these subsectors will be examined below for all three countries.

#### **3.2.1 Forest Industry**

In examining material flows within the forest industry, the emphasis here will be on those aspects that can have important environmental impacts. These include:

- the size and nature of roundwood harvests,
- logging residues left in the forests, and
- the importance of fuelwood to the industry

It should be noted that that the researchers did not search for Canadian data for the first two.

*Roundwood Harvests:* There were profound differences in the harvesting of roundwood within Mexico and the United States, and these would seem to have environmental implications.

In Mexico, roundwood harvests amounted to 1.26 metric tons per hectare of legal forest in 1975 and rose to 2.1 metric tons by 1998. This increase suggests either a shift to more productive plantation forestry and/or an increase in timber removals from mature forests, where tree size is larger. Such growth in productivity per hectare could possibly have serious implications for biodiversity because of the clearance of natural forest habitat.

In the United States, roundwood harvests in 1996 averaged 1.4 metric tons per hectare of forest available for logging. This relatively modest rate reflects the fact that large mature trees have already been harvested or placed under protection and replaced by young trees in managed stands. The average size (measured in terms of diameter at breast height) of harvested trees declined by over 20 percent between 1975 and 1991.<sup>14</sup>

*Logging Residues:* It is also instructive to compare logging residues left in the forest within Mexico and the United States.

<sup>14</sup> Matthews et al. 2000.

In Mexico logging residues left in the forest amounted to 40 percent of total roundwood harvests by weight in 1975 and 44 percent in 1998.

The trend in the US was exactly opposite. In 1975, logging residues left in the forest amounted to 48 percent of total roundwood harvests, but only 23 percent in 1996. The American industry, in contrast to its Mexican counterpart, seems to be removing more of the tree from the forest during its harvest operations. The so-called “residues” are finding a market as mulch, inputs for wood and pulp processing and, to a limited extent, fuel in biomass power plants. However, though the economic productivity of US forest lands has increased, nutrients present in residues have been removed from the forest ecosystem. This situation suggests that, in the absence of some supplemental source of fertilizer, some production forests may be subject to nutrient mining.

*Fuelwood:* Because the burning of wood can be highly polluting, the degree of a country’s reliance on fuelwood as an energy source can have important environmental and human health implications.

Wood and charcoal remain important sources of fuel in Mexico, especially among the rural poor. Fuelwood harvests amounted to 12.3 million metric tons in 1998, equivalent to 58 percent of the total harvest of roundwood—a proportion that has remained the same since 1975. Indeed, despite Mexico’s economic growth and social development over the past 25 years, consumption of fuelwood has grown by 20 percent. Continued high per capita consumption of fuelwood has potential implications both for deforestation and human health.

In Canada, wood supplies about four percent of the national energy supply.<sup>15</sup> Fuelwood harvests in 1996 amounted to 3.3 million metric tons and accounted for about three percent of total roundwood production. This figure represented a significant increase over fuelwood harvests in 1975, which amounted to only 2.2 million metric tons, though this represented a marginally larger percentage of total roundwood production.

In the United States, wood provides three percent of the national energy supply<sup>16</sup>—about the average for industrialized countries. Yet the fuelwood harvest, at nearly 50 million metric tons, accounts for about 18 percent of the total roundwood harvest, roughly six times the proportion in Canada. Also in contrast to Canada, where fuelwood as a proportion of the total roundwood harvest has remained roughly constant since 1975, American fuelwood accounted for only six percent of the total roundwood harvest in 1975, about one-third of today’s proportion. The United States is also unusual in that almost 60 percent of wood used for fuel is harvested directly from forests.<sup>17</sup>

In other industrialized countries, most wood energy is derived from burning black liquor and other wood industry residues. The combustion of wood can be highly polluting, but further analysis would be necessary to determine the propor-

<sup>15</sup> FAO, 1997b.

<sup>16</sup> FAO, 1997b.

<sup>17</sup> Nilsson et al. 1999.

tion of wood burned in power plants fitted with pollution control equipment, as opposed to private homes lacking that equipment.

### 3.2.2 Wood Products Industry

In examining material flows in the wood products industry, we will pay particular attention to:

- the growth and nature of outputs,
- efficiency gains in utilization of inputs, and
- chemical contamination from discarded wood products.

As will be seen below, these aspects of the industry have significant environmental implications.

*Sizeable Growth in Outputs:* Total production of industrial wood products in all three countries has grown strongly since 1975—by 60 percent in the United States, 140 percent in Canada and 60 percent in Mexico. Table 1 shows production of the major industrial roundwood categories.<sup>18</sup>

The US dominates production in all categories of industrial roundwood production. Between 1975 and 1996, production grew most for laminated veneers, particleboard, and fiberboard. The fastest growth occurred in the production of oriented strandboard, which rose nearly 50-fold from an admittedly small base. Lower-value lumber production also rose by 42 percent.

The Canadian picture resembles that in the United States, in that production of processed wood products, such as particleboard and laminated veneers, increased. The growth was, however, much slower than in the US. By way of contrast, Canadian lumber production rose more than 130 percent, much faster than in the US.

**Table 1. Production of Major Industrial Roundwood Categories, 1996**

<b>(Thousand Metric Tons, Air-Dried Weight)</b>			
	<b>United States</b>	<b>Canada</b>	<b>Mexico</b>
Lumber	49,310	31,355	
Plywood and veneer	11,072	1,150	
Panels	17,209	3,799	
Other	6,479	783	
Sawnwood			2,034
Plywood			189
Fiberboard and particle board			271

*Note:* Data for Mexico are for 1998.

<sup>18</sup> Data for Mexico were provided in a slightly different format, so category subtotals are not comparable. However, certain patterns emerge very clearly.



Despite substantial growth in the processed wood industry, Mexican production remains very small in comparison with that in the United States and Canada, as Table 1 illustrates. Production of “sawnwood”—a category used only in Mexican compilations—rose more than 60 percent while production of all boards, panels and plywood almost tripled. Production of veneer sheets rose from 2.5 million tons in 1975 to more than 30 million tons in 1994, the latest year for which data are available.

*Efficiency Gains in Fiber Utilization:* In Canada and the United States, the introduction of more efficient milling technologies has resulted in steady improvements in the quantity of marketable product obtained from a constant quantity of raw wood. The Mexican data do not allow us to ascertain the ratio of inputs to output.

In the United States, the efficiency gains have been impressive. Roundwood inputs for lumber rose 31 percent between 1975 and 1996, while lumber production increased by 43 percent over the same period. Roundwood inputs for panel products expanded by 106 percent, while outputs of panel products soared by 267 percent. These represent significant efficiency gains and they have been complemented by growing use of milling residues in other wood products such as particle board, fiberboard and strandboard. Outputs of all these products have expanded dramatically, though quantities remain small compared with lumber.

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In Canada, the efficiency gains were likely similar, though the figures are not strictly comparable. Roundwood inputs for lumber, plywood and veneer rose by 106 percent between 1975 and 1996.<sup>19</sup> Lumber production, accounting for 96 percent of output in these categories, grew by 134 percent in the same period, while plywood production declined slightly and laminated veneer lumber output climbed 42 percent.

Efficiency gains and increased utilization of wood residues reduce the pressure of rising demand for wood products on harvest rates. In the United States and Canada, some decoupling has occurred between growth in output and the rise in resource inputs. Yet overall inputs have expanded substantially and may be expected to rise as demand continues to grow.

*Chemical Contamination From Discarded Wood Products:* It should be noted that there is a growing demand in North America for pressure-treated wood products in which copper, chromium, and arsenic are used as a preservative. In the United States, this form of arsenic use has increased 20-fold, from 1,000 metric tons in 1975 to 20,000 metric tons in 1996. Arsenic in pressure-treated wood now accounts for over 90 percent of all arsenic use in the country. It appears that arsenic is relatively benign while bound in wood products, but concerns are rising that it may migrate at the end of product life. Discarded wood products are

19 Roundwood inputs for these products are not differentiated in the data provided to WRI.

typically burned, deposited in landfills or cut in chips for use as mulch. Some evidence has emerged in Florida that mulch containing pressure-treated wood has contaminated drinking water with arsenic.

### 3.2.3 Pulp and Paper Industry

Pulp production and papermaking represent a rapidly growing and high-value subsector of the forest products sector. Many of its environmental impacts can be traced back to the fiber, chemical and energy inputs the industry requires in production processes. An important question is whether alternate sources of inputs and efficiency gains in their utilization can diminish the impact of the rising requirement for inputs to feed a growing industry.

*Expanding Outputs:* The two main products of the pulp and paper industry are:

- pulp, an intermediate product that is either processed into paper or exported, and
- paper and paperboard.

In contrast with other industrial wood products, the demand for paper appears to exceed the growth in GDP in industrialized countries. The pulp and paper industries in the United States, Canada and Mexico continue to respond to a rising demand for its products.

As was case with industrial wood products, the United States overwhelmingly dominates paper and paperboard production in North America. The pulp and paper industry is also the largest subsector of the forestry sector. The industry, while consuming less than 40 percent of industrial wood produced by the forest industry, accounts for nearly 60 percent by value of the entire output of the forestry sector and generated US\$138 billion in 1996.

There is a similar pattern in Canada. Paper production accounts for one-third by weight of all domestically produced wood products and 62 percent by value. Shipments of paper and value-added paper products in 1995 generated C\$35.4 billion.

Though the data are not strictly comparable for Mexico, the pattern would seem to be similar. Pulp and paper production represents 65 percent by weight of the production of sawlogs, veneer logs and sawnwood. However, the sector has expanded faster than in Canada or the United States: pulp production has risen by 32 percent and paper production by more than 200 percent since 1975. The fast growth in paper production is a reflection of Mexico's rapidly developing economy, where paper consumption has increased fourfold since 1975.

*Industry Inputs:* The report addresses three main categories of input to the pulp and paper industry:

- fiber sources (mostly wood),
- chemicals and fillers, and
- energy.

Fiber inputs can take four forms:

- roundwood chips from the forestry sector (virgin fiber),
- mill residues from the wood products industry,
- nonwood fiber, such as straw or hemp, in very small quantities, and
- recovered paper.

A notable trend in the United States and Canada since 1995 has been the increased use of recycled paper in pulp and papermaking. This trend has both diminished demand for virgin fiber and reduced the flow of used paper into municipal landfills in areas where paper collection programs are successful. Recovered paper represents two to nine percent of the fibre inputs to the Canadian industry, 11 to 20 percent in the US and 47 to 54 percent in Mexico.

Chemical inputs tracked in our material flow analysis included:

- kaolin, used as a filler,
- caustic soda for dissolving wood fiber, and
- chlorine for bleaching paper.

No data were provided on the use of these chemicals in the Mexican industry, but in Canada and the United States, use of all three would seem to have fallen dramatically in proportion to product output. In Canada, the decline in their use has been absolute. This change would seem to be a result of increasingly strict regulation of wastewater emissions and a variety of industry initiatives to reduce outflows of chemical waste.

Energy inputs into the pulp and paper industry are difficult to track because of a lack of comparable data. We do know that electricity consumption by the industry in Canada (59.78 TWh) and the United States (142.26 TWh) in 1999 represents 12 percent and four percent of their respective total national consumption.<sup>20</sup> These are not trivial proportions.

Data on trends in energy use by the industry are unavailable for Canada and Mexico, but we do know that the US industry increased its total energy use between 1975–96. At the same time, efficiency gains allowed the industry to reduce its energy requirements per unit of output. These gains were not sufficient

to prevent a sizeable increase by weight in energy consumption—from 118 million metric tons in 1975 to 182 million metric tons in 1991 (the most recent date for which data were available).

During this period, interesting changes occurred in the energy mix, with implications for material throughput and the quality of associated emissions. Though fossil fuel inputs (mostly coal and petroleum) rose 18 percent, use of renewable fuels—primarily spent liquor and lesser quantities of hogged fuel and bark—increased 72 percent. In terms of weight, renewables were used twice as much as fossil fuels in 1975 and three times as much by 1991. More detailed data and analysis would enable comparison of the emission profiles resulting from this changing energy mix.

### **3.3 Trade Trends and Their Environmental Implications**

From the perspective of material flow analysis, trade between countries can be characterized as an international flow of materials. As will be seen below, such flows have profound environmental implications for the three countries now belonging to NAFTA.

#### **3.3.1 Trade Trends in Wood Products under NAFTA**

NAFTA dominates world trade in wood products. The value of its exports of sawnwood and wood pulp represents one-half of world wood products exports. The NAFTA countries also account for nearly one-third of the world's import market for sawnwood and one-fifth of the paper and paper pulp import markets. According to Industry Canada, Canada is the world's largest exporter of wood products, with 19 percent of global exports. The United States is in second place, with 13 percent of global exports.

Trade in forest products affects Canada and the United States more than Mexico because almost 90 percent of the forest area in NAFTA is in the two northern countries. Together, they produce 40 percent of global industrial roundwood and more than one-third of all processed wood products, including nearly half the world's paper pulp.

Much of this trade in wood products takes place between the two countries, which before NAFTA were already major trading partners with low tariffs on each other's goods. Trade between the two countries has continued to grow strongly since the agreement was signed. Between 1993 and 1995, the value of US wood exports to Canada increased by nearly 40 percent, while Canada's share of all US wood product exports rose from 15 to 26 percent. Particularly high growth occurred in wood products processed in Canada for re-export to the United States or other countries. During the same period, Canadian exports of

wood products to the United States climbed 55 percent, stimulated by the strong US economy, favorable exchange rates, and a construction boom that fed demand for softwood lumber. As a result, the United States market now accounts for about two-thirds of Canadian wood product exports by value, while Canada accounts for more than 80 percent of US wood product exports.

When considering the environmental implications of such trade, it is important to note that Canada exports a far higher share of its national production than does the United States. The forestry sector is also more important to the Canadian economy than the American sector is to the US economy. In Canada, forestry is the manufacturing sector that contributes the largest share to Canada's GDP and to net trade balance. In 1995, according to Industry Canada, export revenues from forest products totaled C\$41 billion, of which pulp and paper contributed 57 percent, commodity wood products 30 percent, value-added paper products 8 percent and value-added wood products just 5 percent. Canada's most important exports, in terms of world export share, are market pulp (32 percent), newsprint (55 percent) and softwood lumber (50 percent). These are low value-added products, meaning that material throughput is high and monetary return relatively low. In contrast, production of high-value panel products is relatively small, although exports are strong.

20 Trade in forest products between the United States and Mexico shows a different pattern. In material terms, the United States is importing fewer wood products and more paper products from Mexico and is exporting more pulp and less wood than before NAFTA. However, as Mexico continues its economic development, consumption of industrial wood products and paper will grow. The progressive removal of tariffs on imports of wood and paper products from the United States will make them more competitive in the Mexican market and will put pressure on Mexican producers to keep their product prices low.

### **3.3.2 Environmental Implications for Wood Products Trade under NAFTA**

Projections by the UN Food and Agricultural Organization (FAO) indicate that demand for industrial wood products is likely to continue to grow strongly in the North American region. The potential environmental impacts are likely to differ in the three NAFTA countries.

In Canada, reliance on the production and export of low value-added products with high throughput has encouraged high rates of exploitation of fiber resources in order to maintain or increase revenues. This emphasis has tended to discourage investment in more intensive forestry management (plantations, afforestation).<sup>21</sup> As a result, fiber demand continues to be met overwhelmingly by harvesting mature forests. Indeed, Canada is unique among industrialized

21 With a finer disaggregation of material flow and financial data, it would be possible to calculate the dollar return per ton of exported product, which could be a useful indicator of resource utilization value).

nations in producing very little wood from managed forests and virtually none from plantations.

Canada possesses great standing reserves of primary forest, where average tree size is much larger than in secondary-growth forests. As a consequence, clearcutting is still the most profitable and common method of harvesting and replanting is not systematic.<sup>22</sup> Wood from the primary forests of British Columbia, Ontario and Quebec dominate Canadian harvests and clearcuts account for more than 80 percent of the annual harvest area.<sup>23</sup> Given expanding demand for timber and timber products, the flow of fiber from Canada's mature forests may be expected to continue unless measures are taken to encourage more intensive forestry management. Already, more than 60 percent of Canada's forests are under logging tenures or within 10 km of development activity.<sup>24</sup>

In Mexico, the pressure to keep the prices of paper and wood products competitive with US products could increase resistance to additional environmental controls on both forestry operations and mill operations. FAO estimates that deforestation is occurring in Mexico at a rate of nearly one percent annually. Some recent studies have pointed to substantial post-NAFTA increases in logging activity in the northern state of Chihuahua, with potentially damaging impacts on biodiversity and indigenous people.<sup>25</sup>

In the United States, the effort to meet increased demand for wood products is likely to lead, not to significant deforestation, but to continued alteration in forest age and structure. The US Forest Service surveys tree diameter-class data, which can be used as a proxy for age-class data to give a good approximation of forest structure. Changes over time in the distribution of different diameter-classes within US softwood production forests show an overall trend toward smaller trees and more simplified stand structure. The standing volume of the largest diameter class (29.0+ inches) has declined by almost half over the last 40 years, with two-thirds of the decline occurring on the Pacific Coast, especially in the Pacific Northwest. Discussion with US forestry experts confirm that the steep reduction in both the volume of the largest trees and the volume of standing timber in the Pacific Northwest is reducing average tree size and simplifying forest structure. Such simplifications of habitat can have adverse impacts on biodiversity. Species such as the marbled murrelet and the spotted owl, whose evolutionary histories have made them dependent on older, larger forests, risk extinction as a result.

### 3.4 Summary

This preliminary analysis of material flows in the forestry sector within the three NAFTA countries clearly demonstrates that there have been substantial gains in the efficiency with which the sector utilizes both materials and resources. These gains

22 Smith et al., 2000.

23 Smith et al., 2000, p.11.

24 Smith et al., 2000, p.23.

25 Guerrero et al. 2000.

represent at least a partial decoupling between economic growth and environmental damage within this sector. However, the amount of fiber required by the sector as output continues to grow because demand for lumber, wood products and paper is likely to increase. As a consequence, environmental impacts will likely continue to grow and there will be a need to speed the rate of development and adoption for technologies to facilitate gains in efficiency and contain or reduce the environmental impacts of the forestry sector.

The environmental implications of this increasing requirement for fiber differ in each NAFTA country and region within that country. Broadly speaking, in Canada and Mexico, there continues to be growing pressure on natural forests. In the US, the trend is towards a more managed forest which is ever more uniform with respect to age, size, species diversity and overall structure. In all three countries, there remains the potential for losses in biodiversity, though these manifest themselves in different ways. As a consequence, it will be important to put in place environmental policies targeted at areas and issues where these environmental effects are most evident.

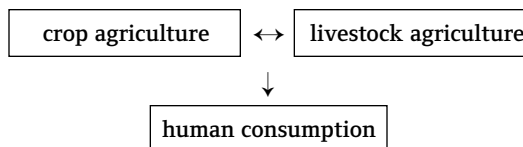
## 4 Material Flows in Agriculture

As was the case with forestry, application of material flow analysis to agriculture can illuminate both the efficiency of the sector and the degree to which it is sustainable. But first it will be necessary to define what was covered by our material flow analysis and what we mean by materials in agriculture and the various subsectors into which these materials flow. Only then will it be possible to discuss in a meaningful way the size and nature of these flows and their environmental implications. Finally, we will look at these flows and their implications in the context of NAFTA and present trends in trade for agricultural commodities and products.

### 4.1 Defining Material Flows and Subsectors in Agriculture

Material flows in the agricultural sector can be characterized in a general way, as follows:

Solar energy + fossil energy + pesticides + irrigation water +  
organic & inorganic fertilizers + seeds =





In other words, the sector requires solar energy, irrigation water, seeds, pesticides and organic and inorganic fertilizers to produce crops and support animals destined for human consumption.

In fact, the picture is a little more complicated (as the bidirectional arrow between crop and livestock agriculture indicates) since crops are used to feed livestock and animal waste is used to fertilize crops. Other internal loops occur as well. Crop residues left on the field provide nutrients to growing plants, while animal slaughter by-products are fed to animals.

For the purposes of the preliminary analysis conducted by the CEC, the agricultural sector was divided into three main subsectors:

- crop agriculture, which involves the growth and harvest of field crops;
- livestock agriculture, which involves the rearing and slaughter of poultry and animals, and
- human consumption, which involves the metabolic processing of plant and animal products by humans.

Inputs to crop agriculture mark the beginning of the material cycle. The CEC study tracks only organic and inorganic fertilizers, essentially because data were not readily available on man-made inputs such as fossil energy, pesticides and irrigation water. It is with the assistance of these inputs that solar energy, water, and nutrients are metabolized into a wide variety of outputs, including grains, fruits, vegetables and other foods for human consumption, as well as feed and fodder crops for livestock consumption. Waste outflows from crop agriculture include the soil eroded from cultivated fields, crop residues (some of which are recycled as nutrients), methane from paddy fields, excess nutrients leached from soils and volatilized into the atmosphere, and the soil eroded from cultivated fields. Many of these flows cannot yet be documented with accuracy.

Among the inputs to livestock agriculture are feed and fodder crops and feedstuffs manufactured from a variety of grains, oilcrops and occasionally animal slaughter wastes and fish protein. Outputs from the subsector include various kinds of meat and dairy products, as well as “non-edible” products such as wool and hides. Waste outflows are composed of slaughter and processing waste, (some of which is recycled as feed), manure (some of which is recycled as organic fertilizer), and methane flows from ruminants.

By and large, human consumption represents the final destination for outputs from both crop and livestock agriculture.<sup>26</sup> The food processing and packaging industry is a highly complex intermediate sector that could not be tracked in this study. However, some estimates have been made of processing and packaging wastes. The food products are, course, metabolized by humans into waste, but this flow was not documented in this study.

26 It is, course, also true that some of these outputs provide nutritional intake for pets—an interesting and major flow that has not been documented for this study but merits examination.

Indeed, because of the relative lack of data on human consumption available for the preliminary analysis, the main focus in the next two sections of this chapter will be crop and livestock agriculture.

It should be noted that, as with forestry, the agriculture sector involves a high volume of international trade in both inputs (fertilizers, seeds, and animal feeds) and outputs (crop and animal products). “Hidden” international flows, in the form of excess nutrients transported across borders in water, or as gaseous nitrogen compounds in the air, are becoming a major environmental issue. Excess nutrient flows are the subject of intensive research in the United States and northern European countries, but exchanges of nutrients in soil chemistry and nutrient flows in water and air were beyond the scope of this study.

## 4.2 Material Flows in Crop Agriculture

In examining material flows in crop agriculture, the emphasis will be on statistics and trends that throw a light on:

- inputs in the form of fertilizers (specifically nitrogen fertilizers),
- outputs in the form of different crops, and
- outflows in the form of soil erosion, migrating fertilizer and crop residues

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Special attention will be paid here to the efficiency of material throughput (that is, the ratio of product to input) and some of the potential environmental implications of changing trends in production and consumption.

### 4.2.1 Fertilizer Application

In Canada, Mexico, and the United States, the application of nitrogen-based fertilizers grew dramatically between 1975 and 1996, the period for which we have figures available.

In the United States, consumption of nitrogen in inorganic fertilizer rose by 18 percent between 1975 and 1996—from 9.4 million metric tons to 11.2 million metric tons. Over this period, the area of arable and permanent cropland declined by five percent, to 179 million hectares. As a result of these two trends, the application rate of nitrogen rose from 50 kg/hectare of arable and permanent cropland to 62 kg/hectare.<sup>27</sup>

This increased application rate was partly a result of the move to increased grain production, which grew by 38 percent over the study period. Whatever the other reasons, the higher rate of application was not fully reflected in increased crop yields. In 1975, 10 kg of nitrogen was applied for every ton of crops produced; in 1996, the comparable figure was just over 11 kg. Thus, measured

<sup>27</sup> A small fraction of nitrogen is applied to pasture, and other land not classified as arable and permanent cropland.

against both cropland area and crop production, the efficiency of nitrogen use has declined.<sup>28</sup>

In Canada, nitrogen consumption nearly doubled between 1975 and 1996—from 563,000 metric tons to 1.7 million metric tons. Over the same period, the area of arable and permanent cropland increased very slightly to 45.7 million hectares—or roughly a quarter of that in the United States. Application rates increased from 12.8 kg/hectare to 36.6 kg/hectare.

In terms of crop production, Canada appears to have moved from a highly efficient application rate to a less efficient one. In 1975, 6 kg of nitrogen were applied for every metric ton of crop output. By 1996, the figure had risen to 13.4 kg per ton of crop output. This shift reflects a trend toward grain production that requires higher rates of fertilizer application. Grain production increased by 38 percent in the United States over the study period, but by 58 percent in Canada, where nitrogen applications rose from 15.2 kg per ton of grain output to 28.6 kg per ton of grain output.

In Mexico, consumption of nitrogen fertilizers rose 75 percent between 1975 and 1996, while the area of arable and permanent cropland increased by more than 70 percent to an area about half the size of Canada's. At 58 kg/hectare, Mexico's nitrogen fertilizer application rate was higher than in Canada or the United States in 1975 in relation to crop area. However, the rate of application rose only slightly in Mexico by 1998 to 60 kg/hectare, or slightly less than the American rate at that time. In Mexico, nitrogen efficiency appears superior to that achieved in the United States, starting at 10.6 kg of nitrogen applied per metric ton of crop produced and improving to 7.8 kg of nitrogen per ton of crop output in 1998.

It should be noted that the average rate at which nitrogen was applied around the world was 83 kg/hectare in 1996/97. By this standard, the nitrogen application rates in the United States, Mexico and especially Canada are relatively low. However, regional application rates can greatly exceed the average figure, rising to 100 and even 200 kg/hectare. As will be seen below, such heavy application can have environmental implications, since it can result in migration of the nitrogen beyond the cropland area.

#### **4.2.2 Crop Outputs**

In this study, total crop output refers to:

- all grains,
- feed and fodder crops (both harvested and grazed),
- dry beans,
- oilseeds,

28 By way of contrast, the efficiency of phosphorus use efficiency improved during the period. Applications per metric ton of total crop output declined from 5.0 kg/ton to 4.1 kg/ton (18 per cent), but potassium efficiency remained relatively constant in terms of output. However, it should also be noted that application rates per hectare of arable and permanent cropland (as opposed to per unit of output) rose by almost nine per cent

- fruits, nuts and vegetables,
- sugar crops, and
- all other food and nonfood crops.

Canada has its crop production dominated even more completely by grain crops and feed and fodder crops than in the United States. Together, these two crops accounted for 95 percent of all crop production. Between 1975 and 1996, Canadian grain crop production rose 59 percent, while feed and fodder crop production rose by 14 percent.

During the same period, oilseed production almost doubled and vegetable, fruit and nut outputs increased nearly 50 percent, but in both cases production rose from a tiny base.

Productivity per unit of land area is much lower in Canada than in the United States, reflecting less favorable growing conditions. Total crop production rose from 2.1 metric tons per hectare to 2.7 tons per hectare in 1996, an increase of 29 percent during our study period.

Mexico has its crop production dominated by feed and fodder crops alone. Their output is three times greater by weight than grain crops and accounts for 58 percent of total crop production.

Outputs have risen dramatically in most sectors of crop agriculture. Grain production increased by 83 percent between 1975 and 1996, and feed and fodder crops by more than 600 percent. The area of land under grain crops climbed by only 10 percent to 9.5 million hectares, implying that production increases were achieved mostly through higher yields. The area of land under forage crops increased even more—by nearly 90 percent—between 1980 and 1998 to 4.9 million hectares. Overall productivity improved from 5.5 metric tonnes per hectare in 1975 to 7.6 tonnes per hectare in 1998, a rise of 38 percent.

It should be noted that coffee is an increasingly important crop in Mexico and throughout the Caribbean and Latin America. Traditionally, coffee has been grown as a crop within a mixed-shade cover of fruit trees and other species. This environment provides a rich habitat, particularly for migratory birds. In recent years, farmers have converted to more intensive “sun coffee” plantations in which coffee trees are grown without shade. About 40 percent of coffee planted in Mexico is now converted to sun coffee production. As a consequence, yields and income from coffee have tended to be higher, as have the environmental impacts.

The United States dominates agricultural production in the NAFTA region. In 1996, the country accounted for 83 percent of all grain production within NAFTA, 77 percent of all feed and fodder crop production, 96 percent of oil seed production and 72 percent of vegetable, fruit, and nut production.

The two largest crop outputs were grains and feed and fodder crops, accounting for 81 percent of total crop production. Feed and fodder crop produc-

tion is still slightly larger in mass terms. However, while grain crop production rose by 38 percent during our study period, feed and fodder crop production fell by 18 percent. The decline in the latter reflects the shift in livestock agriculture from extensive to intensive production systems, where animals do not graze but are fed concentrated feed.

In the same period, outputs of dry beans and oil seeds both increased by around 60 percent, while production of vegetables, fruits and nuts climbed by more than 30 percent.

Overall productivity per unit area grew a substantial 12 percent over the study period. Total crop production rose from 5.0 metric tons per hectare of arable and permanent cropland in 1975 to 5.6 tons per hectare in 1996.

#### **4.2.3 Outflows from Crop Agriculture**

Three of the most important outflows from crop agriculture are:

- soil erosion from cultivated fields,
- nitrogen runoff, and
- crop residues from harvesting.

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All three are “hidden” flows in that they do not enter the economy as agricultural commodities and are therefore not visible in traditional monetary accounts.

*Soil Erosion:* Soil erosion is notoriously difficult to measure.

The United States Department of Agriculture provides estimates based on the Universal Soil Loss Equation. According to this formula, estimates of soil erosion in the United States range between 2 billion and 6.8 billion tons annually.<sup>29</sup> However, the amount of soil erosion fell by 38 percent between 1975 and 1976. This dramatic decline was a result of enactment of a Conservation Reserve Program, which removed marginal land—that most prone to erosion—from cultivation.

In Mexico, soil erosion amounted to 643 million metric tons in 1998, an increase of 71 percent since 1975. This rise probably reflects the extension of cultivated land, since erosion rates fell from 5.5 tons to 3.9 tons of soil per ton of crop production.

Soil erosion data were not provided for Canada.

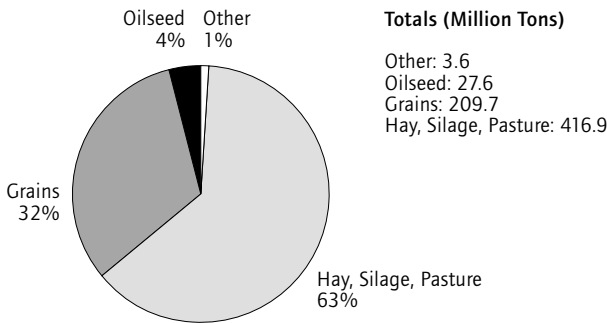
*Nitrogen Runoff:* Great uncertainties are involved in measuring the distribution and transport of nitrogen, because reactive nitrogen in its many forms is highly mobile, moving easily between terrestrial, freshwater and marine ecosystems, and the atmosphere. Mass balances of nitrogen throughput need to be supplemented with regional data and input/output analysis specific to different crops, soil conditions and farming practices.

<sup>29</sup> Trimble and Crosson, 2000.

However, enough is known to be certain that pollution from runoff of excess nitrogen-based fertilizers in aquatic systems is a serious and growing problem in many parts of the world. Indeed, human domination of the global nitrogen cycle is responsible for serious pollution and disruption of biological processes that underpin—among other important functions—food production. Human activity is now fixing nitrogen (creating reactive nitrogen from nonreactive N<sub>2</sub> in the atmosphere) at least as fast as natural terrestrial processes. The United States is particularly affected along the Eastern Shore and the Gulf of Mexico.

*Crop Residues:* Crop residues account for a substantial fraction of crops and represent a potentially large source of recyclable nutrients when left on the field. Residues may also find uses in biomass fuels. When burned, a proportion of nutrients returns to the soil as ash, some enters the atmosphere, to contribute to air pollution and subsequent acidification or eutrophication of ecosystems upon deposit in land or water. The exact proportions of the crop residues left on land and burned are not known. A reasonable estimate might be that outflows onto the land are 5.6 times greater than outflows into the air. However, it is also important to take into account changing agricultural policies and practices that have influenced residue burning.

**Figure 2. Feed Inputs to Livestock in the United States, 1996**



### 4.3 Material Flows in Livestock Agriculture

The principal livestock species are beef and dairy cattle, sheep, pigs and poultry, with goats and horses playing a minor role in Mexico. All animals are fed a diet that includes plants harvested directly from the land (grazing, hay, silage), grain crops, and concentrated feeds that include grains, pulses, oilseeds, fishmeal and animal products from slaughter wastes. The focus of our preliminary analysis was upon:

- feed inputs,
- animal product outputs in the form of red and white meat, and
- animal waste in the form of manure and slaughter wastes.

#### 4.3.1 Feed Inputs

Figure 2 shows the nutritional inputs to livestock in the United States in 1996. The proportions are roughly similar in Canada. In Mexico, forage crops provide a much higher portion of animal feed, some 90 percent, with grains and other industrial crops providing almost all the remainder and animal byproducts less than half a percent.

In Canada and the United States, composition of the feed mix, as well as the inputs required to grow feeds, changed dramatically as a result of shifts from extensive to intensive livestock operations using feedlots and from cattle to hogs and poultry (because these animals are more efficient converters of protein). Thus, the amount of roughage harvested for or grazed by animals declined by nearly 20 percent, while grain consumption by animals increased 45 percent.

As a consequence, a high proportion of the total grain harvest is now fed to animals. In the United States, 53 percent of grain production went to animals in 1996, up from 51 percent in 1975. The picture is somewhat different for grain consumption (production plus imports minus exports). Grain fed to animals amounted to 76 percent of grain consumed in the United States in 1975, but only 68 percent in 1996. The fall probably reflects the shift in American meat production from beef to poultry and hogs. In Canada, 41 percent of the grain harvest was fed to animals in 1996, down from 46 percent in 1975, probably for the same reasons as in the United States. For Mexico, comparable data are unavailable.

Animal, waste dairy and fishmeal products represent a small but important input to animal feeds, providing cheap sources of high quality protein. Use of animal and fish product feeds has increased, but the trends have been more than a little erratic. For example, use of fishmeal rose and then fell in Mexico, perhaps partly because of animal producers' small margins and a constant search for the most cost-effective feeds. Canada experienced a dramatic drop in the use of animal byproducts after 1987, possibly because of public anxiety internationally about potential contamination of meat supplies, as well as the propriety of feeding animal protein to herbivores is directing attention to this aspect of livestock production.

The use of fishmeal in animal feeds has also attracted the concern of some environmentalists as global fisheries come under increasing pressure. Roughly one-third of the world's marine fish harvest is processed into fishmeal and fish oils, most of which are used in animal feeds. Fishmeal is produced from so-called "trash" fish, pelagic species of relatively low value to commercial fisheries but often a staple food for artisanal fishing communities.

### 4.3.2 Animal Product Outputs

In discussing animal product outputs, our focus will be on trends in the production of red and white meat because these highlight differences among the NAFTA countries and have important environmental implications in conjunction with other factors.

In Canada and the United States, probably because of concern about cholesterol, the production of red meat rose by only 1.5 and 9.8 percent, respectively, during our study period. In contrast, red meat production increased 69 percent in Mexico. However, on a per capita basis, red meat production in Mexico is still only 26 kg/person, compared with 60 kg/person in Canada and 71 kg/person in the United States. In all three countries, the over-all trend would seem to be towards white meat, with poultry production rising dramatically since 1975—by 114 percent in Canada, 480 percent in Mexico and nearly 200 percent in the United States.<sup>30</sup>

The trend toward white meat has coincided with the shift towards more intensive livestock-rearing operations. As a result, fewer cows are raised and they are more concentrated spatially. Similarly, many more chickens are raised in fewer, much larger broiler houses. Hogs too are increasingly raised in feedlot operations that have become so efficient fewer animals are required to generate a constant amount of meat. For example, a 38 percent increase in the number of hogs yielded a 48 percent rise in the amount of pork during our period.

These trends have implications both for quantities and concentrations of animal wastes, especially manure, as will be seen below.

### 4.3.3 Animal Wastes

In the preliminary analysis conducted by the CEC, the focus with respect to animal wastes was very much on manure and animal and dairy-processing slaughter wastes.

*Manure:* Not surprisingly, differences in livestock agriculture between Mexico on the one hand, and Canada and the United States on the other, are reflected in the figures on waste.

Because Mexican livestock agriculture is comparatively small in comparison with that in the United States and Canada, the subsector generates much less manure than those in the two northern countries, though the amount is increasing. In absolute terms, manure generation in Mexico rose by a relatively modest 18 percent between 1975 and 1996 to 195,000 metric tons.

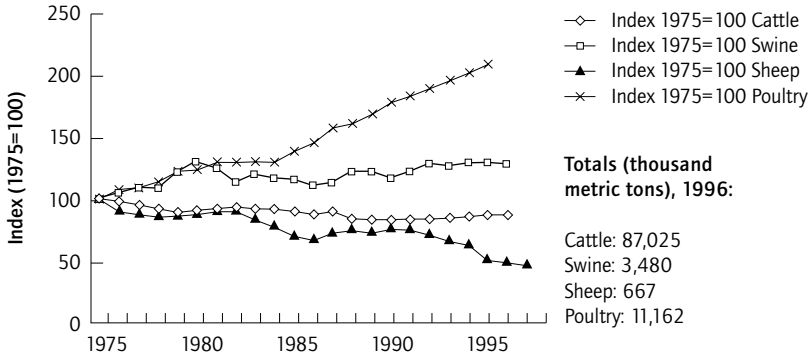
By way of comparison, in the United States, nearly 88 million tons (dry weight) were generated and in Canada just under 17 million tons. The overall

<sup>30</sup> With more disaggregated data on feed inputs to different sub-sectors of the livestock industry, it would be possible to calculate the efficiency of feed conversion, from ton of crop to ton of meat, for different animals. Such a calculation, using the weight of meat, not the live weight of the animal, would be a more accurate estimate of feed conversion efficiency than is sometimes used.



quantities of manure have also fallen slightly as the livestock populations have shifted from larger cows and sheep to smaller hogs and chickens.

**Figure 3. Manure Generation in the United States, 1975-1996**



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Figure 3 shows the effect of this change upon trends in manure generation by all four animals between 1975 and 1996, with cattle and sheep waste declining and poultry and swine waste on the rise. The relatively static picture for swine reflects the fact that hog production has become so efficient that fewer animals are required to produce a constant amount of meat. As noted above, this shift has been accompanied by a move away from extensive livestock operations (where the animals would range freely) to intensive operations (in which the animals are kept in barns or small feedlots). The main environmental concern is that manure produced in highly concentrated feedlots can rarely be returned to fields as organic fertilizer in a cost-effective way. As a consequence, manure—a nutrient-rich resource—must be dealt with as a waste product.

*Animal Slaughter and Dairy Processing Wastes:* In addition to manure, animal wastes include

- animal slaughter wastes, such as bone, blood and unusable body tissues;
- dairy processing wastes consisting mostly of water and the residual material from butter and cheese-making.

Because no comparable data could be found on Mexico, the focus here will be upon animal slaughter and dairy processing wastes in Canada and the United States. Table 2 shows slaughter and dairy processing wastes for the principal

livestock product groups in the United States and Canada. Predictably, animal wastes have increased roughly in proportion to animal numbers.

Because a smaller proportion of animal wastes are reused as animal feed, the leftovers represent a significant waste disposal issue, with implications for animal and human health. Agricultural wastes tend to be regulated less strictly than industrial wastes, although the argument is increasingly made that large-scale livestock production units are comparable to industrial production facilities and should be regulated as such.

**Table 2. Slaughter and Dairy Processing Wastes, 1996**

<b>(Thousands of metric tons)</b>	<b>United States</b>	<b>Canada</b>
Meat slaughter waste	7,347	1,303
as per cent of production	39	73
Poultry slaughter waste	4,592	216
as per cent of production	33	24
Dairy processing waste	35,613	5,952
as per cent of production	114	92
<b>Total waste</b>	<b>47,552</b>	<b>7,471</b>
<b>as % of total production</b>	<b>74</b>	<b>81</b>

#### **4.4 Trade Trends in Agricultural Commodities and Environmental Implications**

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From the perspective of material flow analysis, trade in agricultural commodities and products among countries can be characterized as an international flow of materials. Such flows can have profound environmental implications for the three countries now belonging to NAFTA.

##### **4.4.1 Trade Trends**

Before assessing the impact of present trends in agricultural trade, it is important to understand that the sector is not a large contributor to GDP in any of the NAFTA countries, even the United States whose agricultural production dwarfs that of the other two. Agricultural activity contributes 2 percent to GDP in Canada, 3 percent in the United States and 5.2 percent in Mexico.<sup>31</sup> Most of the sizeable US production is for domestic consumption, though agricultural products and commodities do constitute a significant proportion of merchandise exports—9.5 percent, to be exact. The comparable figure for Canada is higher at 13.7 percent.<sup>32</sup>

Because the United States is by far the largest agricultural producer, it should come as no surprise that the country exports a larger proportion of its agricultural commodities and products to nations outside the hemisphere than to its NAFTA partners. The bulk of its agricultural imports, however, come from

<sup>31</sup> EIU 2000, 1998a, 1998c.  
<sup>32</sup> WTO 2000.

Canada and Mexico. Predictably, the bulk of their agricultural exports and imports remain within the NAFTA region.

According to industry analysts, the NAFTA has stimulated agricultural trade in the region, delivering positive economic benefits at the macro-scale to all three countries. The figures certainly bear out this contention. After 1993, US agricultural exports to Mexico rose by an average of more than 11 percent a year, reaching \$6.2 billion by 1998. Imports from Mexico grew at about 12 percent a year after 1993, reaching \$4.7 billion by 1998. US agricultural exports to Canada expanded by more than five percent a year, attaining a level of \$7.0 billion by 1998. Imports from Canada rose nearly 11 percent a year and were valued at \$7.8 billion by 1998.

Production and export volumes have risen as a result throughout the NAFTA region in most categories of agricultural commodities and products. For example, since 1975 worldwide US exports of poultry meat have risen more than 12-fold, while Canadian exports have more than doubled, and Mexican exports have risen nearly 70-fold, though from an initially very small base. Though import policies have limited US poultry exports to Canada, exports to Mexico have boomed and remained relatively unaffected by the Peso devaluation in 1995. US exports of pork to both countries have also risen rapidly under NAFTA.

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This growth in trade has resulted in a limited specialization among the partners in certain categories of agricultural commodities and products. Thus, US exports to Canada of high value-added processed goods, notably snack foods, have grown very rapidly. US exports to Mexico, by way of contrast, are dominated by bulk commodities. Mexican exports to the United States have seen impressive continuing growth in the high-value horticulture sector and in certain value-added processed products. Coffee represents another growing category of Mexican exports to both Canada and the United States.

The growth in trade and the resulting competitive challenges have encouraged changes within the industry. Intensive methods of raising poultry, hogs and cattle have improved efficiencies, reduced costs and encouraged consolidation within the industry. As already noted, in crop production, while yields have increased per unit of land area, there is also increased reliance on chemical inputs in the form of inorganic fertilizers. Coffee production is moving from a mixed-shade cover to "sun cover" plantations. This change has important environmental implications.

#### **4.4.2 Environmental Implications**

Though there have been gains in efficiency within the agricultural sector, these have not been sufficient to reduce pressures on the environment because of increased production in response to growing demand. This pressure arises from both crop and livestock agriculture.

In crop agriculture, the production of bulk commodities, notably grains, beans, and oilseeds, can be associated with environmental impacts such as soil erosion and habitat conversion. The production of many fruits and vegetables is associated with heavy chemical inputs. Indeed, as noted above, improvements in yields seem generally to be associated with higher application rates for nitrogen fertilizers per unit of land area. The nitrogen can easily be transported off crop areas and is increasingly recognized as a source of environmental problems. In the case of coffee, rising demand has resulted in a shift from coffee crops grown under mixed-shade cover to “sun coffee” plantations. Studies in Colombia and Mexico have shown that sun coffee plantations support 90 percent fewer bird species than do shade coffee plantations.<sup>33</sup>

In livestock agriculture, rising meat production in response to growing demand is ever more associated with local pollution around the increasing number of intensive operations with large concentrations of animals where too much manure is generated to be absorbed by the land. In the United States in 1996, chickens generated more than 8 million tons of manure, a highly concentrated source of nutrients that can be highly polluting when it drains into soils and freshwater and marine ecosystems. Chesapeake Bay and the Delmarva Peninsula on the Eastern Shore of the United States are now notorious for the severe eutrophication caused by the concentration of the nation’s chicken industry in the area. The growth of industrial-scale chicken production in Canada and Mexico will likely reproduce such problems, absent adequate regulation or effective industry codes of practice. Similar difficulties would seem to have arisen around intensive rearing of hogs, which generated 3.5 million tons of manure in the United States in 1996.

#### 4.5 Summary

Though representing only a small fraction of GDP in Canada, Mexico and the United States, the agricultural sector in the NAFTA region is growing at an impressive rate—both in terms of value and also in volume. It is also a land-intensive natural resource sector that, along with forestry, dominates land use and largely governs the amount of habitat available for wildlife.

Many analysts also consider agriculture, in contrast to forestry, to be the most polluting of all economic sectors. Particular problems stem from the fact that farming has traditionally been a nonpoint pollution source and thus difficult to monitor and regulate. Despite industry consolidation and industrialization, the sector remains by and large lightly controlled.

The shape of these environmental challenges varies enormously both within and between the NAFTA countries. Though large-scale intensive agricultural operations are emerging in all three nations, the environmental problems they

<sup>33</sup> WRI, 1998, p. 166.

create will vary enormously depending on the size of the operation, the terrain, its hydrological characteristics, the crop or livestock in question, the areas under cultivation, the degree of crop specialization and livestock concentration and a host of other variables. For this reason, environmental assessment and policies in all three countries should be more specifically targeted at the areas and issues where the adverse environmental impacts of the sector are most likely or are already evident.

Such policies will also have to take into account the fact that production efficiency in agriculture has improved dramatically over the past 25 years, with fewer inputs required to produce a constant amount of outputs for many kinds of crops and livestock products. Yet there is no denying that constant growth in demand for agricultural products has meant that the requirements for material inputs have continued to grow in absolute terms. Similarly, with constant increases in the volume of intermediary and final outputs, the amounts of wastes and unwanted byproducts have also continued to expand. In short, the environmental impacts of the increasing scale of agricultural production have outpaced the environmental benefits that might be derived from gains in production efficiency. For this reason, it is becoming a matter of priority to speed up the development and diffusion of efficient technologies to contain or reduce the environmental effects of the agricultural sector.

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This pattern is typical of material throughput in industrial economies as a whole. Improvements in efficiency brought about by advances in technology, labor productivity and economic restructuring away from energy and material-intensive industries are offset in part by the pace of economic growth. A recent analysis of the United States economy revealed that, while the economy grew by 74 percent between 1975 and 1996, waste outputs grew by only 30 percent. This situation represents an impressive degree of “decoupling,” but it is not sufficient to achieve any absolute decrease in waste volumes. For this study, our documentation of material throughputs was not comprehensive and thus it was not possible to construct a macro indicator showing total material flows in either the agriculture or forestry sector and their relation to sectoral economic performance. But analysis of individual flows or categories of flow—such as, for example, the poultry subsector—indicate that the same trends are present.

## 5 Ecological Footprint

Partly because of the complexity of approaches such as material flow analysis, the concept of an ecological footprint<sup>34</sup> was created to communicate, in tangible and quantitative biophysical terms accessible to everyone, the total resource requirements of groups of human beings—individuals, communities, cities, countries, regions, even the global population. This kind of analysis in its apparent comprehensiveness differs considerably from material flow analysis, which focuses mainly on a limited number of materials, usually from a particular economic sector.

In this chapter, we will flesh out the concept of an ecological footprint, examine its strengths and weaknesses and attempt to apply it to the three NAFTA countries.

### 5.1 The Concept—Its Strengths and Weaknesses

The notion of an ecological footprint has been described as an accounting tool that “aggregates human impact on the biosphere into one number: the bio-productive space occupied exclusively by a given human activity.”<sup>35</sup> More specifically, it involves estimating a population’s consumption of food, materials and energy in terms of the area of biologically productive land or sea required to produce those natural resources (or, in the case of energy, to absorb the corresponding carbon dioxide emissions). The unit of measurement employed is generally a hectare of land (or sea) whose productivity is average in global terms. Thus, biologically productive land serves as a proxy for natural capital and the many resource flows and services rendered by nature.<sup>36</sup>

<sup>34</sup> For a more detailed discussion of the concept of ecological footprint and its application to North America, see Background Paper #4 (CEC, 2000c).

<sup>35</sup> Wackernagel, 1999.

As an environmental and natural resource indicator, the ecological footprint method has the advantage of rolling all possible factors up into a single number. However, calculation of ecological footprint can be challenging. It involves comparing, for the group whose ecological footprint is being investigated, estimates of:

- the amount of land of average global productivity required to meet the group's demands for fossil fuel, arable land, pasture, forest and sea, with
- the actual supply of that land.

Thus, fossil fuel must be converted into the land required to absorb the CO<sub>2</sub>, and so on.

A calculation of the *per capita* capacity of the planet to accommodate the world's population involves dividing all the biologically productive land and sea space by the number of people. Of the resulting 2.1 hectares (ha) required for each individual's needs, 1.6 ha are land-based natural and managed ecosystems and 0.5 ha are ecologically productive oceans. If 12 percent of the planet's biologically productive space were set aside as protected areas to preserve wild species, the space available for each individual falls to 1.8 ha—a figure that, it should be emphasized, includes wilderness areas that should not be used for human activity but for the absorption of CO<sub>2</sub> and other purposes.

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This global calculation has become a kind of ecological benchmark for comparing peoples' or nations' ecological footprints. A region has an ecological deficit if its footprint exceeds its actual land capacity. A region's 'global ecological deficit' "refers to the gap between the average consumption of a person living in that region (measured as a footprint) and the bio-capacity available per person in the world."<sup>37</sup>

A study of the ecological footprints calculated for 52 nations has shown that most countries import ecological capacity from elsewhere and that humanity's ecological footprint is actually larger than the planet's biologically productive space. This situation of "overshoot" with respect to global capacity can exist because nature's capacity to render services such as waste absorption can be exceeded for a period of time and resources can be harvested faster than they regenerate for some time before they are depleted. As well, technological advances, cheap energy sources and easier access to distant resources can mask constraints imposed by increasing resource scarcity.

The ecological footprint is clearly useful in suggesting some proxy indicators of resources. In addition, it can allow decision-makers to explore easily the impact of their actions by highlighting resource use, CO<sub>2</sub> absorption and other components of this approach.

<sup>36</sup> Wackernagel, 1999.  
<sup>37</sup> Wackernagel, 1999.

However, the approach has definite limitations. Some express doubt about the adequacy of transforming energy use into land and point out that it penalizes energy-intensive, industrialized economies because of the forest area required to sequester the CO<sub>2</sub> created by energy use. It is also unclear whether a country's footprint should be compared to its own capacity or global capacity.

Yet other critics argue that because the method involves so much aggregation, it is necessary, though perhaps not entirely possible at this stage in our understanding, to be scrupulous about what indicators are being mixed, why such mixtures are appropriate and how different indicators are compared, weighed and averaged. They point out that with this method each category of consumption must be added up; but since reliable data for indirect consumption (such as embodied energy in goods) is scarce, the approach is prone to error. The level of aggregation is, in fact, so high that many experts doubt the approach constitutes an adequate guide for national policies.<sup>38</sup> In the same vein, many economists doubt whether the approach tells us much that is useful about carrying capacities, assumed rates of technological innovation or progress towards future sustainability objectives.

On the other hand, even proponents admit that such component-based calculations can better measure the impact of different lifestyles, organizations, subnational regions, products and services, the method is still less than perfect because:

- it involves combining data sources that rarely agree,
- data are often unavailable at subnational levels, and
- the method is sensitive to underlying data variations.<sup>39</sup>

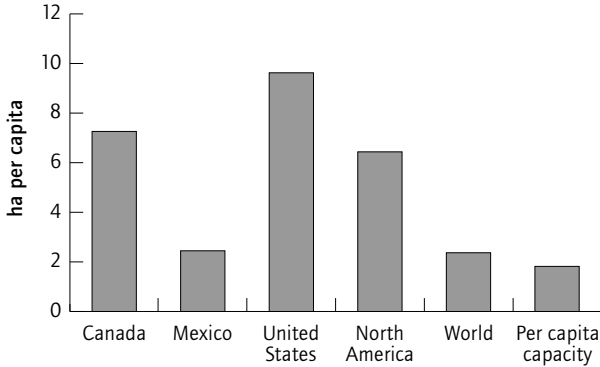
## **5.2 The NAFTA Region's Ecological Footprint—A cursory look**

Because of the many limitations with the approach, the CEC Critical and Emerging Trends Group undertook only a cursory analysis of three NAFTA countries' ecological footprint.

<sup>38</sup> Ayres, 2000.  
<sup>39</sup> Simmons et al., 2000.



**Figure 4. Per Capita Ecological Footprint Comparison (1995 data)**

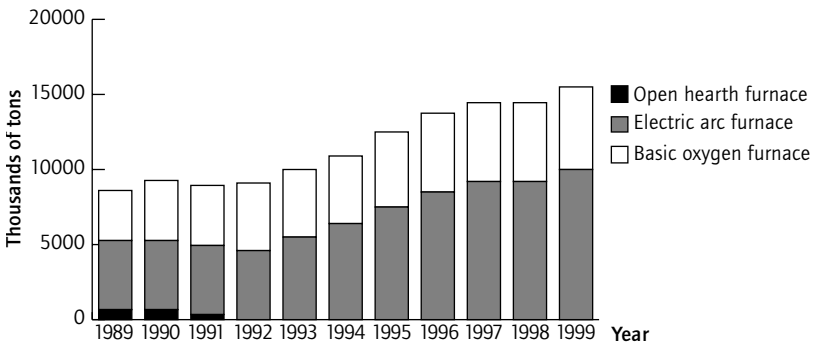


As Figure 4<sup>40</sup> shows, calculations of an ecological footprint for North America do illustrate the extent to which developed countries can have an impact on the global environment. At 1995 consumption levels, the ecological footprint of the average US citizen is estimated to be 9.6 ha; the average Canadian, 7.2 ha; and the average Mexican, a mere 2.5 ha.<sup>41</sup>

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The average North American footprint is 6.4 ha, compared to a world average of 2.4 ha. More seriously from this perspective, since the actual available capacity for human beings on a per capita basis is 1.8 ha, the average North American's footprint exceeds the per capita capacity of the planet by 4.6 ha.

**Figure 5. Total North American Ecological Footprints, by Country (1995 data)**



40 Redefining Progress, 1999.  
 41 Redefining Progress, 1999.  
 42 Redefining Progress, 1999.

As Figure 5<sup>42</sup> shows, the numbers are just as dramatic when the ecological footprint of the countries, as opposed to their citizens, are calculated. The United States has a national footprint of 25.5 million km<sup>2</sup>, but a total capacity of 14.7 million km<sup>2</sup>. In per capita terms, this result means that the country has a deficit of 4.1 ha per capita. Mexico's per capita deficit, at only 1.3 ha, is much smaller. Canada alone still has 5.1 ha of available capacity per person. Thus, the United States and Mexico are net importers of ecological capacity. In a ranking of the 52 countries for which an ecological footprint has been established, the United States, Canada and Mexico rank first, third and thirty-seventh, respectively.

### **5.3 Summary**

While provocative and occasionally useful as a way of exploring certain limited kinds of environmental impacts, it was the view of Trends Group that the ecological footprint should be dropped from the "toolkit" because it has too many flaws to serve as a guide for national or international policies addressing the environment.

## 6 Techniques for Exploring Environmental Futures

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While exploring and communicating past and present environmental trends through techniques such as material flow analysis or ecological footprints can be an important input to environmental policy, they may not be sufficient to provide a solid and persuasive information base that will justify preventive action before environmental problems become severe and pervasive. In order to take such action, it is first necessary to have a fairly clear understanding of what environmental conditions may be like in the future.

Researchers have developed literally dozens of methods for looking into our environmental future, ranging from those assuming a continuation of present trends into the future to those allowing more imaginative and unexpected constructions of the future. The prestigious Battelle Seattle Research Center has grouped these into six useful categories<sup>43</sup> that we will adapt for our purposes here. The categories, grouped in pairs, are:

- environmental scanning/monitoring and trend extrapolation,
- opinion surveys and scenario-building, and
- modeling and morphological analysis.

This chapter will briefly look at the features of each of these. It is important to understand that none of these categories is airtight, and that most people grappling with defining future environmental conditions will use methods from a number of these categories. Indeed, because by definition we cannot know the

<sup>43</sup> Skumanich and Silbernagel 1997.

future, such pragmatism and eclecticism about approaches is clearly necessary. The appropriateness of a technique will depend on the nature of the data, the environmental problem in question and sometimes its level of urgency.

### **6.1 Environmental Scanning/Monitoring and Trend Extrapolation**

Most of the environmental outlook and state of the environment reports issued by government agencies and others rely heavily on the analysis and extrapolation of trends identified by examining data gathered through environmental scanning and monitoring. The kind of material flow analysis described in Chapters 2, 3 and 4 represents a comparatively new technique for analyzing past and present trends that can affect the environment and there is no reason why extrapolations of trends in material flows could not be combined with other kinds of future work to give an insight into possible future environmental conditions.

Environmental scanning and monitoring are essentially data-gathering activities that provide much of the basic empirical data required to understand the environment and provide a basis for the identification and analysis of environmental trends. The data can be gathered by everything from sophisticated sensing equipment to volunteer birdwatchers with some training in observation, identification and record keeping. The data collected in this fashion and analyzed in a variety of ways can also provide an important empirical foundation for other kinds of futures work.

Trend extrapolation involves the extension of past and present trends into the future. For example, there is no reason why trends in material flows could not be extrapolated into the future. However, as noted in Chapter 1, trend extrapolation is partly based on the not entirely unassailable assumption that historical trends will continue into the future. This methodology is often used in environmental outlook and state of the environment reports. State of the environment reports present a thorough picture of a selected reference unit (from subnational through national to regional and global levels) at a specific time while environmental outlook reports present an analysis of existing trends and a future forecast based on those trends.

### **6.2 Canvassing Opinion and Scenario-Building**

Both the canvassing of expert opinion and scenario-building can involve consultations reaching beyond the traditional circles of environmental policy-makers in government and engaging a variety of experts, members of nongovernmental organizations, the private sector and concerned citizens.

Canvassing opinions can be handled in many ways. At one end of the spectrum are various kinds of public opinion surveys. For example, the CEC posted a survey on its web site in September and October 2000 and received 475 responses. Roughly two-thirds of the respondents believed that the state of the environment would worsen over the next 20 years. Interestingly, however, 81 percent also expressed the view that the public commitment to environmental protection would be stronger in 20 years.

Alternatively, the focus may be upon expert opinion and the canvassing effort may involve consultations with environmental scientists, futurists and other experts prepared to make an imaginative leap and envisage new developments and possibly transformative changes in existing trends. An example of such an exercise is the UN University Millennium Project that conducted a feasibility study using 200 “futurists and scholars” from 50 countries. The ranking of issues of global concern that emerged from the futurist and scholar consultation appears in Table 3.

**Table 3. UN University Millennium Project**

Ranking	Issue
1	High population growth
2	Increased scarcity of freshwater, possibly exacerbated by global warming
3	Regional nuclear war
4	Widening gap between rich and poor, both within and between countries
5	Increased food scarcity, and reduction in total food production
6	Globalization—gap in leadership, governance, institutions, and global thinking
7	Degradation of the environment, especially biodiversity loss
8	Increased resistance to antibiotics
9	Nuclear terrorism
10	Energy demand increases

In order to rank these issues, many of the participants in the project relied on scenario-building,<sup>44</sup> the most common approach to futures work on the environment.

The discipline of qualitative scenario-building is exceptionally well suited to preparing for the surprise events that often shape our future and cannot be captured with more quantitative forecasts. The approach involves the development of different scenarios to explore a range of possible future outcomes. For example, scenarios might be developed to show what kind of future environmental problems are possible, assuming different rates of change in drivers or underlying pressures, such as energy use, population growth or demand for natural resources. The resulting scenarios, based on different combinations or changes in drivers, could be a business-as-usual scenario, a worst-case scenario and a best-case scenario. For instance, the events of 11 September 2001, could only have been anticipated under a worst-case scenario.

44 For more details, see Background Paper #2 (CEC, 1999c).

In scenario-building, especially in its early stages, the thinking process is as much a part of the work as the data. Generally, the emphasis is on “thinking outside the box” or making an imaginative leap. There is no need to establish a clear and ordered causality—a basic requirement in the case of environmental outlook or state of the environment reporting. Such an approach is not inherently unreasonable since the future is hardly an easy read: our world is too complex, the underlying forces of change too fragmented and public preference too irrational for any strictly logical model or method to open a transparent and undistorted window onto the future.

It is important to note that, while imaginative leaps may be important in scenario-building, it is often necessary to maintain a connection with scientific knowledge and more quantitative approaches that can be useful in bringing speculation down to earth and revealing less than obvious patterns and relationships between variables and patterns. Chapter 8 looks at the success of such an approach in the case of efforts to anticipate and mobilize action internationally around depletion of the ozone layer.

### **6.3 Modeling and Morphological Analysis**

46 Often scenario-building is supplemented by modeling and morphological analysis<sup>45</sup>, the latter being modeling without as much reliance on quantitative data. Both place more weight on computer models and other technical analytical tools. Both can be indispensable for providing internal consistency to data that go into and emerge from scenarios.

Models are also often employed to understand interactions between the economy and the environment and how these may affect the future. Two schools of thought exist on this approach. The first believes that because of the non-linear relationship between economic change and environmental change, the relationship lends itself more to qualitative rather than quantitative analysis. The second holds that quantitative analysis and even prediction are possible, drawing on various economic assumptions. Formal models can then be applied to test the internal consistency of the scenarios used.

There are many different kinds of models sharing the common characteristic of utilizing formal and often mathematical logic to link the variables and relationships they purport to describe. The two discussed here will be the economic models so familiar to economists and bioeconomic models employing both economic models and scientific models for describing some aspect of the environment.<sup>46</sup> As the experience of Working Group I and II of the Intergovernmental Panel on Climate Change has shown, such models can result in focused, quantitative predictions around different technological and policy assumptions, leading to an equally focused debate.<sup>47</sup>

45 For a more detailed discussion of the issues raised in this section, see Background Paper #1 (CEC 1999b) and Background Paper #4 (CEC 2000b).

46 According to Australian agronomist Oscar J. Cacho, “a bioeconomic model consists of a biological (or biophysical) model that describes the behaviour of a living system, and an economic model that relates the biological system to market prices and resource and institutional constraints.”

47 IPCC 2001.

Economic models are often used to test the internal consistency of sector-specific and economy-wide scenarios built to predict what the environmental impacts would be under various combinations of economic drivers. Such models can be useful tools for isolating and developing quantitative analyses of linkages too complex to think through. In this way, models can help illuminate patterns and trajectories in intricate relationships, such as the consumer response to a change in environmental policy that alters the relative prices of, say, renewable and non-renewable energy. In such a context, models can make it possible to estimate variations in the degree to which renewable, non-renewable and other products are substitutable by consumers. Models can facilitate estimates of the impact of secondary factors, such as the relationship between regulation-induced changes in relative prices and endogenous technological innovation, or the effects of price changes on intermediate inputs.<sup>48</sup> Finally, models can help separate and disentangle different parts of a problem and, hopefully, provide a quantitative answer to some questions.<sup>49</sup>

Yet though specific data now exist on average emission levels, resource input levels and other aspects of average environmental performance within economic sectors, it is often far from easy to link sector-specific environmental issues with more general trends. The challenge lies in estimating probable changes both within sectors (based on variables such as international trade, public preferences, response to fiscal policies) and across sectors.<sup>50</sup> For instance, it is still unclear how best to best integrate economic forecasting with different scenarios for environmental quality. Economic forecasts tend to focus on growth in real Gross Domestic Product (GDP) over the term of two to five years, while the time horizon for work on environmental trends and future environmental conditions can be 25 to 100 years.

Because of the emergence of the new economy, even economic forecasting by itself is becoming more difficult. Information and communications technology would seem to have enabled and speeded up trade liberalization and globalization, creating greater demand for trade liberation, for example, in areas such as the service sector. The technology has also become an endogenous variable that is hard to model. For example, many see information technologies as an increasingly important part of the explanation, not only for growth in productivity, but also for growing gaps in productivity between countries such as the United States and Canada.

<sup>48</sup> As a rule of thumb, the cost of pollution abatement regulations is high for those industries with few options for input substitution, and lower for industries with a higher degree of substitution. But this rule does not mean it is easy to speak precisely about how big a difference exists between different sectors, what will be the probable response of different sectors and what is the optimal policy design to ensure the best possible response. Given that policy design does not occur in a politically neutral environment, Powell and Snape (1992), in discussing the ORANI-based models, have suggested four broad aims to guide the work of the economic modeling community:

- models should not be run entirely within a university or entirely within the client policy agencies;
- models should be accompanied by full public documentation of data, methods and results;
- modelers should involve policy clientele in the design stage of model building;
- model-building should be at arm's length from executive government.

<sup>49</sup> For an excellent example of a CGE model applied to estimate economics costs of environmental regulations, see Jorgenson and Wilcoxon, 1998.

<sup>50</sup> For a review of recent studies linking future economic policies with probable environmental impacts and more general economic-environmental forecast and futures-based work, see Background Note #3 (CEC 1999d).

In looking at the novel intersection of high growth, low inflation and information technologies in the American economy, the International Monetary Fund observed that the current US economic boom might not be the advent of a new age so much as a series of “fortuitous but temporary events” contributing to rapid economic growth in the late 1990s.<sup>51</sup> US Federal Reserve Chairman Alan Greenspan said he saw “something profoundly different in the postwar business cycle,” with technological innovation increasingly driving productivity growth and labor-saving equipment leading to lower prices and improved delivery lead times.<sup>52</sup> “Profoundly different” things and “fortuitous but temporary events” are difficult to build into models for economic forecasting, let alone those addressing economic impacts on the environment.

Similarly, because the economic effects of trade policy are not easily understood, it remains extremely difficult to make quantitative estimates of environmental changes induced by trade liberalization. This observation applies particularly to modeling efforts to test the Kuznets curve hypothesis, which states that after initial worsening of environmental quality as GDP per capita increases, the trends turn around and environmental quality improves as incomes continue to rise.<sup>53</sup> Modeling efforts to test this hypothesis can only reach the conclusion that a single indicator such as GDP per capita is a not reliable barometer for trends in environmental quality. In addition, other economic and non-economic factors such as compositional, technological, regulatory, and scale effects often exert stronger pressures on environmental quality. These factors are intricate in their impact and must be modeled to forecast whether environmental quality will increase, stay the same or worsen, as well as which economic sectors and environmental media will be affected the most by rises in trade and GDP per capita.<sup>54</sup>

This uncertainty is partly due to a lack of understanding of:

- the appropriate ways to measure changes in environmental quality, including the capacity of ecosystems to recover),
- the role of structural and compositional changes in the economy and in altering environmental quality,
- the role of technology in affecting environmental quality, including the sequence with which cleaner production technologies are applied, and
- the relationship between stricter domestic regulations and income and a range of other variables.

Even if one were able to forecast the complex economic responses to new technology, it would still be difficult to predict their environmental impact using models and/or scenario building. The reason is the lack of composite or aggre-

51 IMF 1999.

52 House-sponsored Conference on Technology and Information Growth, April 2000.

53 Kuznets, 1955.

54 The hypothesis however appears to hold for environmental policy. The stringency of environmental policies and regulations seem to increase with trade liberalization and income growth.



gated indicators of environmental quality that would weight changes in different types of environmental indicators. Though the United Nations Commission for Sustainable Development has developed 130 different indicators, most show net change in one media and not overall environmental quality. As well, the need exists for work to develop indicators capable of showing changes in biodiversity, forest cover, habitats and ecosystems.<sup>55</sup>

Though gaps remain in the data and theory needed to support economic and bioeconomic models, these techniques remain one of the few quantitative and replicable methods available for analyzing interaction between the economy and the environment, both in the past and also in the future. Thus, these approaches remain a vital tool in the arsenal of methods available to researchers and policy-makers for anticipating environmental problems and taking action before they become severe and pervasive.

#### 6.4 Summary

The general public and many decision-makers derive comfort from the apparent authority of highly quantitative approaches, such as modeling and trend extrapolation, to futures work. For this reason, such methods represent a powerful tool for persuading the public and advancing decision-making. However, such techniques can rarely predict the unexpected events that can have such a powerful influence on future environmental conditions. For such purposes, more imaginative techniques such as scenario-building can be highly useful. The appropriateness of using any one approach will depend on the goal and circumstances of the analysis, the kind of data available and the nature of the problem requiring analysis. Thus, all of the techniques discussed here, especially when used in combination with flexibility and insight, can make important contributions to our understanding of future environmental conditions.

The next two chapters show how these techniques can be useful, either alone or in combination with other approaches. Chapter 8 discusses a case where scenario-building, in conjunction with other approaches and an array of other factors, helped anticipate an emerging environmental problem—the depletion of the ozone layer—and mobilize domestic and international action to address it. The same chapter shows how empirical examinations based on economic models can puncture myths about future environmental impacts of certain economic developments—in this case, the supposed environmental neutrality of the new economy. The next chapter combines a trade and a water simulation model to illuminate policy alternatives around future competition for water between urban and rural areas.

55 For a review of indicator work, see Background Note #1 (CEC 1999b).

## 7 Modeling Future Competition for Water

Many observers consider the availability of water as one of the most critical factors in food security for many regions of the world. In dry areas of North America, it seems likely that urban sprawl will compete with irrigated agriculture for increasingly scarce freshwater resources. In some areas, meeting the growing demand for water by cities and industry will mean less water availability for irrigation in agriculture—a critical input that could not be included in the analysis of material flows in agriculture within Chapter 4.

In order to understand this play of forces, the CEC decided to explore one of the more comprehensive global models for illuminating these issues and how they may evolve over the next 10 to 20 years. The model was then applied to three scenarios for how competition for water between urban and rural areas may evolve in the United States.

### 7.1 The IMPACT-Water Simulation Model

Over the past several years, the CEC has worked in partnership with researchers at the International Food Policy Research Institute (IFPRI) and Michigan State University to incorporate a Water Simulation Model into the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT). Such an approach allows a modeling of water use and availability against fairly precise models for the operation of relevant market forces.

### 7.1.1 IMPACT

IMPACT has been widely used and its results frequently cited.<sup>56</sup> It is an extension of existing and well-accepted global trade models, such as the International Food Policy Simulation Model (IFPSIM), the Static World Policy Simulation Model (SWOPSIM), the Organization for Economic Cooperation and Development Multilingual Thesaurus Management System (OECD/MTM) and the United Nations Food and Agricultural Organization (FAO) World Food Model. IMPACT focuses on agriculture and is a partial world equilibrium model, permitting long-term projections of prices, supply, demand, and trade.<sup>57</sup>

IMPACT has been applied to 35 countries and 17 commodities. Trade links its sub-models for agriculture in different regions and countries, thereby highlighting the interdependence of countries and commodities in global agricultural markets. IMPACT provides a consistent framework for examining the effects of different food policies and rates of investment in agricultural research on crop productivity, as well as the impact of income and population growth on food security and balances between food demand and supply.

### 7.1.2 The Water Simulation Model

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Our Water Simulation Model (WSM) simulates the availability of water for crops, taking into account:

- the total amount of renewable water,
- nonagricultural demand for water,
- the infrastructure for supplying water, and
- economic and environmental policies at the level of the water, country, and region.

In the model, all surface water is aggregated into a single reservoir, and all groundwater is aggregated into a single source. Every month, the balance of water lost and gained is computed for each basin/country/region with storage regulation and committed flow constraints. Transfers between storage areas are traced on an annual basis. The availability of water is treated as a stochastic variable (that is, a variable whose level is a function of a term of expected value and one that is highly volatile), but one with observable probability distributions. This approach allows examination of the impact of droughts on food supply, demand, and prices.

Demand for water in all basins is aggregated into three sectors: agriculture, industry, and domestic. Agricultural demand includes both the demand arising from watering crops and livestock and the demand resulting from domestic use in rural areas.

<sup>56</sup> For a detailed description, see Rosegrant and et al. 1995. For recent IMPACT results, see Pinstrup-Andersen et al., 1997, 1999

<sup>57</sup> Rosegrant and Cai, 2000.

### 7.1.3 IMPACT-WSM

The IMPACT-WSM model, integrating the water simulation model with the IMPACT trade economics model, allows an exploration of the relationships between water availability and food production at various spatial scales—from river basins, countries or regions to the global level—over a 30-year time horizon. As in the simpler WSM model, the availability of water is treated as a stochastic variable with observable probability distributions in order to examine the impact of droughts on food supply, demand, and prices.

Once the demand for and supply of water for crops has been calculated, it is incorporated into the functions showing yield and the areas devoted to irrigated crops and those supported by rain. Eight food crops are covered:

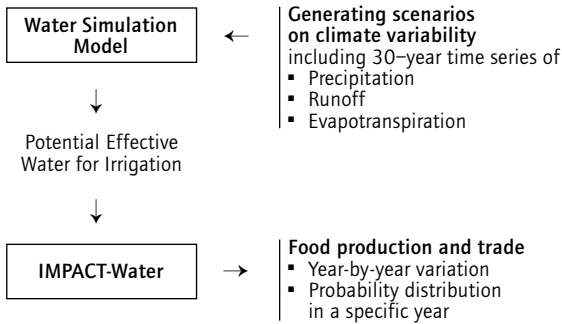
- rice,
- wheat,
- maize,
- other coarse grains,
- soybean,
- potato,
- sweet potato, and
- cassava and other roots and tubers.

The model integrates the supply of water to irrigated agriculture with the infrastructure used to supply that water. This approach makes it possible to estimate the impact of investments in improving irrigation systems and in expanding the potential area set aside for crops.

Because of these characteristics, the IMPACT-WSM model can be used to simulate the impacts of the shift of water from agricultural to other uses at the local, national, regional, and global levels. However, it does have limitations. For example, it would have difficulties predicting the very non-linear changes occurring in a trade war or other form of international conflict.

At present, the model has only been applied to 14 river basins in the US, but vast amounts of data are needed to feed the water simulation portion of the model. It may be expensive, though perhaps doable, to apply it to Mexico (where water shortages may be pronounced in future) or Canada (perceived as being amply endowed with water).

**Figure 6. The IMPACT-WSM Model**



The model has a flexibility that promises to throw new light on the competition for water in all three countries. This competition is likely to grow. In Canada, Mexico, and the United States, much of the agricultural production and economic activity, as well as the population, aggregates in certain already-water-stressed river basins, while water is relatively abundant in others. Using the flexibility of the model to view NAFTA countries by river basin would allow analysis of alternate modes of distributing and using water, given the environmental constraints and increased demand for water in different basins that may complicate future access to water resources. Such an approach would facilitate development of projections of water supply and demand, including:

- projections of the demand for water by municipal and industrial sectors;
- projections of industrial and municipal use of water;
- examination of alternate futures for food production and demand, food trade and international food prices;
- analysis of the impact of various water scenarios on future food supply and demand;
- analysis of the impact of competition for water among sectors on the availability of water for agriculture.

As shown in the next section, it will also be possible to examine the impact of different environmental policies that restrict or change the availability of water for different uses.



## 7.2 Applying The Model – Three American Scenarios

The model was applied to 14 river basins in the United States to produce three scenarios—a baseline and two alternatives. The alternatives involve reductions in Maximum Allowed Water Withdrawal (MAWW)—that is, the physical capacity for withdrawing water, both by diverting surface water and pumping groundwater—available for agricultural and municipal and industrial water uses. In all scenarios, it is assumed that water will always be directed first to meet municipal and industrial demands, which is growing much faster than agricultural demand, as Table 4 shows. Consequently, the two alternate scenarios—ALT1 and ALT2—focus on declines in the MAWW for supplying water to agricultural irrigation.

The three scenarios<sup>58</sup> are:

- *A baseline scenario:* In the baseline scenario, it is assumed that current<sup>59</sup> trends in using and investing in water will continue. It further assumes that, in the entire US, MAWW will rise by 5 percent over the 25 years. The increases in different river basins will range from a low of 1.7 percent to 13.9 percent in different river basins, with the larger increases occurring in basins that are drier or subject to larger withdrawals for intensive agriculture (such as the Rio Grande, Columbia, and White-Red River basins). It is also assumed that increases in the efficiency of irrigation will range from 1.5 percent to 8.0 percent in different river basins, with the greater increases in basins where water infrastructure is already highly developed, such as the California and Colorado River basins. Finally, it is assumed that the amount of water stored in surface reservoirs will be 1,017 km<sup>3</sup> and that this level will be maintained.<sup>60</sup>

<sup>58</sup> All scenarios use hydrologic data (that is, data on precipitation, evapotranspiration, and runoff) that recreates the hydrologic regime of 1961–91 (based on data developed by the Center for Environmental System Research, University of Kassel, 2000). All scenarios assume the gradual phase-out of groundwater mining—that is, pumping it out at a rate faster than it can be renewed—between 2000 and 2025. However, on a net basis, groundwater pumping will increase by 25 cubic kilometers (km<sup>3</sup>) during the period. In other words, while the pumping of groundwater will decline over the 25 years by 8.5 km<sup>3</sup> in areas where the withdrawal of groundwater is high (Colorado, California, Rio Grande, White-Red River basins), pumping will increase gradually by 33.5 km<sup>3</sup> in areas with more plentiful groundwater resources. It is interesting to note that in 1995 the total amount of groundwater pumped was 107km<sup>3</sup>, representing 21 percent of total water withdrawal. “Current” means 1995, the last year for which reliable data are available.

<sup>60</sup> The value is derived from work by the International Committee of Large Dams (ICOLD, 1998).

- *ALT 1 – “Irrigation Takes a Hit”*: The “Irrigation Takes a Hit” scenario assumes a decline of 7.8 percent in MAWW from all river basins over the next 25 years relative to 1995 levels, as a result of significant increases in the amount of water allocated away from irrigation for environmental reasons. For example, less water might be withdrawn for irrigation from the basin of the Columbia River in order to protect or restore salmon habitat. In this scenario, it is assumed that decreases in the MAWW in different river basins range from 2.1 to 13.9 percent, with greater declines in those basins—such as California and Colorado—where water withdrawal is already high. It is further assumed, in contrast with the baseline scenario, that by 2025 about 6.3 percent—or 64.0 km<sup>3</sup>—of current surface storage for water will be lost due to silt filling in reservoirs and not recovered.<sup>61</sup>
- *ALT 2 – “Irrigation Efficiency Grows”*: In this scenario, the same decreases in MAWW are assumed as in the “Irrigation Takes a Hit” scenario, but significant improvements occur in the efficiency of irrigation over those assumed in the baseline scenario. It is assumed that feasible improvements in the efficiency of water use within river basins can compensate for the loss of irrigation water to serve environmental objectives. More specifically, it is assumed that by 2025 the effective efficiency of water use will range rise from 9.5 percent to 16.7 percent in US river basins. In the Colorado and California river basins, for example, it is assumed that the effective efficiency of water use will have increased by 2025 to 0.9—the level Israel now achieves in its irrigation systems. It should be noted that this scenario makes the same assumptions as ALT 1 about the loss of surface water storage capacity due to sedimentation.

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It is important to understand that, in the case of all of these scenarios, while total withdrawals of water rise by five percent over the 25-year period, water consumption barely increases at all. The reason would seem to be that, in addition to increases in the efficiency of water use within basins, agricultural water use represents a diminishing portion of total consumption. In 1995, agricultural water use composed 67.7 percent of total consumption, declining to 63.6 percent in 2010 and 60.8 percent in 2025. Generally, agricultural users consume more water relative to withdrawals than is the case for municipal and industrial users. Thus, even when the total withdrawal of water rises by five percent over the 25-year period, total consumption remains almost unchanged because the proportion used in agriculture declines while rising for municipal and industrial uses.

61 According to estimates by Gleick (1993).

**Table 4. Water Demand, Assessment in the Base Year and Projections in Future Years**

	Irrigation water demand			M&I water demand			Total water demand		
	1995 (km <sup>3</sup> )	2025 (km <sup>3</sup> )	Change (%)	1995 (km <sup>3</sup> )	2025 (km <sup>3</sup> )	Change (%)	1995 (km <sup>3</sup> )	2025 (km <sup>3</sup> )	Change (%)
Ohio and Tennessee	1.01	1.166	15.4	8.37	9.204	10.0	9.38	10.37	10.6
Rio Grande	4.2	4.336	3.2	1.68	2.088	24.3	5.88	6.424	9.3
Columbia	18.13	18.074	-0.3	2.42	3.066	26.7	20.55	21.14	2.9
Colorado	16.66	15.81	-5.1	3.82	5.368	40.5	20.48	21.178	3.4
Great lakes Basin	6.97	7.35	5.5	1.61	2.282	41.7	8.58	9.632	12.3
California	30.35	29.26	-3.6	5.19	6.952	33.9	35.54	36.212	1.9
White-Red Rivers	14.88	14.958	0.5	3.97	4.812	21.2	18.85	19.77	4.9
Mid Atlantic	1.04	0.972	-6.5	8.32	9.162	10.1	9.36	10.134	8.3
Mississippi (upper)	7.54	7.036	-6.7	2.38	2.796	17.5	9.92	9.832	-0.9
Mississippi (lower)	1.53	1.722	12.5	3.68	4.112	11.7	5.21	5.834	12.0
Great Lakes	1.06	1.136	7.2	5.78	6.462	11.8	6.84	7.598	11.1
South Atlantic Gulf	10.12	12.316	21.7	7.65	9.108	19.1	17.77	21.424	20.6
Texas Gulf	11.76	12.224	3.9	5.64	7.604	34.8	17.4	19.828	14.0
Missouri	26.46	28.782	8.8	3.88	5.268	35.8	30.34	34.05	12.2
US	151.71	155.142	2.3	64.39	78.284	21.6	216.1	233.426	8.0

**Table 5. Comparison of Baseline with the two Alternative Scenarios (food production, demand, trade and international prices in 2021–2025)**

	Production ('000mt)				Demand('000mt)			
	1995	2021-2025 Average			1995	2021-2025 Average		
		BAS	ALT1	ALT2		BAS	ALT1	ALT2
Rice	5,476	6,628	5,505	5,942	2,938	4,046	4,037	4,041
Wheat	61,587	85,155	82,011	82,498	31,580	41,009	40,942	40,949
Maize	226,640	300,440	293,490	296,767	177,692	226,740	225,208	226,045
Other grain	27,476	42,070	40,900	41,212	23,560	33,033	33,221	33,126
<b>Total cereal</b>	<b>321,179</b>	<b>434,294</b>	<b>421,907</b>	<b>426,420</b>	<b>235,770</b>	<b>304,828</b>	<b>303,408</b>	<b>304,161</b>
Soybean	64,195	81,455	80,795	80,810	42,274	61,847	61,653	61,680
	209.0	28,925	25,221	25,974	20,948	27,979	27,834	27,866
Sweet Potato	602	754	715	726	616	741	739	740
Cassava and roots	3	0	0	0	207	230	230	-204

	Export ('000mt)				International prices			
	1995	2021-2025 Average			1995	2021-2025 Average		
		BAS	ALT1	ALT2		BAS	ALT1	ALT2
Rice	2,538	2,575	1,464	1,888	285.0	218.4	220.4	219.8
Wheat	30,007	43,170	40,111	40,631	133.0	124.8	126.8	126.0
Maize	48,948	68,330	62,252	65,361	103.0	105.6	108.2	107.2
Other grain	3,916	7,578	6,184	6,583	97.0	86.4	87.4	87.0
<b>Total cereal</b>	<b>85,409</b>	<b>121,653</b>	<b>110,011</b>	<b>114,463</b>	<b>N/A</b>	<b>N/A</b>	<b>N/A</b>	<b>N/A</b>
Soybean	21,921	20,031	19,581	19,717	247.0	242.8	244.2	244.0
	342	952	-2,608	-1,887		176.0	179.0	178.4
Sweet Potato	-14	13	-23	-13	134.0	90.2	92.4	91.6
Cassava and roots	-230	-230	-230	106.0	81.6	82.6	82.2	



Under ALT 1, our “Irrigation Takes a Hit” scenario, the harvested area subject to irrigation in the US declines, compared to baseline values for 2021–2025, by 13.7 percent for rice, 15.5 percent for wheat, 6.2 percent for maize, 7.2 percent for other grain, 2.7 percent for soybeans, and 1.3 percent for potatoes. Irrigated yield falls by 4.0 percent for rice, 11.5 percent for wheat, 8.0 percent for maize, 10.0 percent for other grain, 9.2 percent for soybeans and 14.7 percent for potatoes. Production decreases in irrigated areas amount, therefore, to 16.9 percent for rice, 25.2 percent for wheat, 13.9 percent for maize, 16.6 percent for other grain, 11.7 percent for soybeans, and 15.8 percent for potatoes. Under ALT 2, the “Irrigation Efficiency Grows” scenario, the production declines are not nearly so great—10.4 percent for rice, 10.7 percent for other grains, 8.0 percent for soybeans and 12.7 percent for potatoes. Relative to the baseline, the largest declines in production under both alternate scenarios occur in those basins characterized by greater water scarcity at the beginning of the projections period.

This decline in irrigated production, leads to a fall in the contribution of irrigation to total food production, but only slight changes in the contribution of rainfed production. For the whole country, irrigated cereal production in 2021–2025 represents 19.0 percent, 16.5 percent and 17.3 percent of total production under the baseline, ALT 1 and ALT 2 scenarios, respectively. Under both alternate scenarios, the contribution of irrigation to production falls significantly more in the river basins characterized by greater water scarcity—the Colorado, California, Rio Grande and Texas Gulf river basins. Only very slight changes occur in rainfed production under all three scenarios. ALT 1, the “Irrigation Takes a Hit” scenario, leads to a slight increase in rainfed production for 2021–2025 (about 0.2 percent compared to the value under the baseline), but only because there is a small increase in the international (and therefore the US) price for crops due to the decline in US production.

Table 5 compares the three scenarios in terms of the resulting crop-by-crop food production, food demand, food trade and international commodity prices in 2021–2025. Under ALT 1, the “Irrigation Takes a Hit” scenario, there are within the US marked declines in total annual cereal food production, total cereal demand and total cereal exports, compared to the baseline scenario. These decreases are much less under ALT 2, the “Irrigation Efficiency Grows” scenario. The same pattern holds for soybeans. The impacts are most dramatic in the case of sweet potatoes because irrigation supports about 80 percent of total production. While the baseline results in potato exports of 0.94 million tons in 2021–2025, the “Irrigation Takes a Hit” scenario reverses the trade flow, leading to 2.5 million tons of sweet potato imports for the same period. The impacts in all cases are much less under the “Irrigation Efficiency Improves” scenario.

The modeling shows that water diversions affect food production much more in dry basins (such as the Colorado, Texas Gulf basins) and in basins where

irrigation currently contributes more to total production, (such as the Missouri, Arkansas, California and White-Red River basins). In 2021–2025, these account for 95 percent of the shortfall in cereal production under the “Irrigation Takes a Hit” scenario as compared to the baseline. In such basins where environmental constraints are most evident, it would clearly be desirable to give high priority to improved management of water resources.

### 7.3 Summary

The results of applying the IMPACT-WSM model to US river basins suggest that additional transfers of water to meet environmental objectives can be achieved without a devastating impact on overall US food production and trade. Although local effects on agricultural employment and related sectors can occur under a scenario of increasing competition for scarce water resources, the most important effects would be concentrated in specific basins where production shortfalls occur. It would be here that interventions might be necessary to compensate farmers negatively affected by environmental diversions. However, as the “Irrigation Efficiency Improves” scenario demonstrates, investments in the development of improved irrigation systems can mitigate many of these negative impacts, even when water is reallocated for environmental purposes. Investment in such improvements could be encouraged by policy reforms—such as, for example, more aggressive water pricing—to encourage conservation and constrain the municipal and industrial uses assumed under our scenarios to be the first claimant for water.

Such actions become more important when one considers that, even under the baseline scenario, deficits in the water available for irrigation will occur in some dry basins in the western United States, as well as in the Midwest where intensive use of water for irrigation purposes takes place. Clearly, efficient use of water is becoming important for all regions because of environmental constraints and rapid increases in the demand for water by municipalities and industry. Sound management of US water resources will be needed, not only to serve environmental purposes and meet the needs of agricultural and other users, but also to make cereals available to developing countries at affordable prices in increasingly integrated regional and global food markets.

The IMPACT-WSM model can also be used to provide insights into even larger dimensions of water availability and use. For example, it could be used to model:

- the forces intensifying variations in the amount of water available for irrigation (for example, global climate change, pollution, transfer to municipal and industrial uses, and environmental conservation); and
- forces that may reduce this variability (for example, infrastructure investment, international water sharing, and development of new water sources).

Of such forces, the most dramatic in its impact may well be climate change. Though only substantial sensitivity analysis would allow careful estimates of the impacts of atmospheric warming, we would conjecture that the main effect would be to exacerbate the stresses to irrigated agriculture in water-scarce regions.<sup>62</sup> For example, if mean annual temperatures rise 3–4 degrees, rainfall in the US corn belt is projected to decline by about 10 percent. Low rainfall and increased evaporation could significantly limit corn production in the region.<sup>63</sup> The predicted rise in global temperatures could also increase world irrigation needs as much as 26 percent just to maintain current levels of production.<sup>64</sup>

62 Rosegrant and Cai, 2000.  
63 Rosenzweig and Parry, 1994.  
64 Postel, 1989.

## 8 Lessons for Futures Work

Though no method for exploring future environmental conditions reveals the true shape of tomorrow, each has its strengths and there have been some notable successes—and failures.

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Perhaps the most successful of these involved the use of scenario-building and other techniques to illuminate the growing problem of ozone layer depletion and mobilize concrete action on a global basis to ameliorate the situation. This chapter presents some of the lessons in that experience futures work. By way of contrast, the chapter also looks at how expectations of the environmentally benign effects of information and communications technology have failed to be borne out and how there may be a lesson here for predictions about other emerging technologies.

### 8.1 A Success for Futures Work—The Case of Ozone-Layer Depletion

Responses to depletion of the ozone layer and climate change offer valuable lessons into the importance of scenario building. When scientists brought forward in the mid-1970s the hypothesis of accelerated stratospheric ozone loss tied to increased chlorine loadings, scenario-building around the future human health and economic effects of this development prompted events that led—13 years later—to the establishment of an international regime geared to eliminating ozone-depleting chemicals. By any account, this rapid progression remains a remarkably brief one in the evolution of any public policy.

The sequence of events involved:

- release of a credible scientific hypothesis of anticipated global environmental degradation by Rowland and Molina in 1974;
- development and deployment of improved techniques to measure stratospheric ozone;
- empirical confirmation of accelerated ozone layer depletion through on-site testing in the Antarctic;
- development and release of an analysis that linked trends in ozone layer loss to human-health and environmental effects;
- the development of low-cost alternatives to CFCs by the private-sector;
- a commitment in 1990 through a multilateral fund to support costs of conversion away from CFCs; and
- agreement on the Montreal Protocol in 1987 and its amendments in 1992, perhaps the most effective international environmental policy yet to be devised.

62 This comparatively speedy progression from scientific hypothesis to international accord did not happen by accident. An important ingredient for success was the rapid development of a persuasive scientific basis, consisting of credible theoretical assumptions, monitoring and assessment based on empirical data and comprehensive models. The nature of the scenarios for human health and economic effects was also crucial: they were business-as-usual scenarios, intended to illuminate the most probable impacts in the absence of anticipatory or adaptive action.

As well, the scientific work and scenarios were accompanied by a package of reasonable and effective policy responses to the situation, including market-based instruments, technological innovation, regulations and other measures. Especially important was the use of economic modeling to show that cost-effective substitutes could be found for ozone-depleting substances. With the real possibility of public investment in research and development and a variety of other incentives from the public sector, the transition away from ozone-depleting substances then appeared feasible and cost-effective. By contrast, the Kyoto Protocol on Climate Change has not been able to promise such an easy transition.

Another significant contributor to success in the case of ozone-depleting substances was the serious effort to engage the scientific community and other experts on the issue.<sup>65</sup> It is also impossible to overstate the importance of effective information systems to communicate in a way accessible to the public the implications of the different scenarios. Though sophisticated models can isolate pressure-state-response sequences, quantify market failures and

65 A similar effort was also made in the case of climate change. When concern was raised in the late 1970s about the possible longer-term impacts of increased atmospheric carbon loadings, the first step in better assessing the scientific credibility of such concerns focused on Working Group I of the Intergovernmental Panel on Climate Change (IPCC). It has been argued that by engaging a broad range of scientific and other experts in the IPCC, the scientific basis upon which concrete commitments have emerged in Kyoto and at the domestic level helped build support for anticipatory action.

calculate the right mix of policy responses, information bottlenecks can thwart progress. As the World Bank notes in its *1998–99 World Development Report*, markets can fail “because information problems aggravate environmental difficulties or prevent their solution.”<sup>66</sup>

The sequence of steps followed in the move from a scientific hypothesis on depletion of the ozone layer to a broad international accord on anticipatory action were so successful they deserve emulation in other high-priority areas of environmental concern. As the analysis of material flows in forestry and agriculture have shown, increases in production in both sectors because of rising demand are far outweighing efficiency gains arising from new technologies and productivity improvements, with the result that adverse environmental impacts are becoming ever more severe. Thus, scenario-building supported by science-based modeling, investment incentives to make available “cleaner” substitutes, reasonable policies, and effective communications seems like a winning approach that could be applied to other areas of high-priority environmental concern such as forestry and agriculture.

## **8.2 Avoiding Facile Predictions—The Case of the New Economy**

When information technologies were being introduced in the 1970s and 1980s, many pundits, and not a few economists and environmentalists, predicted structural changes that would result in a new, more environmentally benign information economy. Electronic communication would replace paper, creating a “paperless office” that would make it less necessary to harvest trees for pulp and paper. Telecommunications would enable the electronic delivery of information, reducing the need for postal services. Finally, electronic communications would destroy distance as an obstacle to human interchange, reducing the need for energy-intensive transportation.

Arguably, the new economy has arrived. In 1998, an estimated 200 million people were wired together through 43 million computers. Today, one in 40 people has access to the Internet. E-commerce is growing at staggering rates. In the United States alone, total transactions through e-commerce were worth US\$127 billion in 1999 and are expected to increase to US\$1.4 trillion by 2003. It is, therefore, perhaps not too soon to start seeing some of the environmental benefits.

Whether offices are more “paperless” or not, the demand for pulp and paper products has not lessened. Indeed, as Chapter 3 amply shows, the rapidly growing demand for pulp and paper products in the three NAFTA countries has caused such dramatic increases in production that they far outstrip efficiency gains due to technological change and productivity improvements. The consequences for the environment may well prove serious.

<sup>66</sup> World Bank, 1998.

Contrary to expectations, the volume of mail delivered has also continued to increase in most countries. In 1998–1999, Canada Post processed 9.6 billion pieces of mail, an increase of 400 million from the previous year.<sup>67</sup> Since 1999, the US Postal Service has handled annually over 200 billion pieces of mail, an increase of some 30 billion pieces since 1993.<sup>68</sup>

Indeed, the new economy, instead of substituting for old means of communication such as postal delivery, would seem to have added new modes of communication. For example, because of the obvious emphasis the global economy places on speed, a whole new industry of express mail and package delivery has emerged and boomed in the last decade. Fedex began in 1973 with a total delivery of 186 packages. The company now delivers 3.1 million packages each day, for total earnings (1998) of US\$16.8 billion, an increase of six percent over 1997. Fedex is hardly alone: UPS, the largest such service, delivers three billion parcels and packages a year with annual earnings (1999) of US\$24.8 billion. Last year, nearly five billion tons of goods were moved around the globe.

Again contrary to expectations, people move more, too. The International Civil Aviation Organization (ICAO) reports a five percent increase in total scheduled air traffic in 1999 over 1998, as well as a rise of six percent in international scheduled air traffic. This translates into 2.63 billion passenger-km for 1999, a figure expected to climb to 3.038 billion passenger-km by 2001, representing an expected annual growth rate of seven percent a year.

Such figures should not surprise us because the global economy is all about moving people and things from one place to another. It should not be forgotten, however, that this new mobility requires fleets of airplanes and trucks, virtually all of which burn fossil fuels. Fedex operates 40,000 trucks and 600 aircraft. UPS has 157,000 trucks worldwide and 500 aircraft. DHL Worldwide Express operates 320 aircraft around the globe. These aircraft fleets are over and above the commercial aircraft fleets and cargo fleets that already fly.

Clearly, information technology has been intensifying human interchange. The effect has been both to increase the demand on older means of communications and transportation and create new and expanding markets for emerging modes. As CEC Background Report 4, *Booming Economies, Silencing Environments and the Paths to our Future*, points out, "...with this one, very limited example, one can begin to flesh out the relationship between scale, technology, compositional and product effects. For example, although the services sector of the new economy is assumed to be cleaner than twilight industries, the point is that any economic activity has environmental consequences. All those parcels and pieces of mail are moved around by airplanes and trucks. Without targeting aircraft travel, it is worth noting that the IPCC recently released a report on the contribution that jet aircraft make to climate change, through CO<sub>2</sub> emissions and water vapor emitted at high altitudes. In the former area, major North American

67 See <[http://www.canadapost.ca/business/corporate/about/newsroom/fast\\_facts/default-e.asp](http://www.canadapost.ca/business/corporate/about/newsroom/fast_facts/default-e.asp)>.  
68 See <<http://www.usps.com/history/pfact00.htm>><http://www.usps.com/history/pfact00.htm>>.

airports at peak periods are among the largest sources of greenhouse gas emissions... Similarly, a 1996 report by the US Department of Commerce (Environmental Trends and the US Transportation System) noted that while vehicle emissions have declined, the exception is NO<sub>x</sub>. The report also notes that while air regulations have lowered total emissions, recent data show a “slowing of the improvements” made over the past two decades for two reasons: a total increase in transport (scale effects) and a growth in unregulated off-road vehicles, also known as sports utility vehicles or SUVs (regulatory and product effects). The scale effects and reversing trends in air pollution are just one sign of the new global economy.”<sup>69</sup>

As such, the case of information and communication technology should be further studied to discover whether its failure to reduce pressure on the environment was predictable, as well as lessons that might be applicable to technologies now emerging.

### **8.3 Summary**

Two lessons can be learned from the success of efforts to create effective international policies for controlling ozone-depleting substances and the excessively sanguine expectations about the environmental implications of information and communications technologies. The first is that skillful scenario-building can effect real change if backed by solid scientific modeling and evidence, a realistic mix of policies that take into account the transition cost in meeting their objectives, and effective communication that engages the scientific community, other experts and the general public. The second is that scale, composition and product effects can all too easily overwhelm the efficiency gains resulting from technological change.



## 9 Conclusion

As the previous eight chapters have shown, the CEC's Critical and Emerging Environmental Trends project has been productive. It has marked the first application of material flow analysis to the forestry and agricultural countries. It has enabled groundbreaking projections of future competition for fresh water between agriculture and urban sprawl in the US to the year 2025, using a hybrid IMPACT model. The CEC has also released four background reports identifying environmental trends, different economic drivers of environmental change, as well as methods to anticipate future environmental challenges. The lessons from this work have been many and most cast further light on the future environmental implications of trade liberalization and the methods needed to assess them.

In early 2002, this work on emerging environmental trends has merged with ongoing work on the effects of NAFTA on the environment. The goal of this fusion will be to improve environmental assessments of market integration of the North American economy, with emphasis on the environmental effects of trade liberalization in the past, and in the future. The approach taken will involve environmental assessments that integrate the futures or forecasting work carried out over the course of the Critical and Emerging Environmental Trends project, with analytic work on the effects of NAFTA since its inception. An important focus will be on sector-specific analyses, building on the insights described here with respect to trends in agriculture, forestry and energy. The ultimate goal will be to develop appropriate and proactive policy options to mitigate environmental damages associated with trade expansion and economy-wide reforms, as well as to maximize potential environmental benefits arising from market integration.

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